Integrated Natural Resource Management

Linking Productivity, the Environment and Development

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Preface

In 1998 a new vision was launched for the Consultative Group for International Agricultural Research (CGIAR). The CGIAR supports 16 international research centers with a combined budget of $350 million per annum. The new vision focused on alleviating poverty and conserving the environment. This new orientation was driven by changes in the external environment in which the CGIAR operated. Other organizations were increasingly filling the traditional plant breeding and crop protection role of the CGIAR. Large multi-national agro-industrial companies were now important players in this arena and in addition the national research systems in countries such as India and Brazil were taking on many of the traditional roles of the international centers. A second external factor was that the new environmental agreements that had emerged from the Rio process were creating demands for research in developing countries–most notably because those international agreements dealing with forests, desertification, biological diversity and climate change all had major implications for the livelihoods of the poor. The CGIAR had the capacity to meet the hitherto unmet research needs associated with these emerging agendas.

A task force was established by the CGIAR to examine how the research of the centers could be adapted to provide more emphasis to integrated natural resource management. The task force comprised prominent natural resource scientists both from the centers, from national research systems and from advance research institutes. Views on the potential role of the CGIAR in integrated natural resource management differed widely. Many felt that the CGIAR should restrict itself to natural resource issues relating to soil and water management–an area where a considerable track record existed. Others sought to broaden the agenda to address the full range of environmental issues on the international agenda.

It became apparent that a diversity of research activities were going on at the centers that fell under the general heading of integrated natural resource management. Some centers were at the cutting edge of on-farm action research, while inter-center groups were working on issues such as common property resource management. Other groups of scientists were dealing with the livelihoods of forest-dependent people, the opportunities and impacts of climate change for the poor, and integrated coral reef management. A wide range of integrative tools was being used and it rapidly became apparent that the sharing of the information on these approaches could improve the performance of all concerned. A “community of practice” became established and continuing interchanges on natural resource management issues were organized through a dedicated web site. In preparation for the second task force meeting, held at the headquarters of the World Fish Center in Penang, Malaysia in August 2000, a series of papers were commissioned to address the full range of natural resource management issues being addressed by task force members. The papers were posted on the web site and were subject to peer review by members of the task force. At the meeting the papers were presented and discussed. Some of these papers were written by scientists from the centers, others by their collaborators in national research systems and others from advance research institutes. On the basis of the discussions in Penang the papers were further revised and a selection of them were subsequently published in the on-line journal *Conservation Ecology* (http://www.consecol.org). The publication stimulated a great deal of interest and in 2002 one of the papers was awarded a prize for scientific excellence as the best paper to emerge from the CGIAR in that year. In order to ensure the wide availability of these papers they are now being reprinted in this volume. Since this field is evolving rapidly we have updated several of the papers in order to ensure that recent work in the field is cited.

One of the issues that emerged from this work is that a disproportionate amount of research on environmental issues is carried out in industrialized countries and responds to their environmental interests. Yet many of the changes that are occurring to the world's climate, biological diversity, deserts and forests have major implications for the livelihoods of poor people in developing countries. In addition many of the measures being undertaken or proposed to mitigate environmental problems have implications for the poor, for example, they might benefit by planting trees to sequester carbon, they might lose their access to land if areas of forest are preserved for biodiversity. The CGIAR and its partners are already addressing some of these issues and plans are advanced for an expansion into areas such as climate change mitigation and adaptation, conserving forests as resources for the poor, on-farm biological diversity conservation, desertification, improved water management etc. The papers in this volume constitute a record of integrated natural resource management thinking and activity in the centers at the time of writing. They lay the foundations for a considerable expansion of activity into this vital area of research.

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1.

Research to Integrate Productivity Enhancement, Environmental Protection, and Human Development

Jeffrey A. Sayer[1] *and Bruce M. Campbell*[2]

ABSTRACT

To meet the challenges of poverty and environmental sustainability, a different kind of research will be needed. This research will need to embrace the complexity of these systems by redirecting the objectives of research toward enhancing adaptive capacity, by incorporating more participatory approaches, by embracing key principles such as multi-scale analysis and intervention, and by the use of a variety of tools (e.g., systems analysis, information management tools, and impact assessment tools). Integration will be the key concept in the new approach; integration across scales, components, stakeholders, and disciplines. Integrated approaches, as described in this book, will require changes in the culture and organization of research.

KEY WORDS: adaptive capacity, decision making, impact assessment, integration, scale, social learning, systems modeling.

INTRODUCTION

In the 1960s, a huge gap existed between the technologies used by farmers in developed countries and those available to poor farmers in the tropics and subtropics. International

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development assistance agencies have made major investments during the past 40 years in attempts to develop advanced agricultural technologies for poor tropical countries. The research centers supported by the Consultative Group for International Agricultural Research (CGIAR) have been major conduits for this aid. The CGIAR supports 16 international research centers with a combined budget of US$350 million per annum. These efforts are widely credited with having averted large-scale famines that had been anticipated in Asia in the 1970s and 1980s. The impacts of such research have been more modest in addressing the needs of Africa. Much of this research adapted technologies from developed countries to conditions in developing countries; it targeted innovations that could yield quick benefits to respond to urgent needs. Major investments went into genetic improvement of a few commodity crops to enhance productivity and improve resistance to pests and diseases. The gains were largely confined to areas of high agricultural potential, and they often benefited the more prosperous farmers, missing the poorest of the poor. In many cases, this research yielded short-term gains at the expense of long-term degradation of soils, water, biodiversity, and noncultivated land. The initial spectacular gains of the green revolution are unlikely to be maintained (Conway 1997).

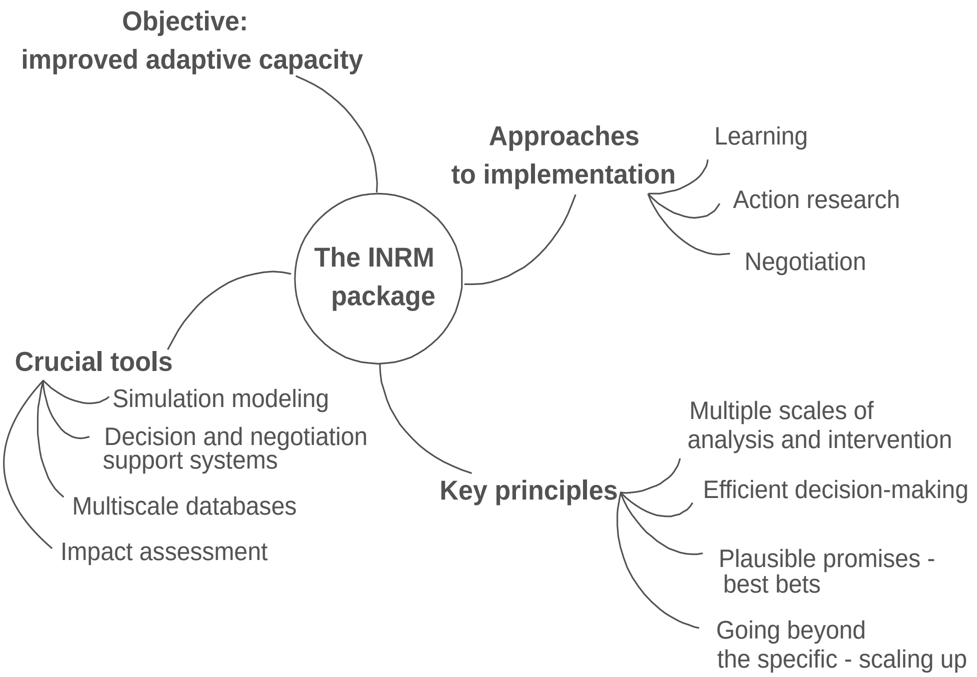
There is now widespread recognition that the sustained improvement of the well-being of poor farmers in developing countries will require a different kind of research (Ashley and Maxwell 2002, Costanza and Jorgensen 2002). Cutting-edge agricultural technology is still needed, but it has to be set in local contexts and be applied in ways that recognize the special conditions of poor farmers. It will have to give more emphasis to management of risks, reduction of dependence on agricultural inputs, avoidance of long-term depletion of productive potential, and more careful control of environmental externalities (Conway 1997). The advent of economic globalization and the increasing domination of agriculture by a few large companies poses special risks for the poor (Korten 1995). Equity in the distribution of benefits is emerging as a major issue.

Green revolution science underestimated the complexity of the systems in which small-scale producers operate. Crop production, for example, is usually only a small part of a broad livelihood portfolio that may encompass a wide variety of off-farm activities, the gathering of forest products, the raising of livestock, etc. Productivity enhancement will remain important, but risk reduction, improved food security, and the maintenance of social capital will assume greater importance. The farming systems of poor people in the tropics are subject to a multitude of exogenous influences. For instance, they are subject to highly variable rainfall, especially in semiarid areas, a constantly changing economic climate with resulting swings in input costs and market prices, dynamic land use changes, and various other episodic events (e.g., the massive rise in AIDS in Africa; widespread fires associated with el Ninõ events in Southeast Asia, etc.) (Campbell et al. 2002).

Research on complex systems is not simple, because of multiple scales of interaction and response; a high frequency of nonlinearity, uncertainty, and time lags; and multiple stakeholders with often contrasting objectives and activities (Costanza and Jorgensen 2002, Ashley and Maxwell 2002, Gunderson and Holling 2002). Furthermore, many earlier attempts to conduct research at the level of large, complex systems are widely seen to have generated needs for excessive amounts of data, to have been very costly to conduct, and to have yielded few results of immediate practical value. This problem has become particularly important in the context of funding allocation strategies based upon ex-post analysis of the impact of research on production. It has been very difficult to attribute any direct impact to much of the research that has been conducted on complex farming systems. This has led many to conclude that natural resource management or agro-ecosystem research is an expensive luxury.

In August 2000, the CGIAR convened a meeting in Penang, Malaysia to address these dilemmas faced by natural resource researchers and to examine ways in which research might be redirected to meet the challenges. This volume brings together a selection of the papers that formed the subject of the Penang meeting. Papers and discussion at the meeting yielded significant new insights into the ways in which the CGIAR and similar research institutions might modify their way of doing business. The focus was on the use of techniques and approaches drawn from a number of fields of science to yield results with short-term benefits for the poor and their environment. The key components of this new vision of integrated natural resource management (INRM) will be discussed. They involve an interlinked package (Fig. 1) including: (1) the reorientation of the objectives of research, (2) adding weight to participatory approaches to implementing the research, (3) a series of principles that underlie the research (e.g., broadening temporal and spatial scales of analysis), and (4) the use of a variety of analytical tools (e.g., systems analysis, information management tools).

Figure 1. Some of the key features of INRM research.



THE OBJECTIVE OF INRM: TOWARDS ADAPTIVE CAPACITY

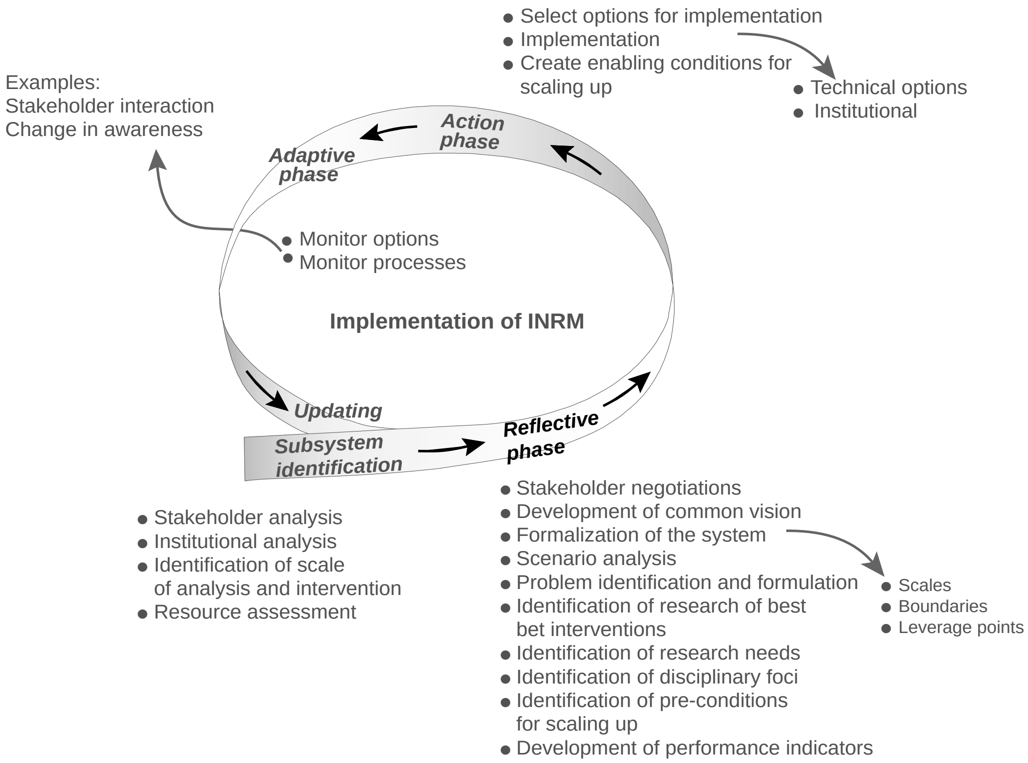
In mainstream productivity enhancement research, the prime objective is to improve yields of the dominant crops using plot-specific technologies. In a multi-stakeholder situation with small-scale producers, there will be multiple objectives, and it is unlikely that any single production objective will suit all stakeholders. Standardized technologies that work in many contexts will be only part of the solution. Given the complexity and dynamism of systems, one of the prime objectives will be to improve the adaptive capacity of the system, i.e., its ability to sustain a flow of the diverse products and services that poor people depend upon, and to do so under constantly changing conditions. Research will need to strengthen the farmer's ability to manage a broad range of production factors, thus increasing her flexibility and her ability to respond to exogenous influences (Hagmann et al. 2002, Oglethorpe 2002). Considerable focus will be on the managers themselves, helping them to achieve the skills and acquire the technologies that will enhance their control over their own destinies (Lynam et al. 2002, Lal et al. 2001). High-technology research on the components of agricultural systems is still vital, but it has to be placed in the context of specific biophysical and socioeconomic conditions.

THE APPROACH: LEARNING TOGETHER FOR CHANGE

Three key elements form part of the approach to implementing INRM: (1) management needs to be adaptive; (2) INRM must move further along the research–management continuum; and (3) the approach must provide for, and be based upon, negotiation among all stakeholders. INRM research draws heavily upon, and reflects the advances in, our understanding of social learning (Daniels and Walker 1999, Hagmann 1999, Maarleveld and Dangbégnon 1999). Thus INRM must be based upon continuous dialogue and deliberation among stakeholders; this incorporates adaptive management as well as political processes related to conflict among stakeholders. Ultimately, in the ideal scenario, all management is experimental and all research involves managers; there is little distinction between management and research (Roussel et al. 1991). Natural resource management is like jazz; it requires constant improvization. This implies that researchers can no longer remain exclusively external actors, but need to engage themselves in action research to develop appropriate solutions together with resource users (Hagmann et al. 2002, Abel et al. 2002). Good process facilitation is an essential component of its implementation. This process facilitation is a formal scientific equivalent of the rituals and traditions that socialize complex resource management processes in all human societies.

Natural resource managers are constantly confronted with surprises. Stakeholders change their aspirations, and exogenous factors have unpredicted influences on the system. Managers have to deal with uncertainty and changing targets. One of the key lessons in dealing with complex systems, therefore, is that management must be organized in a way that promotes active and conscious individual and social learning. The inverse relationship between the complexity of systems and our ability to make precise, and yet significant, statements about their behavior suggests that sustainable management of natural resources must be adaptive (Zadeh 1973, Holling and Meffe 1996, Oglethorpe 2002). The steps within our adaptive management cycle (Fig. 2) are (1) subsystem definition; (2) reflection and negotiation; (3) action; and (4) evaluation, readjustment, and adaptation. As a result of the evaluation, we move back into the reflective phase and update our conceptualization of the system. This adaptive management cycle is discussed in several papers in this volume (Hagmann et al. 2002, Harrington et al. 2001, van Noordwijk et al. 2001, Lal et al. 2001, Lynam et al. 2002, Douthwaite et al. 2001).

Figure 2. The learning cycle in INRM research.



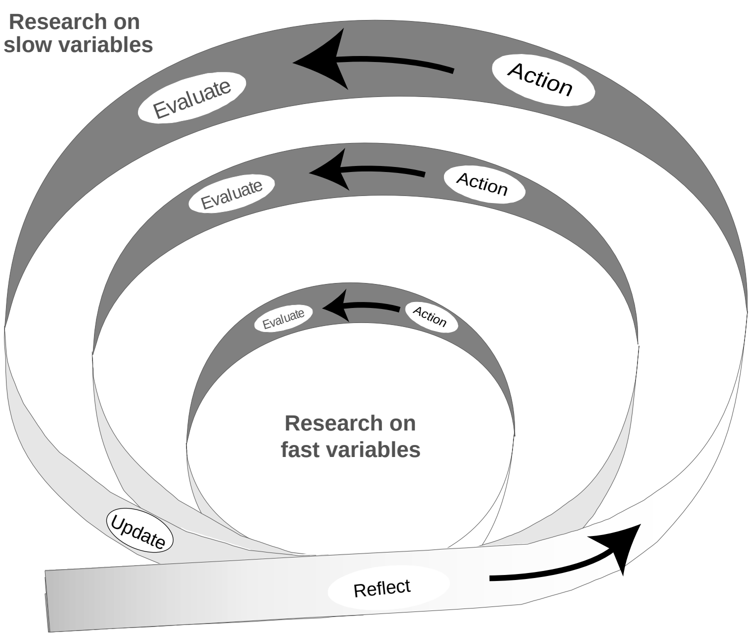
In the adaptive learning cycle, researchers are one, among many, stakeholder groups. The research is conducted as part of an experimental management process involving the full range of stakeholders. Thus, participatory approaches are fundamental and collective action is the norm (Douthwaite et al. 2001, Hagmann et al. 2002, Abel et al. 2002). Because numerous stakeholders are involved, negotiation processes are key to the action cycle; thus, actions are an outcome of various negotiation processes. Negotiation occurs throughout the adaptive management cycle, in particular in establishing a common vision during the reflective stage, and in selecting options for implementation in the action phase. Given the emphasis on multiple stakeholders, it is not surprising that many of the successful cases of INRM have as a key objective the development of social capital (Garrity et al. 2002, Lovell et al. 2002).

UNDERLYING PRINCIPLES: GOING TO SCALE BUT REMAINING PRACTICAL

Multiple scales of analysis

A key feature of INRM is its attempt to integrate across spatial and temporal scales. INRM research should never involve just a single snapshot in space or time. In the real world, different processes are taking place over different time frames; some processes will be studied using short time frames, whereas others may have to be studied over decades, usually only possible through simulation (Lovell et al. 2002). As a result, INRM research usually does not involve a simple learning cycle. It will normally depend upon a number of interlinked and superimposed learning cycles (Fig. 3), as some phenomena will have been through many learning cycles, whereas others may not even complete a single cycle within the project time frame. It is particularly important for INRM research to take slow variables into account.

Figure 3. Overlapping learning cycles for different INRM processes.



These slow-changing variables affect the dynamics of more rapidly cycling processes and may exceed thresholds or trigger breakpoints, thus causing sudden and surprising shifts in systems. Accumulations of toxic chemicals in soils, water, and organisms, gradual erosion of soil fertility, and depletion of groundwater are all slow variables that need to be tracked in studies of complex resource systems.

Generally, INRM research will never be conducted at a single spatial scale; work often will be required at three scales (Allan and Starr 1982, Holland 1995, Beaulieu et al. 2002). Thus, work at the farm/household level may require component studies at lower levels, such as the plot level or the intra-household level, to understand the important processes that lead to the emerging characteristics at the farm/household level. Work at the farm/household level will also generally require work at higher levels, e.g., at the institutional framework established by local government. Two components of spatial scale can be recognized, a biophysical component (from plots to global scales) and an institutional component (from household norms of behavior to global policy instruments). These are not usually congruent, thus adding further complexity (Lovell et al. 2002).

Decision-making processes

Many conceptual models of INRM focus on decision-making processes. Lal et al. (2001) go so far as to term the learning cycle in INRM the "Adaptive Decision-Making Process". Decisions by individuals or households to adopt or not adopt new technology or land use practices depend on a multitude of factors and external influences that will vary from situation to situation, and will be dependent on incentive structures, information flows, etc. (van Noordwijk et al. 2001). Central to the decision-making process is the analysis of trade-offs and competing interests (Garrity et al. 2002, van Noordwijk et al. 2001). In much INRM research, the farm household is selected as the main decision-making unit (Lal et al. 2001). Although this may be appropriate in many circumstances, there are situations, most notably involving common property systems, in which other stakeholders at other spatial scales may be key.

Plausible promises

INRM should lead to tangible benefits on the ground; it must be a problem-solving approach (Hagmann et al. 2002, Harrington et al. 2001, van Noordwijk et al. 2001). The motivation to jointly engage in experimentation and research is that there is some "plausible promise" of a beneficial change (Douthwaite et al. 2001). Plausible promises are often made with reference to "best-bet" interventions involving technological and/or institutional innovations. The successful INRM cases are invariably built around very specific intervention possibilities that achieve adaptation and uptake (Garrity et al. 2002, Hagmann et al. 2002).

Scaling up: going beyond the specific

INRM research, because it considers numerous variables, many of which are locality specific, has been criticized for yielding only local solutions. However, if natural resource systems are characterized adequately and variables are measured across the full range of variation of the system, then INRM models will yield results that have application across broad ecoregional domains.

The dissemination of conventional agricultural technology research products, e.g., high-yielding crop varieties, follows a simple linear route from researcher to extension worker to farmer (the "transfer of technology" model). INRM research does not yield technological packages amenable to this sort of dissemination (Douthwaite et al. 2001). In INRM, the farmers, extension officers, and researchers are all stakeholders, participating from the initiation of the research. Lovell et al. (2002) conclude that scaling up to benefit many people is largely a function of planning and investment at the outset to create the enabling environment that will meet various pre-conditions for scaling up. One of the conditions for scaling up is the adequacy of social capital (Lovell et al. 2002, Hagmann et al. 2002). Scaling up is most likely to happen in the INRM approach if top-down and bottom-up approaches to development are properly reconciled. Both are likely to be needed for an effective delivery of benefits from INRM research (Lovell et al. 2002). The adaptive management cycle is key to scaling up: repeated learning cycles ensure an improvement in the "plausible promise' through its adaptation to existing systems by ever larger numbers of producers (Douthwaite et al. 2001).

Any INRM research endeavor should usually have impacts at a number of spatial and temporal scales (Harrington et al. 2001, Lovell et al. 2002, Jones and Thornton 2002). The work of Hagmann et al. (2002) provides an example of impacts at multiple scales. These authors undertook research that spanned from the plot to the policy scale; their work resulted in successful interventions at the plot level and important reorientation of thinking within the national extension service.

THE TOOLS FOR INRM: CONFRONTING COMPLEXITY

Systems modeling

The problems of nonlinearities, unpredictability, and time lags in natural resource systems suggest that systems modeling is a fundamental tool for INRM research. Systems modeling is appropriate at many points in the adaptive management cycle. It can be used to conceptualize the system, to build a common understanding among stakeholders, to identify leverage points for interventions, to analyze different scenarios, to form the basis of decision support systems, to assist in stakeholder negotiations, to identify systems performance indicators and to assist in evaluation of impacts (Campbell et al. 2001, Lal et al. 2001, Lynam et al. 2002, van Noordwijk et al. 2001).

Negative attitudes toward modeling abound, often based on the heavy data requirements of large and complex simulation models. Although such complex models undoubtedly have their place, we are attracted by the concept of "throw-away" models, working computer-implemented models that are built in a few days to solve a particular problem and then are discarded. Much recent INRM research has used participatory modeling, in which stakeholders assist in the development of models and model results are fed back to communities using participatory techniques such as role plays (Lynam et al. 2002).

Across-scale modeling is in its infancy in NRM. Jones and Thornton (2002) demonstrate a method whereby plot-level models can be run for large extrapolation domains and the results can be aggregated to provide useful information at the regional level. Jones and Thornton (2002) also demonstrate the use of a series of interconnected models, ranging from global to plot models.

Decision and negotiation support tools

Given the complexity of INRM systems, it is likely that some kinds of decision or negotiation support tools will be necessary. The term "decision support system" suggests that a single management authority will make decisions that will then be imposed on the various actors and stakeholders. Thus, van Noordwijk et al. (2001) prefer the term "negotiation support system". To function adequately, a negotiation support tool, itself, must be the subject of negotiation and shared development efforts between stakeholders (van Noordwijk et al. 2001, Garrity et al. 2002). Lal et al. (2001) conclude that using a decision support tool that is built in a participatory manner will increase the chance of achieving a shared vision.

Multiscale databases

Increasingly, decision support systems or systems models are being linked to a variety of databases. Even when not linked in this manner, INRM will invariably require that data from different sources be managed in some kind of database. Data can be of a spatial or nonspatial nature, and both qualitative and quantitative data can be included. Geographical information systems are usually involved in the data management system. Jones and Thornton (2002) demonstrate the use of databases at various scales that are linked to models at various scales. GIS and modeling are also crucial for scaling up. As Harrington et al. (2001) note, such tools should not be abused to support top-down mechanical extrapolation of technologies; rather, stakeholder decisions should be informed by spatial analysis.

Impact assessment

Impact assessment is a key feature of INRM, being a tool for adaptation, learning and performance enhancement; providing data for further negotiation among stakeholders; and for resource allocation decisions. Hagmann (1999) pleads for more focus on developing plausible strategies on how research contributes effectively to impact, and then for regular monitoring of the implementation of these strategies, rather than carrying out impact assessment studies that are not linked to the learning cycle. Indicators for evaluation must be selected at an early stage of the work. To select indicators from the vast array of possibilities, Campbell et al. (2001) and Gottret and White (2001) suggest that the capital assets concept may be an appropriate organizing principle, whereas Bossel (2001) suggests that systems concepts should guide indicator selection. A number of papers in this volume focus on the use of indicators (Bossel 2001, Campbell et al. 2001, Gottret and White 2001). The approach advocated here is unlike that used in conventional impact assessment of agricultural research, which generally focuses on ex-post measures of crop yields. Classic ex-post impact assessment tools can be compared to end-of-year school exams, whereas INRM impact assessment tools should be seen as equivalent to continuous assessment.

THE WAY FORWARD

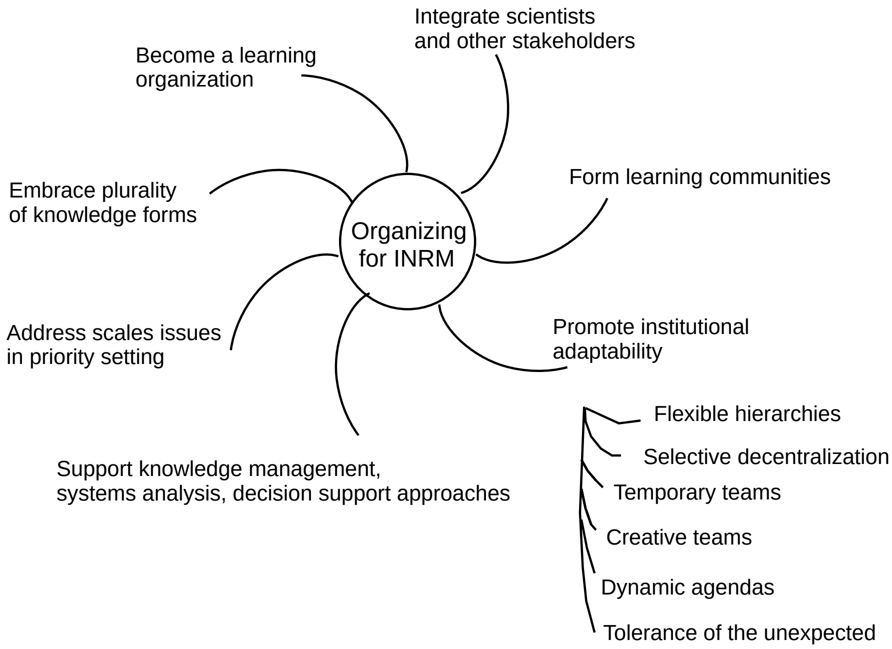
The successful examples of INRM research are those that have drawn upon and have integrated tools and concepts from different disciplines and scientific fields. This is what distinguishes modern approaches to INRM from some earlier discipline-based studies of natural resource problems (Belsky 2002, Rosa and Machlis 2002). If the real needs of poor farmers in developing countries are to be met, then integrated approaches are essential. The farmers themselves are practicing integrated management of their resources, basing their management on knowledge acquired over generations (Berkes et al. 2000). Effective INRM research should link seamlessly with the knowledge of the client farmers. If scientists continue to operate in a simple, reductionist, technological world, they will fail to achieve the potential pay-offs that could be obtained by linking modern science to the traditional knowledge base. More importantly, however, changes occurring in the world defy the understanding of the small farmer. Macro-economic changes, increased climate variability, etc., will be major determinants of human well-being in poor countries, and science must contribute understanding of these phenomena to research on the system (Campbell et al. 2002). Similarly, the development trajectories followed by the poor will have major implications for the global environment.

The world is becoming more integrated, and integration emerges as the most important concept in the INRM approach: there is a need to integrate across disciplines, across scales, across stakeholders, and across components (Lal et al. 2001, Costanza and Jorgensen 2002, Belsky 2002, Ashley and Maxwell 2002). However, the marginal costs of adding each additional component into the system have to be considered and have to be less than the marginal benefits of such additions. A clear articulation of the problem, plausible solutions, and tangible potential benefits must still underlie all research investments.

A common criticism of the ecological approach to NRM is that it attempts to describe a multi-component system in which everything is connected to everything else, and that such complexity defeats useful analysis. Recent theory and supporting observation suggest, however, that this complexity is not boundless, but has its own natural subdivisions and boundaries, and that 3–5 key variables often drive any particular system (Holling et al. 2000). Thus, defining a set of key processes and components can yield progress toward a goal of sustainable production.

Integrated approaches to natural resource management, as described in this volume, will require major changes in the culture and organization of research (Ashby 2001, Costanza and Jorgensen 2002, Hagmann et al. 2002). It is a new way of doing business. The management environment is faced with a long-term future that is unknowable; it has to deal with non-equilibrium conditions, multiple aspirations, and ambiguity. Although we see INRM being built on a social learning process, we also see the organizations involved in INRM becoming learning organizations, in which top management promotes institutional flexibility, conditions favorable to complex learning, integration of scientists with other stakeholders, etc. (Fig. 4).

Figure 4. Proposed characteristics of organizations undertaking INRM research (based on Ashby 2001).



Many of the arguments used in this paper are similar to those that predominate in the modern management science that is taught in business schools. Many of the problems of managing complex natural resource systems are similar to those of running a commercial company in a rapidly changing world. However, agricultural, forestry, and other NRM institutions have mostly evolved to deal with much simpler and more predictable conditions. They now have to change. Reconciling the need for increased supplies of food and fibers with the need to maintain the environment and to do this in a way that can bring a billion people out of absolute poverty is not a problem that can be solved by laboratory science alone. We need a predictive science that can enable us to produce more, to do so sustainably, and to do so on the basis of a limited resource base. This is the modern science of INRM that we describe in this volume.

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2.

Blending "Hard" and "Soft" Science: the "Follow-the-Technology" Approach to Catalyzing and Evaluating Technology Change

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ABSTRACT

The types of technology change catalyzed by research interventions in integrated natural resource management (INRM) are likely to require much more social negotiation and adaptation than are changes related to plant breeding, the dominant discipline within the system of the Consultative Group on International Agricultural Research (CGIAR). Conceptual models for developing and delivering high-yielding varieties have proven inadequate for delivering natural resource management (NRM) technologies that are adopted in farmers' fields. Successful INRM requires tools and approaches that can blend the technical with the social, so that people from different disciplines and social backgrounds can effectively work and communicate with each other. This paper develops the "follow-the-technology" (FTT) approach to catalyzing, managing, and evaluating rural technology change as a framework that both "hard" and "soft" scientists can work with. To deal with complexity, INRM needs ways of working that are adaptive and flexible. The FTT approach uses technology as the entry point into a complex situation to determine what is important. In this way, it narrows the research arena to achievable boundaries. The methodology can also be used to catalyze technology change, both within and outside agriculture. The FTT approach can make it possible to channel the innovative potential of local people that is necessary in INRM to "scale up" from the pilot site to the landscape. The FTT approach is built on an analogy between

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technology change and Darwinian evolution, specifically between "learning selection" and natural selection. In learning selection, stakeholders experiment with a new technology and carry out the evolutionary roles of novelty generation, selection, and promulgation. The motivation to participate is a "plausible promise" made by the R&D team to solve a real farming problem. Case studies are presented from a spectrum of technologies to show that repeated learning selection cycles can result in an improvement in the performance of the plausible promise through adaptation and a sense of ownership by the stakeholders.

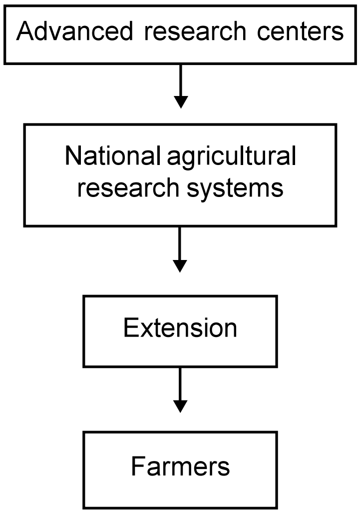
KEY WORDS: actor-oriented approach, follow-the-technology approach, integrated natural resource management, learning selection approach, participatory technology development, social construction of technology.

INTRODUCTION

On its web site (http://www.inrm.cgiar.org/), the Consultative Group on International Agricultural Research (CGIAR) defines integrated natural resource management (INRM) as "the responsible and broad-based management of the land, water, forest, and biological resources base—including genes—needed to sustain agricultural productivity and avert degradation of potential productivity." A workshop held in August 2000 titled Integrated Natural Resource Management in the CGIAR concluded that implicit in this definition is a focus on human well-being and thus an emphasis on systems rather than commodities and on processes rather than technologies (International Center for Living Aquatic Resources Management 2000). As such, INRM is attempting to carry out types of research and intervene in ways that are very different to the yield improvement work that has been CGIAR's mainstay in the past. CGIAR centers have achieved most of their impact by delivering improved varieties to relatively simple environments. The new knowledge is embedded in the seed, which farmers already know how to plant and save; few or no new management skills or changes to routine are needed (Douthwaite et al. 2001). As a result, researchers have been able to assume a simple, rather linear view of the technology development and transfer process, which is described by Chambers and Jiggins (1986) as the transfer-of-technology (TOT) view presented in Fig. 1. The widespread success enjoyed by the TOT approach in starting the Green Revolution has helped to ingrain the approach to such an extent that it has been commonly applied to the development and transfer of types of technology other than improved germplasm (Kaimowitz et al. 1989).

Since the publication of the landmark paper describing the "farmer-back-to-farmer" approach (Rhoades and Booth 1982), there has been a growing realization within the CGIAR system that the TOT approach is flawed. One indication of the problem is the failure of natural resource management research to achieve adoption rates similar to those of plant breeding. For example, in a recent comprehensive review of research on soil fertility in West Africa, Bationo et al. (1998:33) concluded that " ... over the past years a considerable amount of technologies to improve the productive capacity of African soils have been generated. These technologies have not been transferred or implemented by the intended beneficiaries."

Figure 1. The transfer of technology (TOT) view of the way innovations originate and are passed down to farmers (adapted from Chambers and Jiggins 1986).



The unhappy situation is that in many parts of Africa farmers have little choice but to continue to degrade their soils and their environment. It is just this scenario that INRM was set up to address. But how will INRM achieve its goals in practice? What tools and methodologies are INRM practitioners going to use?

A CLASH OF TWO PARADIGMS

If everyone saw the world in the same way, then making INRM operational would simply be a matter of agreeing on a few tried and trusted methodologies with the stakeholders involved and then following the formula to implement them. However, life is not that simple. On the one hand, INRM practitioners are going to have to work with colleagues in the CGIAR system and in the national agricultural research systems (NARS) who feel that if they cannot come up with something better than what the farmers are already doing, then they should give up and go home. These colleagues generally find that they agree with the underlying principle of the TOT approach, i.e., that scientific knowledge is, or certainly should be, superior to farmers' knowledge, and so have a problem relating to participatory approaches that eulogize farmers' knowledge. On the other hand, INRM practitioners will have to work with farmers who may ignore realities that seem obvious to scientists. Hence, understanding that people see reality differently and the ability to negotiate shared realities are fundamental to successful INRM implementation. Constructivism is the epistemological basis of INRM that supports the idea of multiple realities. Understanding the difference between the constructivist paradigm and the positivist-realist paradigm, which underpins the "science-is-best" basis of the TOT approach, is important to comprehending the nature of the paradigm change necessary to make INRM operational within the CGIAR system and NARS.

Positivist-realism is associated with "hard" science, which sets up hypotheses and tests them with repeatable and quantifiable experiments. Practitioners of hard science (e.g., most natural scientists and some social scientists) are trained to believe that the world they experience has an independent reality that they are discovering in their experiments. The repeatability principle implies that knowledge gained in this way is independent of its context and separate from the individual. A corollary of this view is that, because scientific rules are universal, then people need to change, not technology. Furthermore, because scientific knowledge has passed the rigor of the scientific process, it is seen as superior to farmers' indigenous knowledge, which generally has not. Hence, the TOT approach, applied in its purest form, stipulates that the role of agricultural scientists is to use the scientific method to understand, structure, and model reality to develop technologies that benefit farmers. It is then the job of extension to "project" the scientists' knowledge onto the minds of farmers as accurately as possible, and the responsibility of the farmers to receive it. Farmers are supposed to be passive recipients in that they are not expected to adapt the message if it is based on "good" science and properly delivered. If farmers do not adopt it, it is their fault for being backward.

Constructivism is associated with "soft" science, which looks at social phenomena that cannot be reduced to their component parts or repeated outside of their complex settings. Case studies that paint a rich, thick picture of phenomena are a mainstay of the soft sciences. Constructivism provides the epistemological foundation for "participatory" approaches. Soft scientists contend that, contrary to the realist-positivist position:

- knowledge is not passively received and "mapped" onto a learner's brain but is actively "constructed" by the learner, who fits it into his or her existing mental maps or, less commonly, constructs a new model of reality and makes it part of his or her lifeworld. This construction process is social, because the mental maps may be culturally defined, and because part of the interpretation is undertaken by a group through negotiation; and
- people's ability to learn and understand is adaptive in the evolutionary sense, in that cognition serves a person's need to process information to conceptually organize and understand the world he or she experiences as a means of survival. In the words of Maturana and Varela (1987), " ... knowledge is effective action in the domain of existence," and there is nothing absolute or external about it.

In practice, few, if any, scientists in the CGIAR system today would ever see farmers as completely passive adopters of a message. Nevertheless, most people would agree that positivist-realism, rather than constructivisim, is still the dominant paradigm in many CGIAR centers and in most national research systems. Therefore, it will require a paradigm shift for INRM to become a mainstream activity. Paradigm changes are not easy, as Thomas Kuhn

(1970) points out; he notes that scientists will go to great lengths to defend their belief structures, to the extent that research is not about discovering the unknown, but rather " ... a strenuous and devoted attempt to force nature into the conceptual boxes supplied by professional education." To this end, a research community will often suppress novelties that undermine its foundations.

Like the research into farming systems that was carried out in the 1980s, INRM runs the risk of being dismissed on the grounds that it is too woolly and has little quantifiable impact. The Bilderberg Consensus, which helped establish INRM within the CGIAR system, identified improved adaptive management as the key to achieving relevance and impact in INRM, and hence avoiding the fate of farming systems research. Adaptive management is essential because, as Campbell et al. (2001) point out, there is an inverse relationship between the complexity of systems (INRM systems are complex) and our ability to make precise and yet significant statements about their behavior.

The successful introduction of INRM technology can have unexpected and even negative consequences, as one of the present authors learned first-hand in Tanzania (N. C. de Haan and E. Musuyaka, *unpublished manuscript*). In the early 1990s, an NGO in Tanzania ran a project to improve child nutrition. It introduced an agro-ecologically well-adapted bean variety that was more nutritious than local varieties. The NGO targeted its technology at women, who are traditionally in charge of feeding the family. The new variety of bean proved very popular, and its adoption rate soared. Despite this, after the first few years, the nutritional benefits for local children had evaporated. It eventually emerged that the bean had also proved popular among men, who started to cultivate it for the market on land that had previously been women's property for growing food for home consumption. So, instead of the technology helping the targeted group, it in fact benefited another group to the detriment of the first.

INRM activities need management strategies that adapt as they go along to ensure that the project has impacts that are, on balance, positive. Successful management strategies in INRM therefore need to be based on effective monitoring and evaluation systems to guide learning. Given that change is expected during the course of a project, the monitoring and evaluation system itself must also be adaptive and flexible.

In this paper we develop the "follow-the-technology" (FTT) approach to guide the fostering and evaluation of technology change in the context of INRM. The approach needs to be:

- comprehensive and adaptive enough to deal with the complexity of INRM systems and
- constructed from language and concepts that both hard and soft scientists can understand and relate to.

The second requirement may be rather hard to achieve. The present authors come from both hard and soft science backgrounds and, while we were writing this paper, we had to negotiate a shared understanding between ourselves and our two guiding paradigms. We hope this is reflected in the paper and is useful for others.

DEVELOPING THE FOLLOW-THE-TECHNOLOGY APPROACH

Learning selection: the core model

The model at the core of the follow-the-technology (FTT) approach is the learning selection (LS) model (Douthwaite 2002, Douthwaite et al. 2002) that describes the “social construction” and adoption of new technologies, including machines, seeds, computer software, and financial systems. The LS model is based on an analogy between technology change and Darwinian evolution that is recommended as being useful in understanding innovation processes (Nelson 1987, Mokyr 1990). This evolutionary analogy suggests that technology change is driven by a process analogous to natural selection. We call this analogy “learning selection,” but it is not a perfect analogy. Rather, it is an “analogy as a heuristic,” or an analogy that suggests useful ways of thinking about innovation processes from the point of view of the much better understood evolutionary process (Ruse 1986).

The Bilderberg Consensus has already identified evolutionary approaches as areas of potential breakthrough for INRM. We believe that one reason why this prediction may become reality is because both positivists and constructivists understand and accept Darwin’s theory of natural selection and will be comfortable thinking about technology and system change in evolutionary terms. For this reason, the analogy is a good basis for negotiating a shared understanding. Moreover, as Dawkins (1995:*xi*) wrote, “Never were so many facts explained by so few assumptions ... the Darwinian theory command(s) superabundant power to explain.” Finally, the specific analogy we are suggesting, between natural selection and learning selection, highlights the learning processes of the actors involved in INRM, something that Campbell et al. (2001) identify as key to the effective management of complex systems. Natural selection consists of three mechanisms:

- *Novelty generation.* As a result of random genetic mutations and sexual recombination of differing genetic material, differences between individual members of a species crop up from time to time.
- *Selection.* This is the mechanism that retains random changes that turn out to be beneficial to the species because they enable those possessing the trait to achieve better survival and breeding rates. It also rejects harmful changes.
- *Promulgation and diffusion.* These are the mechanisms by which the beneficial differences are spread to other areas.

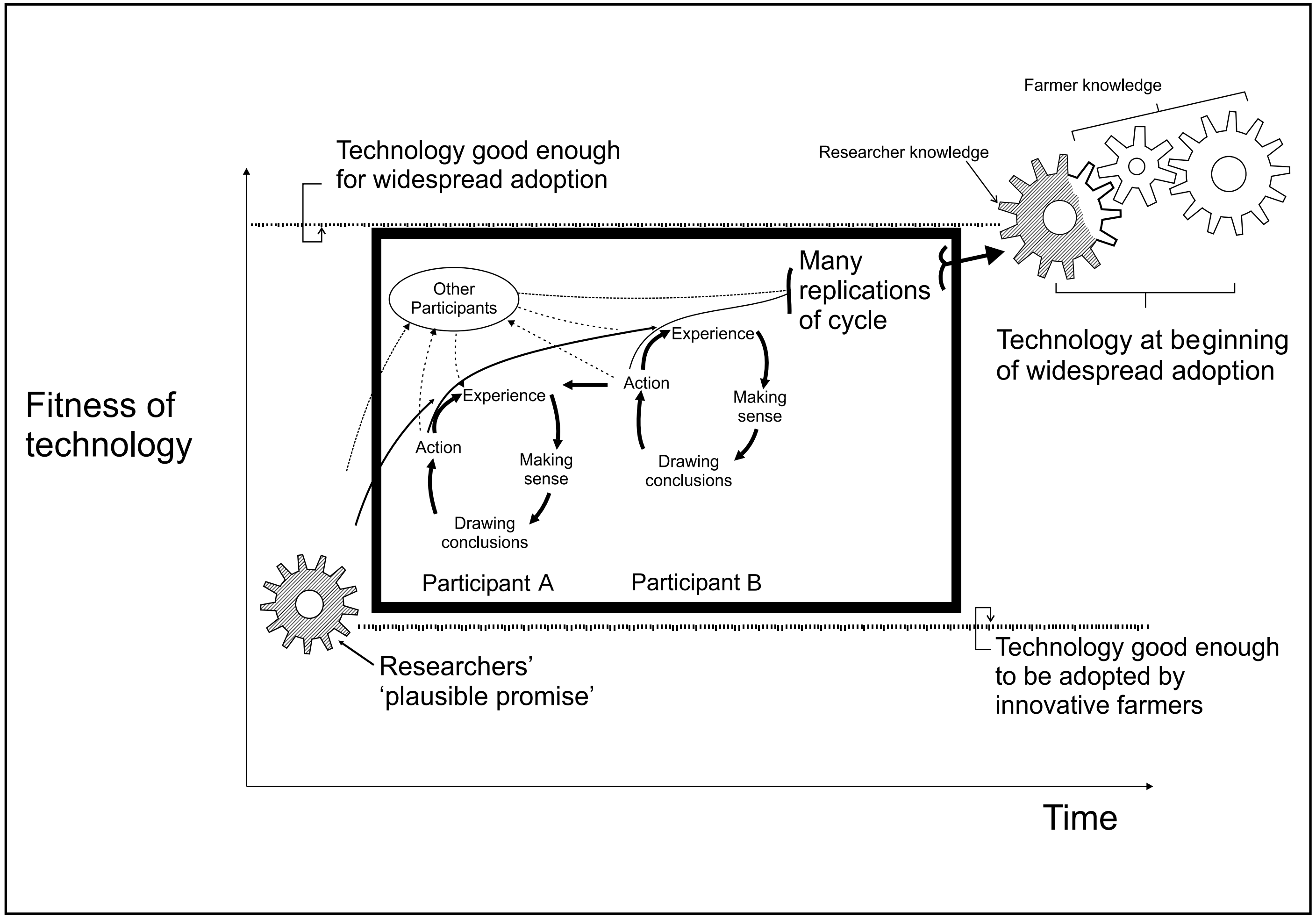
To understand how learning selection is analogous to natural selection, let us take the example of one of the stages in the early adoption of *Mucuna pruriens* in Benin (Fig. 2). *M. pruriens* is a herbaceous legume that forms the basis of an NRM cover crop and green manure technology. Participant A is a female farmer who decides to plant an *M. pruriens* cover crop in her field after seeing a demonstration in her village by researchers that shows the legume’s ability to improve soil fertility. As a result of growing *M. pruriens*, the farmer has an experience of the crop that she tries to interpret on the basis of the information in her existing mental models of reality. Her observations and understanding lead her to the conclusion that *M. pruriens* is more immediately useful as a way of suppressing *Imperata cylindrica*, a grass weed that caused her to abandon some of her land. The following year, she uses *M. pruriens* to try to reclaim this land by cutting the *I. cylindrica* at the beginning of the rainy season and broadcasting *M. pruriens* seed in the hope that it will outgrow and smother the *I. cylindrica.* By carrying out this experiment, she is generating a novelty as well as beginning another learning cycle, the result of which will be a selection decision on her part as to whether to continue to plant *M. pruriens* in this way.

Other people, including farmers, researchers, and laborers, might also observe Participant A's experiment and, as a result, experience their own learning cycles, resulting in their own changed perceptions and actions (Fig. 2). For example, Participant B might be a researcher who learns that the ability of *M. pruriens* to suppress *I. cylindrica* is more important to farmers than its ability to improve soil fertility. Learning this would then influence further researcher novelty generation and selection decisions, as well as efforts to promulgate and diffuse the technology. The net effect of all these learning selection cycles is to improve the fitness of the technology, i.e., its suitability for the environment in which it is used, and hence its market appeal and adoption rate. This is analogous to the fitness increases that occur in the living world as a result of natural selection. The concept of fitness or adoptability in the sphere of human activity is also similar to Lyotard's (1984) concept of performativity, which he defines as the best possible input:output ratio. Lyotard argues that performativity itself is the main way to legitimize knowledge.

Learning selection, however, does not just happen. It comes about only if the key stakeholders, i.e., the people directly involved in using and replicating the technology, are sufficiently motivated to modify it; they must also have sufficient knowledge to generate and select beneficial changes (van Mele and Zakaria 2002, Conroy et al. 2002). Experience shows that, for all but the simplest technologies, there is a need for at least one stakeholder who understands the technology to champion it and fill knowledge gaps until the key stakeholders have learned enough to take over (Douthwaite 1999). This takeover marks the end of the early adoption process and is the point at which market selection, as opposed to learning selection, begins to work. As this happens, the people adopting the technology change from Rogers' (1995) "innovators" to people who want the technology to work reliably and profitably.

According to Merriam-Webster (2000), technology can be defined as " ... the practical application of knowledge ..." (by people). If all technology can be thought of in terms of knowledge, this definition implies that there is no inherent difference between agricultural and other types of technology. Hence, agriculture and INRM can potentially learn much about technology change from other fields. To determine whether or not it was possible to generalize the LS approach, Douthwaite (2002) tested it by looking at the extent to which it fit outside agriculture, and explored ways in which the model could be strengthened by experience and literature from other fields. He found that, not only is the LS model much more widely applicable, but the democratic user-led type of innovation it describes is able to harness the innovative potential of the people who are directly affected by the technology. Douthwaite shows how a grassroots development process in Denmark was able to produce a wind turbine industry with a 55% share of a world market worth U.S.$1 billion per year,

Figure 2. The learning selection model, which shows how the fitness of a technology changes during the early adoption phase.



surpassing even the United States, which spent more than $300 million funding a top-down development program led by the National Aeronautics and Space Administration (NASA). The origins of the Danish industry were a few agricultural machinery manufacturers and ideologically motivated hobbyists who began building and tinkering with wind turbines (generating novelty). There were many early teething problems but the owners organized themselves into a group who lobbied successfully for design improvements (selection), working closely with manufacturers to solve problems. The owners group developed a cooperative ownership model and pressured politicians to support the sale of their electricity to the national grid at a fair price (promulgation and diffusion). In contrast, NASA led a hard science development approach that implicitly assumed that scientists could develop the perfect wind turbine with little input from owners and users. NASA's approach failed.

Another example of the power that a grassroots innovation model can harness is the development of the computer operating system Linux, which is a " ... a world-class operating system ..." that has coalesced " ... as if by magic out of part-time hacking by several thousand developers all over the planet connected only by the tenuous strands of the Internet ..." (Raymond 1997). Linux started life when a Finnish computer science student, Linus Torvalds, wrote a Unix-like operating system that he could run on his PC; he had grown tired of having to queue for hours to gain access to Unix on the university mainframe. When he finally got the core of his operating system working, he posted it on the Internet so that others could try it out. Best of all, he gave out the source code so that other people could understand the program and modify it if they wanted to. Just like the first Danish wind turbines, early versions of Linux were not technically sophisticated or elegant, but they were simple and understandable, and they touched a chord with hackers and people like Torvalds himself who get a kick out of generating novelty for the sake of being creative, not for money.

After the first release, Torvalds' main role in the development of Linux was not to write code for features people wanted, but to select and propagate improvements to the system from the ideas that streamed in. Ten people downloaded version 0.02, and five of them sent him bug fixes, code improvements, and new features. Torvalds added the best of these to the existing program along with others he had written himself and released the composite as version 0.12. The rate of learning selection accelerated as the number of Linux users increased, and, to cope with the volume of hacks (novelties) coming in, Torvalds began relying on a type of peer review. Rather than evaluate every modification himself, he based his decisions on the recommendations of friends he trusted and on whether people were already using the patch (modification) successfully. He, in fact, played a similar role to that of the editor of an academic journal who makes sure that submitted articles are reviewed but retains final control over what is published and what is not. This approach allowed Torvalds to keep the program on track as it grew from 10,000 lines of code to 1.5×10^6, all written by volunteers.

Such has been the success of Linux that Microsoft, which until recently was the richest company in the world based on market capitalization, is privately worried. Vinod Valloppillil, a Microsoft engineer, analyzed the open-source software movement in a confidential memorandum that was leaked and posted on the World Wide Web. Valloppillil (1998) wrote, "Linux could win ... The ability of the open source software process to collect and harness the collective IQ of thousands of individuals across the Internet is simply amazing." Microsoft jealously guards its own source code to make sure it remains closed, and users cannot modify it. Although Linux is not yet seriously threatening Microsoft's 90% domination of the PC market, by the end of 1998 Linux was installed on 17% of the servers that run computer networks, including the Internet, which was a 7% increase from the previous year. Windows NT, the market leader, remained fairly static at 38% (Shankland 2000).

The fact that a grassroots community development model can lever more creative talent than one of the richest companies in the world has, we feel, an exciting resonance for INRM. To succeed in complex environments, INRM interventions must be able to foster and motivate the innovative potential of local people, or else scaling up from pilot site to landscape will not occur (Hagmann et al. 2002). Douthwaite (2002) has developed a practical guide on how to launch and manage a learning selection innovation process by starting with a plausible promise and then building a development community of motivated users. The guide, which is presented in Appendix 1, is intended for R&D managers working in the public or private sector.

The analogy between natural selection and learning selection is not perfect. One important difference is that natural selection is blind, whereas learning selection is not: genetic mutations occur at random, but technology and system change can be directed, e.g., by product champions. The "thinking" nature of learning selection implies that, to understand the processes involved, we have to go beyond simply identifying novelties generated or selection decisions made and delve into the reasons why people behave the way they do. Consequently, a cornerstone of the LS approach is the seemingly obvious relationship articulated by Lewin (1951), who maintains that people's behavior (*B*) is a function of the interaction of the person (*P*) with his or her environment (*E*), or B=f(P,E). This is the theoretical justification for the fourth and fifth steps in the guide (Appendix 1) to managing a learning selection approach that involves working with motivated people and choosing pilot sites where there is a real need. MacKeracher (1994) explains the Lewin model in this way. Behavior can include any outcome of the learning process, including adoption, modification, selection, a change in attitude, and communication to others. *P* stands for the person (the learner) and can include any characteristic that affects learning, such as existing models of reality. *E* stands for the environment and can include any factor within the context that might affect learning, including the number and quality of interactions with other people, the nature of the technology being tested, and the physical, cultural, and socioeconomic settings.

Whereas the learning selection model has been developed and verified on several types of technology, including seed-based technology (Douthwaite 2002), it has not been used in an INRM context to initiate or manage innovation. As we've already acknowledged, INRM needs to operate in complex settings (Horne et al. 2002, Snapp et al. 2002). These settings are likely to involve more complex social interactions than the learning selection model has so far dealt with, and therefore it needs to be adapted and expanded to take this into account. In particular, a rather more robust framework is needed than that provided by Lewin's model, which does not take into account the groups, social learning, or social organizations surrounding technologies (Saad 2002).

Understanding people's actions: the actor-oriented approach

This is where the actor-oriented (AO) approach, developed by Norman Long (1997) at the Wageningen Agricultural University, can help, because it seeks to understand how different stakeholders react to technical and social change by concentrating on three interlocking analytical concepts: intervention, interface, and lifeworlds.

Intervention

Long (1989) describes intervention as an attempt from outside a system "... to organize and control production ..." within it. The introduction of a new agricultural technology is therefore an intervention into an already existing situation. The focal point of interest in the actor-oriented approach is how people negotiate and transform this technology (used here in the broadest sense of the word). The intervention results in actual changes to the status quo and the expectation of further changes. These changes are what Long (1992) calls "structural discontinuities," and they are what people react to when they decide how they are going to adapt and transform the technology and their social networks to fit into their own mental maps of reality or lifeworlds. One possible reaction is, of course, to ignore the technology and to try to maintain one's lifeworld unchanged. It is exactly these reactions, or lack of them, that the AO approach seeks to identify and study.

Lifeworlds

Lifeworlds are the realities that people adaptively construct for themselves. They are the sum total of the mental maps and models that people have built to allow them to cope in their environments and, as such, are made up of past experience and personal and shared understanding. Lifeworlds are what lead people to react in the ways that they do when they confront an intervention (a new technology). Thus, the lifeworld concept encompasses both the people and part of the environment construct in Lewin's (1951) model. Schütz and Luckmann (1974) describe a lifeworld as a " ... lived-in and largely taken-for-granted world." This taken-for-granted nature of lifeworlds makes them difficult to study, because people often do not understand the concept or realize the limits of their own lifeworlds unless they are challenged (Long 1992). The methodological importance of the lifeworld concept is that it explicitly acknowledges that people have different realities and makes understanding these realities a primary research activity. This is very different from more traditional approaches that put a premium on the scientist's understanding of problems and solutions.

Interface

The interface concept is closely linked to that of intervention. Social interface is defined by Long (1989) as " ... the critical points of intersection or linkages between different social systems or levels of social order, where structural discontinuities based upon differences of normative values and social interest are likely to be found." In other words, interfaces are the areas in which different social groups experience mutual friction and, if the introduction of a new technology is going to cause problems or create opportunities (i.e., structural discontinuities), the interface is where they will be found. Long goes on to say that " ... the concept implies face-to-face encounters between individuals or social units representing different interests and backed by different resources." It is by identifying these interfaces and then studying the perturbations that occur as a result of the intervention that we can understand how interventions are modified by everyday life, and vice versa (Arce and Long 1992). The interface concept is thus contained within Lewin's concept of environment in his model.

Methodologically identifying interfaces is important, because they allow us to identify all the groups that are involved in and influenced by a technology without overlooking something important, as happened in the Tanzanian bean example.

The concepts and value of intervention, lifeworlds, and interface can be illustrated with an example from the Philippines (Douthwaite et al. 2002). A mechanical rice harvester was introduced into the Philippines in 1983 by both the public and private sectors. This was the intervention. Initially, the machine was purchased by hundreds of farmers (one social group) who wanted to reduce wage payments to manual harvesting teams (another social group). The traditional arrangements surrounding the hiring of harvest labor teams by farmers was the interface, and the structural discontinuity was the farmers' decision to depart from these arrangements and use the machine instead. The harvest laborers found themselves out of work and started sabotaging the reapers by hiding iron rods in the rice crop that broke the reaper cutter bar. The harvest laborers also started to refuse to harvest fallen crop manually or to harvest in muddy fields where the reaper could not work. Finally, they boycotted other farm operations, such as transplanting and weeding on the adopting farmers' fields, resulting in a structural discontinuity at another interface. Some reaper owners abandoned their machines, and the adoption rate fell sharply.

The structural discontinuities led to negotiations between the two groups that resulted in an institutional innovation (an emergent structure) that has allowed both groups to incorporate the reaper into their lifeworlds. The manual harvest teams started to hire the reapers from the owners, because they found that the machines allowed them to harvest more crop and increase their net income. As a result, they were able to share in the benefits of the technology, and their attitude toward it changed.

THE FOLLOW-THE-TECHNOLOGY APPROACH IN PRACTICE

As we've seen from the bean and reaper examples, we need a methodological approach to INRM that is adaptive and flexible enough to be able to respond in a timely way to unexpected events and unintended consequences. The problem with "cookbook" approaches to monitoring and evaluation is that they all come with fixed preconceptions, embodied in the indicators chosen, of what is going to be important. The methodological importance of the follow-the-technology (FTT) approach is that it does not try to predict the future in this way. Rather, it does what the name suggests and follows the technology, using this intervention as the entry point into a complex situation, and then allowing what is discovered to determine what is important. In this way, it narrows the research arena to fit within achievable boundaries.

In practice, we should attempt to follow the progress of the technology from first adoption by identifying and asking the classic journalistic questions (What? Why? Who? When? Where? How?) about the:

- novelties generated,
- selection decisions made, and
- promulgation mechanisms used.

Furthermore, we should be looking for these effects in areas of interface while seeking to understand people's realities and how they affect the answers.

The FTT approach as a monitoring and management tool

Researchers in Nigeria (G. Tarawali, B. Douthwaite, N. C. de Haan, and S. A. Tarawali, *unpublished manuscript*) have demonstrated the relevance of the FTT approach to INRM. This approach is currently being applied to the monitoring, evaluation, and ex ante impact assessment of the following project.

In the late 1990s, scientists from the International Institute of Tropical Agriculture (IITA) in Ibadan; the International Livestock Research Institute (ILRI) in Nairobi, Kenya; the International Centre for Research in the Semi-Arid Tropics (ICRISAT) in Hyderabad, India; the International Fertilizer Development Center (IFDC) in Muscle Shoals, Alabama, USA; and the University of Durham in Durham, UK, developed "best-bet" options or technology packages that sought to integrate the most appropriate solutions that each institute had to offer. The pilot site chosen was Bichi in the northern Guinea savanna in northern Nigeria, and the best bet was considered to be an improved version of an intercropping technique already used by local farmers, in which they alternated rows of sorghum with rows of cowpeas. In the best-bet version, two rows of ICRISAT's best sorghum variety were intercropped between four rows of IITA's and ILRI's best dual-purpose cowpeas, and planting densities were much closer than those traditionally used. The normal practice of local farmers is to plant early-maturing cowpeas at the start of the rains in alternate sorghum rows and later-maturing cowpeas for fodder in the remaining rows when the rains become more regular (Mortimore et al. 1997). The expectation in the design of the best-bet package was that farmers would be able to harvest two crops of the improved early-maturing cowpea.

Eleven farmers began a trial of a version of the best bet with fertilizer and pesticide (BB+) and one without these inputs (BB). Their agreement to try out the best-bet package represented the intervention in terms of the FTT approach.

After the first season, farmers and researchers had been through several interactive learning selection cycles (see Fig. 2) in which they had generated novelties and made selection decisions. Only one farmer had attempted to double-crop his improved cowpea. Rains at the time the first crop was harvested meant the other farmers decided not to cut down their cowpea plants for fodder, because they would not be able to dry them. Instead, they chose to continue harvesting the few late pods. However, the one farmer who did generate the novelty (a novelty to the community) of double-cropping had good results, and his learning experience influenced others to try double-cropping the following year. Researchers played an important role in promulgating the double-cropping innovation. The other mutual learning experience was that the BB (without inputs) treatment did not perform adequately. Farmers were insistent that, because the BB experimental plots occupied a large percentage of their farms, they were going to add fertilizer and pesticides. The experiment was changed as a result.

We are currently using the FTT approach to analyze the interface between the researchers and the farmers to determine the extent to which farmers adopted the best-bet technology because it seemed to make a plausible promise of benefiting them, or whether they had other reasons. We are also following the technology out into farmers' fields to see exactly how much of the technology they have adopted. We are using a geopositioning system to map the corners of fields where some level of adoption has taken place and then entering these data, as well as photographs and word descriptions, into a geographical information system. This database will help us identify any novelties that farmers may be generating, the selection decisions they are making, and the degree to which the technology is diffusing. We will then use a variety of survey and focus group tools to attempt to understand farmers' motivations for their actions. The concept of interaction indicates that we should look at how their membership in different groups affects farmers' participation, motivations, and behavior, whereas the concept of lifeworlds will lead us to explore how people's past experiences and current cultural practices affect the integration of technology into their systems (learning selection).

THE FTT APPROACH TO CATALYZING, MANAGING, AND MONITORING RURAL TECHNOLOGY CHANGE

The FTT approach can be used to catalyze rural technology change by following specific steps (Appendix 1), together with the monitoring and evaluation approach described above. In summary, the first step in the FTT approach takes place when researchers develop a solution to a real problem facing local farmers that at least some of the more innovative ones are willing to accept as feasible (the plausible promise). This plausible promise is the catalyst around which the product champion seeks to build and nurture a co-development team of researchers and key participants, i.e., those who have the most to gain and lose from the innovation. As such, the plausible promise is critical to project success. Whether or not a research intervention represents a plausible promise is determined by the adopters, not the researchers.

The monitoring and evaluation of the process that unfolds focus on identifying the novelties generated, selection decisions and mechanisms, and promulgation mechanisms. The actor-oriented analytical structure helps explain actions and outcomes through the concepts of the interface and lifeworlds, which may not be logical from a scientific perspective. These concepts can also help explain people's motivations, which drive adoption processes. For example, they can help the project champion understand the extent to which farmers are collaborating because they believe in the plausible promise, or whether they are adopting the technology because of other incentives, e.g., access to subsidized inputs or jobs for their relatives. It also forces the monitoring and evaluation team to look at all the actors involved in the process and not only those targeted by the research team that developed the best bet.

The FTT approach to monitoring and evaluation can also be used to follow and understand any technology change process, not just one that started with a plausible promise based on research. It can also be used to analyze the history of an innovation to understand existing adoption patterns. Such understanding is clearly important to managing ongoing INRM interventions and planning future ones.

CONCLUSIONS

Successful INRM requires people from different disciplinary and social backgrounds to work together. Epistemological differences between the hard and soft sciences may be one constraint to effective collaboration. The follow-the-technology (FTT) approach to catalyzing, managing, monitoring, and understanding rural technology change was developed in this paper to provide a framework that both realist-positivists and constructivists can work with. The core model is based on an analogy between technology change and Darwinian evolution, which is much better understood. One strength of this analogy is that it can provide a basis for both hard and soft scientists to negotiate a common understanding and language, because normally both camps accept Darwin's theory.

Successful INRM also requires management and monitoring and evaluation systems to be adaptive and flexible, because the operational contexts will be complex and unpredictable. Rather than trying to measure and monitor everything that might be important during an INRM project, the FTT approach does what the name suggests and follows the effects of the project interventions. The focus of the monitoring and evaluation effort is then determined based on these findings, rather than on preconceived ideas of what is going to be important, who is going to be affected, and what criteria to measure. In this way, we expect that project managers will receive more relevant feedback faster and be able to make the changes necessary to promote beneficial impacts and avoid negative ones.

The FTT approach can also be used to catalyze technology change. We gave the example of Linus Torvalds, the developer of Linux, who was able to use a very similar approach to leverage more creative talent than Microsoft, one of the richest companies in the world. We believe that the FTT approach is able to make the plausible promise of being able to catalyze the innovative potential of the technology users, which is necessary to scale up the technology from the pilot site to the landscape.

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APPENDIX 1

The learning selection approach to co-developing innovations with users (after Douthwaite 2002).

1. **Start with a plausible promise**
   The first step to take when attempting to induce change through learning selection is to produce a "plausible promise," or something that convinces potential stakeholders that the new technology can evolve into a tool or process that they really want. Experience shows that it is difficult to enlist co-developers if the whole project is abstract. Mokyr (1990:9) believes that the process of inventing plausible promises is by its nature something that " ... occurs at the level of the individual." He says that creating a plausible promise is " ... an attack by an individual on a constraint that everyone else has taken for granted." It is not something that lends itself to a broad consensus approach. Therefore, creating a plausible promise is often about doing excellent, groundbreaking science that produces something that at least a few innovators in the target group might find useful.

   The plausible promise does not need to be refined or polished; it can be imperfect and incomplete. In fact, the less final it is, the more scope there is for the stakeholders to innovate and thus gain ownership of the technology. The more problems there are, then the greater the chances that the key stakeholders will give up in frustration. A delicate balance must be maintained.

2. **Find a product champion**
   The next step is to identify the innovation or product champion. He or she needs to be highly motivated and have the knowledge and resources to solve problems. Someone from the R&D team is likely to be suitable, because he or she will probably have both the necessary technical knowledge and the motivation; it always helps if the product champion already has a stake in the technology. He or she must also have good people and communication skills because, to build a development community, it will be necessary to attract people, interest them in what is going on, and keep them happy working for the common cause. The product champion's personality is therefore crucial.

3. **Keep it simple**
   Don't attempt to dazzle people with the cleverness and ingenuity of the prototype's design. A plausible promise should be simple, flexible enough to allow for revision, and robust enough to work well even when not perfect. The critical comments of your colleagues don't matter. Your potential co-developers' needs and knowledge levels do. For example, if you are designing a combine harvester and you know the manufacturers and farmers you'll be working with are familiar with a certain type of

thresher, then use that in your design, even if it is technically not the most elegant solution. As John Gall (http://www.quoteland.com/qldb/author/59) said, "A complex system that works is invariably found to have evolved from a simple system that worked."

4. Work with innovative and motivated partners

Allow the participants in your learning selection process to select themselves based on the amount of resources they are prepared to commit. Advertise or write about your plausible promise in the media, do field demonstrations, or post on the Internet and wait for people to contact you. Don't give inquirers anything with a resale value for free. For example, if your prototype has an engine, then charge the market value for it. Otherwise, people may be motivated to adopt it to get something for nothing. In addition, people generally value something more highly if they have paid for it, and they will be more committed to sorting out the problems that emerge.

On the other hand, you must make it clear to the first adopters that they are adopting an imperfect product and that they are working with you as co-developers. You need to reassure them that you will be contributing your own resources to the project and will not abandon them with a lemon. You should be prepared to offset some, but not all, of the risk they are taking in working with you. Getting the balance right is very important here, too.

5. Work in a pilot site or sites where the need for the innovation is great

Your co-developers will be influenced by their environment. Their motivation levels will be sustained for a longer period if they live or operate in an environment where your innovation promises to provide great benefits. In addition, they are more likely to receive encouraging feedback from members of their own communities.

6. Set up open and unbiased selection mechanisms

a) *The product champion/selector*.

As soon as you have the key stakeholders working with you and generating novelties, you need ways of selecting and promulgating beneficial changes. Initially, the product champion usually plays this role. An effective selector must be able and prepared to recognize good design ideas from others. This means that, when this person is also the inventor, he or she must be suitably receptive and thus able to accept that others might have better ideas.

Very few people are capable of effectively championing their products and selecting novelties at the same time. This is because, to be good at the former, it is necessary to believe deeply in the product's benefits and be able to defend it against criticism. An effective selector, on the other hand, must keep an open mind and be able to work with others to question fundamental design decisions.

If a product champion defends the technology too strongly or shows bias, then "forking" occurs, and the disaffected person or group branches off to do what he or they felt prevented from doing by the selector. It is good to have people test alternative design paths, but, if it is done in frustration or spite, then cliques form, making any comparison and subsequent selection between rival branches difficult. Creative talent is split, and energies can be dissipated in turf wars.

b) *Alternative selection mechanisms.*
Even if the product champion can be open-minded and unbiased, he or she may have problems convincing others. One option is to set up a review mechanism that is well respected by the key stakeholder community. There are a number of ways of doing this. Three that work are review by an independent organization, peer review, and the provision of enough information to potential adaptors that they can make informed selection decisions themselves.

7. Don't release the innovation too widely too soon

For the innovation to evolve satisfactorily, the changes the stakeholders make to it need to be beneficial, and, because those generating the novelties will have gaps in their knowledge, product champions should restrict the number of co-developers so that they can work with them more effectively. When people show enthusiasm for a prototype, it is very tempting to release it as widely as possible, but this should be resisted. The technology will always be less perfect than the inventor initially thinks.

However promising the technology might appear to be, there are many things that can and will go wrong. First adopters need to be aware of this and have ready access to the product champion. Otherwise, their enthusiasm will quickly turn to frustration, and the product champion will end up defending the technology against criticisms when the problems appear. Once the product champion becomes defensive, he or she will be far less useful at solving problems.

8. Don't patent anything unless it is to prevent someone else from privatizing the technology

In learning selection, people cooperate with each other because they believe that all will gain if they do. The process is, therefore, seriously damaged if one person or group tries to gain intellectual property rights over what is emerging. First, the community spirit is damaged. Second, patents are monopolies that immediately reduce the novelty generation rate and thus slow down future development and the flow of ideas.

9. Realize that culture makes a difference

The Tanzania bean example given in the text shows just how much difference local culture can make. The negative impact of women being dispossessed from their land would not have happened in a culture that gives women stronger rights to property. Culture can also influence the degree to which knowledge is guarded within a particular group, or spread around. Learning selection is going to be greatly impeded in cultures where new knowledge is carefully guarded, either by keeping it secret or taking out and enforcing intellectual property rights.

10. Know when to let go

Product champions need to become personally involved and emotionally attached to their projects to do their jobs properly. However, this makes it easy for them to go on flogging dead horses long after it has become clear to everyone else that the technology is not going to succeed. Equally, project champions can continue trying to nurture their babies long after they have grown up and market selection has begun. It is, therefore, a good idea to put a time limit on the product champion’s activities.

3.

Success Factors in Integrated Natural Resource Management R&D: Lessons from Practice

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ABSTRACT

This paper analyzes integrated natural resource management (INRM) lessons and success factors based on a practical case study over more than 10 years in Zimbabwe. The work was geared toward enhancing the adaptive management capacity of the stakeholders in their resource-use systems. One main result was the development and institutionalization of an approach for participatory and integrated NRM research and extension. The INRM approach described is grounded in a learning paradigm and a combination of theories: the constructivist perspective to development, systemic intervention, and learning process approaches. Participatory action research and experiential learning, in which researchers engage themselves as actors rather than neutral analysts in an R&D process to explore the livelihood system and develop appropriate solutions together with the resource users, has shown high potential. However, this should be guided by a clear strategy, impact orientation, and high-quality process facilitation at different levels. The case study revealed the importance of a "reflective practitioner" approach by all actors. More effective response to the challenges of increasing complexity in NRM requires a shift in thinking from the linearity of research–extension–farmer to alternative, multiple-actor institutional arrangements and innovation systems. To overcome the weak attribution of research

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outcomes to actual impact, it also suggests an alternative to conventional impact assessment in INRM R&D interventions.

KEY WORDS: change management, facilitation, impact assessment, institutionalization, learning processes, local organizational development, natural resource management, participatory approaches, systemic intervention.

INTRODUCTION AND BACKGROUND

The term "integrated natural resource management" has no universally accepted definition. It is an emerging concept, understood as "the responsible and broad-based management of the land, water, forest, and biological resources base (including genes) needed to sustain agricultural productivity and avert degradation of potential productivity" (CGIAR-INRM-Group 1999). This definition allows a wide-spectrum interpretation. Many conceptual, methodological, and institutional questions need to be clarified and answered to reach a common understanding of the role and contribution of INRM research. What products and results should research deliver, what should be the role of extension, and how can the efforts of all actors be integrated in an effective, institutional arrangement to bring about the desired impact? This complexity and integration at different levels pose serious conceptual and organizational challenges where roles and mandates between the actors are based on a component technology focus. Conventional linear models, methodologies, and tools do not fit an INRM framework that tries to take a more holistic perspective to deal with dynamic complexity of resource-use systems. Various alternative approaches and methods are being developed, rediscovered from other scientific fields and adapted to INRM (e.g., action learning, Lewin [1946]; and process approaches, Corten [1980]).

We analyze practical experiences in participatory, integrated research and extension in NRM in rural livelihood systems in Zimbabwe since 1990 and South Africa since 1998. We discuss conceptual, methodological, and institutional lessons and draw conclusions on future challenges in INRM. We review development of the approach in Zimbabwe, discuss specific building blocks in INRM, and present an emerging conceptual framework. The main elements considered are conceptual underpinnings, complexity, integration of components, scaling up and out, modeling, and impact assessment in INRM.

THE LEARNING CASE: APPROACH DEVELOPMENT IN INRM R&D IN ZIMBABWE

Evolution of the INRM approach

INRM work began in Zimbabwe in 1988 as part of a collaborative program between the National agricultural extension service (AGRITEX), German development co-operation

(GTZ), and later the strategic ally, the Food Security Project of Intermediate Technology Zimbabwe (ITZ). The program started off with a technical research focus on soil and water conservation in the semiarid areas of southern Zimbabwe (Chivi, Zaka, and Gutu districts in Masvingo province). Over time, it iteratively integrated more technical and social elements of the rural livelihood systems into the original INRM framework. The ability of rural people to develop and optimally use their own potential, together with the goal of making a real impact at the farmers' level, guided the project's evolution.

Once success at the farmer level was evidenced through NRM innovations developed jointly with farmers, with broader adoption of social and technical innovations, scaling-up considerations led to institutionalization of the approach within the extension service. The extension service was to provide the facilitation to trigger large-scale implementation of the INRM process. The focus on developing institutional capacities to scale up the process turned the program into an institutional experiment that became a more self-conscious intervention through ongoing monitoring, analysis, and conceptualization of the experiences.

From more than a decade of work at institutional, conceptual, and field levels, six major learning cycles of action and reflection in development of the approach can be distinguished. They reveal technical and institutional insights at farmer and service provider levels that propel continual readjustments and reorientation of the focus. The main stages of this INRM action–learning process are summarized as:

- Phase 1 (1988–1990): on-station research on conservation tillage;
- Phase 2 (end of 1990–1992): adaptive on-farm trials on conservation tillage with individual farmers and farmer groups;
- Phase 3 (1992–1994): opening up: farmer participatory research and participatory technology development with individual farmers and farmer groups on broader natural resource management technologies;
- Phase 4 (1994–1995): refining the concept and approach for collective innovation processes (local organizational development) in INRM;
- Phase 5 (1996–1997): conceptualization of experiences and scaling up: piloting a competency development approach at institutional level to the extension service as facilitators of such processes at large scales;
- Phase 6 (since 1998): institutionalization, scaling up and out: organizational change program within extension service to adapt the organization service delivery approach. Large-scale competence development and networking at NGO level were other focal areas during this phase, with field activities expanded.

Since 1998, the lessons learned in Zimbabwe have been used to expand and further develop the approach in the northern province of South Africa as a second major learning case. Greater details of the evolution of this INRM approach are documented in Hagmann (1999) and Hagmann et al. (1997, 1998, 1999).

Main elements of the approach to INRM

The INRM approach, as it emerged from experiences in southern Zimbabwe, is a value-driven, community-based learning process in which local people and external service providers share ideas and learn together (Conroy et al. 2002, Davis-Case 2001). Outsiders and/or insiders facilitate this process. The basic strategy to strengthen the adaptive capacity of the natural resource management system at the local level is:

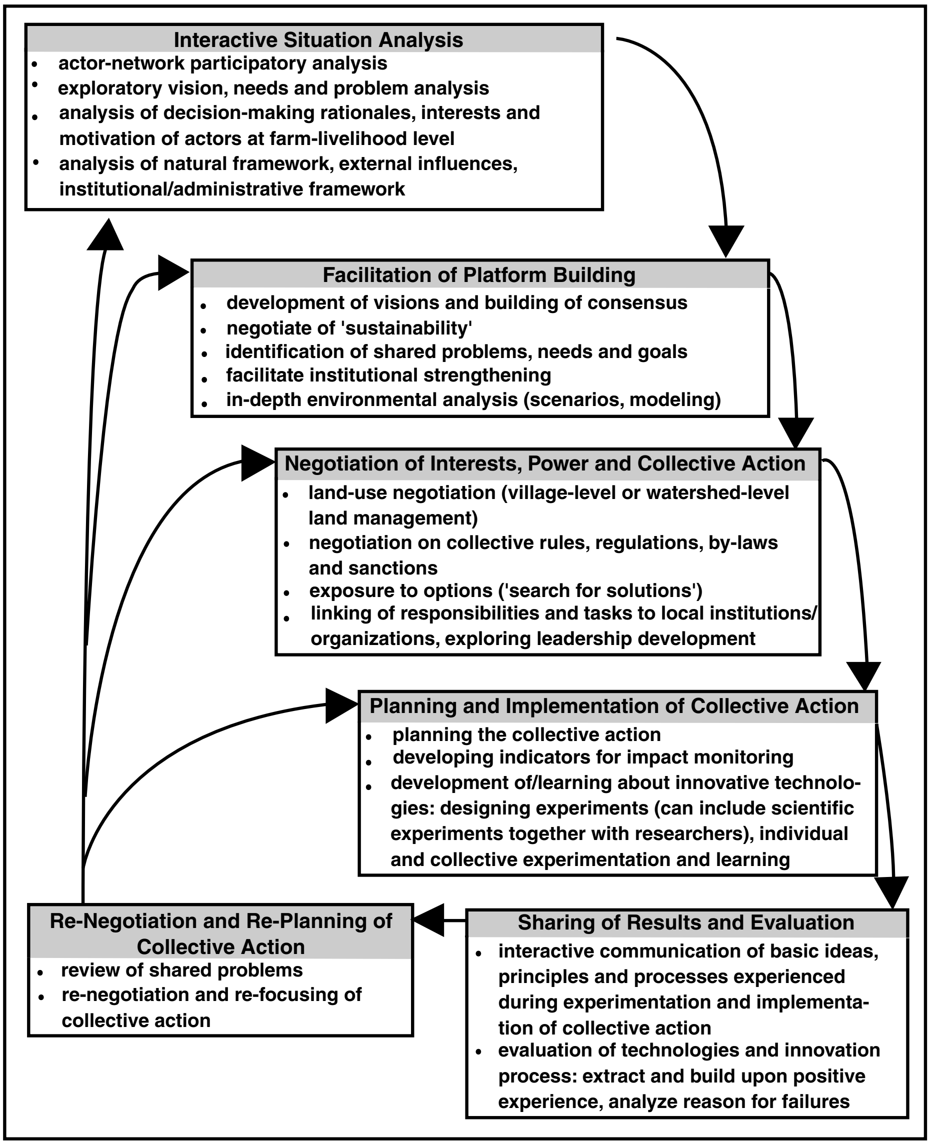
1. To strengthen the collective capacity of local groups, institutions, and organizations for self-organization, collective action, negotiation of their interests, and conflict management, as well as their articulation and bargaining power vis-à-vis authorities, service providers, and policy makers ("local organizational development").
2. To enhance farmers' capacity to adapt and develop new and appropriate innovations by encouraging them to learn through experimentation, building on their own knowledge and practices and blending them with new ideas in an action learning mode. Usually these are agricultural technologies and practices, but they also address social, organizational, and economical innovations.
3. To enhance collective learning through action and social learning, facilitation of self-reflection, sharing knowledge, and networking.
4. To negotiate the management of natural resources and related services, policies, etc., through stakeholder platforms of communities, service providers, and other key players.

This core strategy is implemented through a variety of concepts, methodologies, and supporting strategies. The INRM process is mainly guided by the vision and values to which the intervening and facilitating agents, as well as the communities, agree and subscribe. These core values are:

- full ownership of the process by the community and control over their own resources;
- self-reliance of local communities;
- self-organization, sharing, and cooperation;
- inclusivity of all stakeholders and groups;
- equal partnership among farmers, researchers, and extension agents, who can all learn from each other and contribute their knowledge and skills;
- equitable and sustainable development through negotiation of interests among these groups and by providing space for the poor and marginalized in collective decision making; and
- natural resource conservation as part of the generation contract.

The implementation process follows a sequence of flexible steps that are initially facilitated through outsiders (see Fig. 1; Hagmann 1999:65).

Figure 1. Sequence of process steps of the INRM R&D process at the community level.



The methodological sequence can be viewed as a cyclical spiral of collective action, reflection, and self-evaluation (Fig. 1). Each cycle brings new learning experiences on which the next cycle can build. Not even the situation analysis is static; it will provide more insights during implementation that might require new actions. This action learning is an iterative process, aimed at full engagement and ownership of the process by local people with their own goals, values, and needs (Douthwaite et al. 2002, Douthwaite 2002).

Results and impacts of INRM R&D

The INRM process concentrated on local impact, while analyzing and conceptualizing the lessons for scaling up and creating broader strategic research results. Long-term impacts of the participatory innovation development and extension approach in INRM cannot yet be fully quantified because large-scale assessment has not been finalized. However, the impacts up to 1996 have been qualitatively assessed and described (Hagmann et al. 1997, Murwira et al. 2000). We will present some of the key impacts.

Some local impacts (farmers' level)

More than 20 innovations in the field of land husbandry were developed in cooperation with farmers. These ranged from agricultural implements and tillage techniques to soil fertility techniques (a range of different manures, fertilizers, and organic matter management), soil and water conservation technologies (physical, biological, and agronomic measures), crop husbandry (natural pesticides, inter/relay cropping), rangeland improvement, fencing techniques, etc. (Fig. 2).

Figure 2. Technical innovations developed and tested based on farmers' and researchers' ideas (Hagmann et al. 1997).

Soil and water conservation techniques	***Other agronomic and biological soil management methods***
• tied ridges/furrows • basin tillage (widely spaced ridges/ semi-circular bunds) • creative vetiver applications • methods for rill reclamation • the modified "*fanja-juu*" • infiltration pits • stone bunds • subsurface irrigation for gardens • inverted bottles for irrigation in gardens • plastic sheet to prevent rapid drainage (gardens) • mulching in gardens • mulching in fields	• innovative planting techniques • various planting dates (various crops) • various methods of making compost • spreading of termitaria as fertilizer • various manure and fertilizer applications • green manure with crotalaria species • planting and use of hedgerows • a relay cropping system • various intercropping combinations • natural pesticides • raising of indigenous trees • chicken manure as topdressing
Implements • animal-drawn disc ridger • donkey-drawn toolbar (multiple purpose) • a knife-ripper tine mounted on the plough beam • a planting device mounted on the plough beam • animal-drawn weed roller	

There was a large-scale spread of a spirit of experimentation: up to 80% of the households in the intervention areas experimented with soil and water management and other NRM technologies, continually improving their effectiveness and management. The most successful technologies were related to soil fertility and water conservation (Fig. 2).

Capacity has increased for adaptive management, self-organization, problem-solving, and collective management of natural resources, e.g., conflicts, by-laws, local organization, and articulation vis-à-vis outsiders, policy makers, and service providers. For example, in one ward of approximately 1000 households, leadership changes induced through a local organizational development process enabled a rise in membership of farmer and other local organizations from 120 to 800 members within two years. Social capital became strong enough to challenge service providers (e.g., turning down extension agents who were not considered useful) and to deal with development and NRM issues confidently by themselves. Through solving leadership problems between modern and traditional institutions, rules and by-laws for common property resources, such as grazing schemes, were set up. Diversification of land use and crops, as well as a more site-specific utilization of spatial variability, have had an impact on the adaptive capacity of the resource-use system. Male-headed and female-headed households were assessed as equally active. Articulation of women in general, from both female- and male-headed households, increased to the extent that women often challenged men openly in discussions.

Some impacts in relation to scaling up of the process of INRM (institutional level)

More than 300 extension agents have developed the facilitation competence for INRM and have facilitated INRM processes in Zimbabwe. So far, quantitative impact assessment beyond the pilot areas is not yet available, but each extension agent is actively practicing this approach. In some areas, they apply it to their whole area (about 1000 farmers); in other areas, selected communities are being facilitated to use this approach. Gradually, a scaling up to watershed or district level might be reached. Cross-village sharing and cooperation and supra-village organization and representation are growing.

There are increasing requests for training from other actors (NGOs, consulting firms, etc.). This enhances harmonized approaches and a more homogeneous scaling up. Institutionalization and active promotion of such approaches in the extension department through organizational development matched the participatory approach. Changes in organizational culture, structure, and procedures developed from this effort enhanced the participatory extension in INRM.

Some strategic research/public good outputs (conceptual levels)

Numerous international publications have been generated from this project (see *Literature Cited* and Hagmann 1999, Murwira et al. 2000). Other outputs include:

- process analysis, approaches, and methodologies for innovation in NRM (e.g., approach for participatory extension, a model for linking research and extension, methodologies for learning process implementation);
- technologies and technological research (e.g., publications on soil and water management); and

- process analysis, approaches, and methodologies for competency development in facilitating action learning (Moyo and Hagmann 2000), design of process for institutionalization of participatory approaches and organizational change in national agricultural research system institutions (Hagmann et al. 1998).

FUNDAMENTAL CONCEPTUAL AND METHODOLOGICAL LESSONS AND SUCCESS FACTORS

The INRM approach developed in Zimbabwe is composed of various concepts and approaches drawn from different scientific disciplines. The synthesis of lessons learned and conclusions about success factors are based on our long-term practical experience. The vast majority of cases in agricultural research focus on linear technology development in NRM. Participatory research and stakeholder involvement are applied to improve the relevance of the work within a linear, positivist paradigm (Scoones and Thompson 1994) in which ownership of the process remains generally with the researchers. Other cases working toward integrated natural resource management (e.g., Murphree 1993, Uphoff 1996, Farrington and Lobo 1997, Ashby et al. 2000, Gass 2002) have taken a more holistic perspective. Particular features that distinguish our work from most of these cases can be categorized as:

- process-based action research in which ownership of the process is with the local people/ resource users;
- application of "systems thinking" in the sense of "systemic intervention," combined with learning process approaches, which allows exploration of the system from within; and
- systematic application of action learning for "experiential approach and concept development" in INRM interventions, which includes a more strategic perspective on impact assessment.

This paper focuses on the most innovative parts of our INRM work in Zimbabwe and South Africa, which are structured along the key elements of INRM approaches: underlying concepts, dealing with complexity, integration, scaling up and out, modeling, and impact issues.

Foundation for INRM interventions: different perspectives, concepts, approaches, and methodologies

In this framework, the key points relate to constructivism, sustainability and adaptive capacity, research vs. innovation, experiential learning, facilitation, and interdisciplinarity.

Constructivist perspective and social learning

There is a need to clearly differentiate between the roles of the resource managers in INRM ("insiders") and the roles of research/extension outsiders in support interventions for INRM.

Natural resource management by local resource users is always "integrated" as they deal with resource management from their own complex livelihood perspectives (Saad 2002). This does not mean that the integrated perspective leads to sustainable resource use, but based on our experience in Zimbabwe at micro and meso levels, the degree of sustainability in resource use is largely a result of rural people's knowledge, culture, values, norms, and capacity to act and organize themselves. Any managed change depends on conscious decisions of the actors to change their behavior (van Mele and Zakaria 2002). Decisions, however, are always based on the actors' existing perceptions and construction of reality, not on externally perceived realities. Therefore, if external agents intend to influence peoples' decisions, they are most likely to be successful if they have inputs into people's reality construction process (e.g., through raising awareness and through facilitation of decision-making processes) (Snapp et al. 2002).

This simple, but fundamental, fact calls for a constructivist perspective (Berger and Luckmann 1967, Röling 1996) in INRM R&D interventions, where negotiation of perspectives and interests is central. In practice, this implies that outsiders can be most effective if they have a truly facilitative role in a social learning process among the actors and stakeholders. The goal of social learning in collective action should be the creation of an environment in which the multiple, complex objectives of individuals are articulated and recognized, and where freedom for diversity and situation-specific solutions is inherent (Saad 2002). Collective accountability for natural resources is built through generating a common vision. Experiences from Zimbabwe highlight environmental learning and analysis that builds from stakeholders' values, together with the creation of new social norms, generating common vision and values. Existing local institutions and organizations should ideally be the basis for building this process.

Successful interventions in INRM thus need to be facilitative, based on a constructivist epistemology (see Douthwaite et al. 2001, Douthwaite 2002) and soft-systems methodologies (Checkland and Scholes 1990). There are two different schools of systemics, which are often termed "hard" and "soft" (Bawden 1995:8). Hard-systems approaches attempt to understand entire systems, e.g., cropping enterprises, whole farms, groups of farms, or even communities, by looking at them from the outside, assuming that the system variables under study are measurable, that the relationships between cause and effect are consistent, and that they may be discovered by empirical, analytical, and experimental methods. Soft-systems thinkers look at "human activity systems" arguing that systems are creations of the mind or theoretical constructs to understand and make sense of the world. Hence, soft-systems methods aim to generate knowledge about processes within systems by stimulating self-reflection, discourse, and learning (Hamilton 1995:35-36).

This does not mean that positivist, hard approaches have no place and are being replaced. Both hard and soft research methods are needed: soft participatory action research on processes of NRM (e.g., organization, collective management, competence development, conflict management) and conventional hard research on technological and social issues (e.g., soil conservation, agronomic practices, socioeconomic studies). The use of hard approaches within a constructivist framework differs substantially from conventional approaches.

Sustainability and adaptive capacity

Experience within complex, dynamic livelihood systems in Zimbabwe and South Africa led us to conclude that the only thing that is sustainable is change itself. Sustainability in development and in NRM is a continual value-dependent, political and social negotiation process that cannot be determined by outsiders for the insiders. Sustainable NRM, and even development in general, can be seen as a social learning process in which the goal is to increase human capacity to solve problems and adapt to changing conditions: "adaptive capacity" (Holling et al. 1998, de Boef 2000). In this framework, sustainable NRM is decided less by technical expertise than by learning and negotiation among stakeholders. Collective, active adaptive capacity is the key determinant for sustainability.

From linear research to innovation as a complex social process

Recognition of innovation as a socio-technical and collective process (Latour 1993, Richards and Diemer 1996, Kuby 1999) was central to the intervention. The spread of innovations and impact failed when working with individual farmers, be it with collectively managed resources, individual plots, or innovations. Societal norms in the communities meant that "natural-born" innovators were often avoided and victimized (out of jealousy) rather than imitated. Thus, the social environment needs to be highly conducive if innovations (social and technical) are to spread, be it in NRM or any other part of the livelihood system. Thus, the NRM learning process was never separated from the complex livelihood context. This implies that the external intervention facilitated platforms for negotiation and participatory action learning at the community level and enhanced the communities' exposure to ideas and technologies. Farmer experimentation and sharing among community members enabled rural people to increase awareness of their reality construction, negotiate changes, and come to a commonly shared perception.

The linearity of research–extension–farmer as the conventional pathway for innovation and impact proved rather ineffective in Zimbabwe, even if improved through feedback loops from farmers to researchers through on-farm trials. Innovation was much more than research, involving a whole system that is creative, multi-actor, motivating, and inspirational. Research, extension, and farmers are just three actors in a nonlinear, dynamic system. The direct cause and effect of a certain activity is almost impossible to assess. This has important consequences for INRM research. In contrast to the linear model, research can no longer stay "outside" and investigate objective, transparent, and predictable elements of a system. Again, researchers need to understand themselves as part of an actor system contributing to innovation processes that are not controllable and predictable. The roles of different types of research (e.g., basic, applied, adaptive) can no longer be separated clearly because they are all part of a simultaneous innovation process. Implications of this perspective are further described in the section on *Understanding complexity.*

In terms of intervention methodology, making INRM operational requires a "learning paradigm" (Röling and de Jong 1998) with a flexible combination of concepts and methodologies. Participatory action research (PAR; Lewin 1946, Selener 1997), experiential learning (Kolb 1984, Davis-Case 2001), systems thinking (Checkland 1985), chaos theory, and self-organization (Wheatley 1999) are implemented through facilitation of process interventions at all levels, and are guided by a clear vision and strategy to form the foundation for approaches geared toward collective action and human, as well as social, capital-building. Most important in designing and implementing such approaches are pragmatism, empathy, and common sense. It would be reductionist to consider any single concept, approach, or methodology (e.g., PAR) as the panacea methodology.

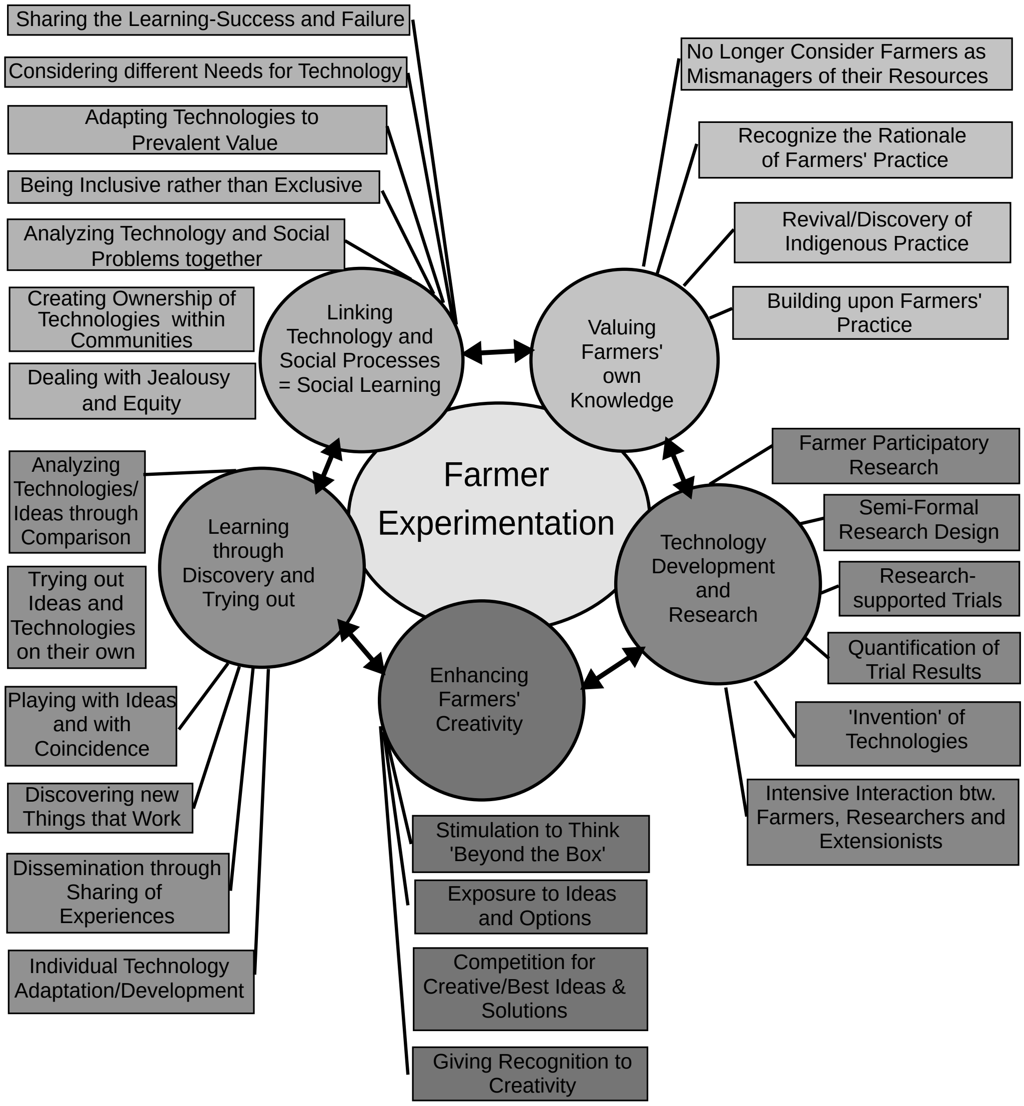
Experiential learning: from adoption to adaptation through farmer experimentation

Experiential and discovery learning (Kolb 1984, Hamilton 1995) played a key role in enhancing farmers' creativity and capacity to innovate in INRM. Farmer experimentation (Fig. 3) has been central to the operation of experiential learning processes. Often, it is simply seen as a tool in participatory research. However, we discovered several important side effects beyond the "tool" aspect, which were less visible, but played a central role in building the adaptive capacity of farmers. These include farmer experimentation as:

- A methodology for discovery and experiential learning. It creates curiosity and a spirit of trying and discovering.
- A way to value farmers' own knowledge. Farmer experimentation improves the understanding of biophysical processes by farmers (land literacy) and reveals the interrelationship between farmers' knowledge and scientific knowledge. This contributes to a better mutual understanding and raises the status of farmers' knowledge, in turn raising confidence in their own solutions.
- A way to enhance farmers' creativity. Curiosity and confidence encourage and trigger creativity in finding solutions. People develop their own solutions rather than waiting for answers from outside.
- A methodology that links technical and social processes and generates social learning. A collective experimentation process automatically raises technical and social issues. Any technology will be adapted to social conditions if farmers are trying them out and sharing their experiences with others.
- A methodology for research and technology development. It helps researchers and farmers to work effectively together and develop technologies. In this way, research has a major role to play.

Experience in training and scaling up shows that, in most cases, farmer experimentation is understood simply as a tool for research and technology development; its other strengths are overlooked. To demonstrate its wider value to people with no experience of this way of working, exposure visits to experimenting farmers proved very effective. These allowed people to see that, in terms of land literacy and NRM in general, farmer experimentation is the core methodology for enhancing their understanding of the resource

Figure 3. Important components of farmer experimentation (Hagmann and Chuma 2002).



system and for generating creative solutions to the challenges faced: in other words, their adaptive capacity. Putting farmer experimentation into action required a number of practical methods and tools to enhance farmers' understanding of their ecosystem. A range of different, easy-to-apply "learning tools" (simulation models) were developed to support the process.

Facilitation of participatory learning and action research

In Zimbabwe and South Africa, across a number of sites with different facilitators, process facilitation, as a non-instrumental form of intervention (Röling 1996), proved to be the foundation of the learning process in INRM. The quality of facilitation was more important than any particular tool or learning aid, and this skill proved to be more difficult for development agents and local people to learn than any other skill needed for implementing the learning process. The core of reflective facilitation (Groot and Marleveld 2000) is about asking the "right" questions at the "right" time in order to enhance people's self-reflection and self-discovery without pre-empting the responses or pushing in a preconceived direction. These questions should mirror to people the consequences of their present perceptions and behavior, and possible solutions in the long run, thus leading to a deep self-reflection and ownership of the problems that they express.

The values of ownership, participation/emancipation, and social learning were crucial in facilitating the construction of new realities. Local ownership was created by basing the interventions on local organizations that took full ownership and responsibility. Intervention was geared toward strengthening those organizations through enhancing accountability, improving leadership, and facilitating critical self-awareness and self-discovery of inherent local (human) values.

Values probably had the greatest influence in farmer decisions in INRM. Through skilled facilitation, these core values, such as social harmony, collectivity, inclusivity, and environmental values, surfaced and could be debated in relation to farmers' present situation and behavior. These facilitated debates often triggered deep self-reflection. Over a number of iterations, they brought about some new social norms, often expressed through slogans and songs (e.g., "nobody knows nothing, nobody knows everything").

The main difficulty is steering the facilitation process. Some supportive skills and conditions can be outlined as:

1. *A clear vision and the values of the process goal*. This vision needs to be built upon values such as development through participation, ownership, inclusiveness, people's self-development, openness, transparency, and accountability. With this vision, the facilitator can handle situations flexibly and can pose the right questions to enhance learning. The facilitator needs to lead the process, but not its outcome. Often, this can be enhanced through exposure to successful cases, which provide real, concrete examples of such a vision.
2. *Empathy and the culture of inquiry*. The facilitator must be able to empathize with group members in order to react appropriately. Empathy goes beyond knowledge about group dynamics; it is a skill that depends on personality and emotional intelligence (Goleman 1988). Another skill is the "culture of inquiry," the ability to question fundamental as well as apparently simple things and get down to details. Real problems often lie in the details, which need to be disclosed before a solution can be developed. People's mental models often need to be made apparent and deconstructed through their own reflection to generate new ways of thinking and acting.

3. *A clear understanding of the process design and steps***.** Unless the design is clear, facilitators face problems guiding the process. Beginners to process facilitation need an “operational framework” as a handrail to guide them. Such a framework defines the objectives, key questions, issues, core methodologies, and partners for each process step. Only after thorough training and experience in these steps can facilitators understand and implement them confidently and modify them according to their own experience, empathy, and common sense. Understanding the process with its usual ups and downs also helps to reduce the frustrations often experienced when things do not go in the desired direction. Having gone through a whole process cycle, facilitators know that these frustrations are part of any nonlinear learning process and can handle these situations by putting them in context.

Facilitating learning in INRM also requires knowledge about ecological principles and practices, where specific learning tools play a crucial role (Hamilton 1998, Loevinsohn et al. 2000, Hagmann and Chuma 2002).

Interdisciplinarity: a strategy toward integrating the disciplines

INRM, by its complex nature, is highly interdisciplinary. Accordingly, external research and extension interventions can contribute most effectively if they are also interdisciplinary. As experienced in Zimbabwe and South Africa, this poses a great challenge to linear, discipline-based support organizations and to individual scientists. Often, problems are compartmentalized and dealt with through a multidisciplinary team. Each member, with individual disciplines, works on one compartment, but because the different compartments are difficult to integrate, no higher level synthesis and synergy emerge. Based on our experiences, we drew several lessons. A truly interdisciplinary approach in INRM research requires a coherent strategy departing from the desired development impact of the intervention and the users to be addressed. Different research questions can be formulated based on this strategy, which provides a clear framework. It needs to be developed from the top or the whole, along the following questions:

- What do you want to achieve in INRM?
- If your INRM research is to be successful, who (e.g., farmers, farmer organizations, researchers, extensionists, policy makers, NGOs) would do what differently? Behavioral changes can be used as impact/performance criteria.
- What is required to support behavioral change?
- What are the products and the outputs of INRM research to enhance these factors?
- What is the role of other actors?
- What are the INRM research questions leading to these outputs?
- How can these INRM research questions be best dealt with (approaches and methodologies)?
- With whom and how does INRM research have to collaborate to be effective?

It is almost impossible to build such a strategy from single, disciplinary issues, or from problems that arise at the local level. In other words, one requires a solid framework, providing orientation and direction first. This impact-oriented thinking model provides the basis for integrating and determining priority issues. It also provides the space to experiment with innovative approaches without losing focus. The next step, once the strategy is clear and "owned" by research teams, is to build small interdisciplinary teams with a very good understanding of each other's disciplines and thought models. Building joint conceptual frameworks often occurs only after a team has "grown together" in joint work for at least six months. Core teams need to manage and steer the disciplinary scientists to make their contributions and create the feedback loops. Not everybody needs to be fully interdisciplinary.

Building interdisciplinary teams has two central elements: teamwork (which depends on personality factors, but can be enhanced through team building focused on behavioral issues) and the interdisciplinary science base (which needs to be learned and negotiated between the disciplines). The capacity to practice interdisciplinary research in INRM needs to be built up experientially. It is not a matter of qualifications in disciplines, but of expertise in practice. Scientists need to become reflective, analytical practitioners who are good at conceptualization. These components form a foundation for INRM interventions. Other components, equally necessary to make INRM interventions successful, e.g., systems thinking, will be discussed in the following section.

Understanding complexity: from systems analysis to exploring systems from within

Another fundamental conceptual issue in INRM is complexity. Understanding complexity in action-oriented INRM means dealing with complexity. Trying to understand the livelihood system by becoming an actor (acting within the system instead of analyzing from outside) was the key factor in identifying the most effective intervention points and pathways to maximize impact. It was important to start exploring these systems from the perspective of farmers' INRM, rather than from the top. Through this, a policy dialogue emanated and farmers' reality was recognized as a fact, rather than outsiders making assumptions about their reality (e.g., when policy makers were confronted by farmers about the implications of certain conservation laws). System boundaries had to be widened beyond the livelihood system to include the whole innovation system, with institutional support in INRM.

As a conceptual base for the iterative learning cycles, systems thinking, chaos theory, and self-organization provide useful elements for a framework. Although the behavior of social systems cannot be accurately predicted through external analysis, their reaction to changes, e.g., through intervention, is most revealing. Kurt Lewin (1946) described this: "If you want to know how things really work, just try to change them." Thus, external, "clinical" systems analysis and static intervention design, as practiced in farming systems research and in many research and development projects, have failed to address the real issues that make things work or fail (Bawden 1995). The Zimbabwe case fully confirms this, with unexpected revelations about social dynamics after five years of intervention when hidden conflicts between modern and traditional authorities surfaced and finally could be dealt with.

A rather similar mechanism also applies to complex ecosystems with slow-acting variables and rapid effects, which are very difficult to predict even if based on long-term observation. Because such systems can only be analyzed at the point $0 + X$ time, it is impossible to assess their dynamic complexity with a clear reference point. Analysis is always based on moving reference points and targets, a major problem for both systems analysis and impact assessment. It implies that we should give up the notion that we can ever analyze, understand, and control all the factors in complex, nonlinear systems like livelihoods and ecosystems from outside. Through interaction with the system in action research interventions and by analyzing and interpreting the system's reaction to changes, we are able to better understand characteristics of the whole system. Such research contrasts with the reductionist realist–positivist paradigm. Instead of analyzing as many separate components of a system as possible and how they interact, the action research intervention would induce change in certain components of the system. The reactions will reveal the interactions between the parts and which other parts of the system must be understood in depth and dealt with at the given time and situation. Process approaches are required in this exploration analysis, which aims to define an open-ended, flexible intervention strategy. Wheatley (1999) describes this insight from a historical perspective:

> *Johann von Goethe applied his genius to the problem of seeing the wholeness of nature. He was intrigued to understand any phenomenon not as an isolated event, but as a consequence of its relationship to other phenomena. In traditional science, the scientist invents the questions and then interrogates the object of study. But Goethe describes how we can move from interrogation to receptivity, being open to what is occurring, allowing ourselves to be influenced by a whole that we cannot see. We can dwell with the phenomenon and feel how it makes itself known to us.*

In practice, this implies a focus on parts of the system and their interaction in order to study the dynamics of the whole system. The part is not the whole, but can lead to it. Bawden (1995) comes to similar conclusions in relation to "holism" and "reductionism." In essence, the interplay of systemic thinking and process approaches allows the methodological exploration of dynamic and complex systems. Exploration through action research requires the ability to facilitate and to understand that there are many other parts, problems, and issues that one does not know, but that play an important role. The drivers in systems exploration in Zimbabwe were the desired impact (which provided direction), together with farmers' problem perceptions of the system, with its unfolding, dynamic complexity. This approach required considerable flexibility in planning; activities had to be adapted after each cycle of learning and exploration when new, higher priority problems revealed themselves.

Central to systems exploration were learning process approaches and participatory action research (PAR) at the levels of both farmers and interventionists. Process approaches enabled exploration of the systems and optimization of outsider intervention. At the farmer level, they triggered a continual, iterative improvement of natural resource management. Cyclical self-reflection and self-evaluation through PAR created ownership and increased the local people's capacity to innovate.

In setting priorities for INRM interventions, "systemic intervention" was the main principle. The decision about which system components to research was based on the smallest possible intervention with the greatest possible effect. This is the main principle of systemic intervention (Königswieser and Exner 1998). If regularly monitored, it allows for dynamic adaptation of the intervention strategy, informed by iterative learning and insights gained through systems exploration.

Integration of diverse elements in INRM: not losing focus

Integration of a multitude of aspects is another fundamental conceptual issue in INRM. Considering the complexity of INRM and livelihood systems, the main challenge is not to get lost in hundreds of research questions at the expense of impact. Keeping it all together with integration through the strategic focus on impact was central to the INRM research process in Zimbabwe. Design and management of the intervention process were the main drivers for integrating research. Based on the principle of systemic intervention, events and problems were dealt with as they occurred within farmers' reality, rather than being anticipated and prescribed. As a result, the technological focus and research broadened. To maintain focus and manage priority problems and issues, a strong strategic orientation at the outset guided the choice of priority research topics and the integration of different components. This "guiding star" was provided by the interventionists' vision and by the farmers' own goals. Review of successes and failures then determined the continual adaptation of the intervention design. Often, ongoing issues needed less attention, were outsourced through networks to other actors, or had to be neglected due to limited capacities and resources within the community. Strategic partnerships and networking were highly important.

In South Africa, the strategic orientation was complemented with sound conceptual and operational frameworks. Guiding principles for process facilitation and management were all developed and conceptualized from the Zimbabwean experience. These elements were essential tools in building the competency of facilitators. In particular, the guiding star, the value base, and guiding principles enabled facilitators to respond flexibly, as they were reference points to fall back on in case of insecurity.

Integration of NRM also touched other dimensions. Integrating hard and soft issues in research and extension was very important in effective support of farmers. In Zimbabwe, two different types of research were carried out and integrated through the process:

1. *Research on the process of INRM* (mainly soft, interdisciplinary, participatory action research, e.g., on local organizational development, communication interfaces, innovation, and knowledge development, and on institutional change and competence development). This action research, grounded in farmers' reality, integrated local and scientific knowledge. Farmer experimentation helped greatly to match internal and external ideas and knowledge. Research on process was actively supported by:
2. *Process-supporting research* on technological and social issues and problems (mainly more conventional hard research, e.g., on soils, land use, soil and water management technologies, and state of degradation, and also socioeconomic studies).

Both types of research were required to achieve impact at different levels. Hard studies were often used to demonstrate the need for soft approaches such as building capacity for adaptive management or for deepening the basis and outcomes of farmer experimentation and assessment. The broader framework of soft action research allowed evaluation of hard research outputs. Questions for hard research emerged from the action research process; results were directly fed back to help stakeholders make informed decisions. Hard issues automatically come in as soon as technical innovations become central. The interdisciplinary research team and research managers play key roles in integration; they need to prioritize which trait to follow and how to bring the loose ends back together.

Scaling up the process through facilitating service providers: challenge of organizational change

Scaling up INRM is another fundamental conceptual challenge. In Zimbabwe this was conducted through service provider agents and networking. It has been assumed that scaling up would build the adaptive capacity of people and develop technologies and models for INRM. This, in turn, would increase the adaptive capacity of the whole natural resource-use system. This assumption was confirmed by successes in technology innovation and social organization. Scaling up has developed along social and political dimensions in Zimbabwe, from village to ward to district to province. The external facilitator was critical in triggering these learning processes, starting from the community level. The agricultural extension service, the main government institutional actor, seemed to be the most pragmatic solution for scaling up through service provider organizations, which had been operational in all wards of the country. In terms of logical institutional arrangements, a farmer-based organization would have been more appropriate, but no effective group could be identified. Within the extension service, a vertical scaling up from ward-level extension agent to district to province to national levels seemed necessary. This strategy for scaling up in the extension service consists of four main steps, overlapping or in parallel (see Hagmann et al. 1998):

1. Development and implementation of case studies (pilot activities) of communities where participatory INRM approaches are practiced as learning cases for approach development and as show cases (from 1991).
2. Raising awareness for change and familiarization with alternatives through exposure of extension staff to the case studies (field visits and presentations in workshops, networking, and initial training activities; 1993 to 1995).
3. Initiation of institutional learning about implementing participatory extension through development of field-level capacities within extension (from 1994). This was to address a shift in attitudes, concept, and skills.
4. Organizational development and change management to transform the organizational culture, structure, and governance to match the new approaches.

A clear strategy for scaling up from the start of implementing case studies has proven to be the ultimate success factor in Zimbabwe and South Africa. It provided guidance for the direction of the case study and the research, for interaction with different levels of institution, and for approach development. The lesson through the drought in 1992, which suddenly shattered rigid thinking about interventions, is that situations that appear static and unchangeable can move unexpectedly. Steadiness and perseverance are useful in piloting innovative approaches.

The core element in scaling up through service providers was competency development. Enhancing adaptive capacity at the resource manager level requires support institutions with adaptive capacity to react flexibly to the needs and requirements of the process. The same principles apply to both institutions and farmers (Cooke 1997, de Boef 2000; B. Cooke, *unpublished manuscript*). Competency development in learning processes at the delivery level (field extension and research agents) has been demanding. People have to engage themselves in process-oriented research. Cognitive understanding and external analysis alone proved insufficient to build competence. The process must be experienced and understood emotionally and is critically linked to emotional intelligence (Goleman 1998). Without this experience, the learners were never able to understand what social learning processes mean in practice, and how to facilitate them. Our experiences in competence development demonstrated that training and coaching staff on the job over 1–2 years (several learning workshops and follow-up coaching) effectively address knowledge, attitudes, and skills (Moyo and Hagmann 2000).

At organizational and management levels among service providers (in our case, extension organizations), genuine institutionalization of participatory approaches engages them fully in their own process of change. Planning procedures, priority setting, hierarchy, management styles, linearity, and discipline are some of the components that must be adapted through management change focusing on learning organizations (Senge 1990). Thus, scaling-up processes through support institutions are more than dissemination of approaches (Lovell et al. 2002).

Scaling out: from farmer to farmer

An active scaling-out process was facilitated through farmer learning tours and exchange visits across communities, wards, districts, provinces, and countries (e.g., Zimbabwe–South Africa) and between farmers and other sources of innovations (e.g., research stations, specific farmer innovators). These exchanges of knowledge and experiences have been highly effective when integrated with a larger, community-based innovation process. The choice of community representatives and the designing of their terms of reference by the community (e.g., reporting back) were central to triggering large-scale INRM activities. This decentralized, non-monopolist and non-hierarchical approach to rural knowledge management was very effective. It was backed up by production of farmer reference materials on technological options, which summarized farmers' own experiences with technologies. One major future thrust would be the development of farmer networks for sharing information and experience. Rural resource centers, farmer libraries, and, in the long run, Internet use will play important roles. However, it is easier to replicate and adapt technologies than emancipatory processes supporting the adaptive capacity. For such processes, service providers are needed as facilitators, at least initially.

Modeling: building bridges to communicate lessons learned

Modeling, another fundamental component of INRM for the purposes of this research refers to the conceptualization of intervention processes and the simplification of biophysical processes through learning tools. Both types of model were tools to communicate and support the action-learning process at different levels. Conceptual models were developed and visualized to explain the major steps in INRM research and extension. Operational models made the implementation of INRM more transparent to research and extension agents. Without these models, it would have been extremely difficult to communicate the characteristics of INRM intervention processes for competency development. Thus we were "using new images and ideas as a means of creating shared understandings that will allow us to do new things in new ways" (Morgan 1997).

At the farmer level, a simple range of models as learning tools was developed, e.g., a simple rainfall simulator with farmers analyzing the effects of different soil management technologies on soil and water conservation (Hagmann and Chuma 2002). These models were highly effective in making biophysical processes visible and letting farmers discover for themselves and debate the implications and the systems interaction in their much more complex real world (e.g., fields, watershed). The understanding of complex ecological principles that farmers gained through this insight greatly motivated them to experiment and thus increase their adaptive management capacity. However, the models need to be simple and readily available at user level as a tool to support discovery and negotiation, rather than to predict detailed conditions or behavior of complex systems in the future.

Impact assessment: monitoring and improving strategy

Impact assessment is a fundamental conceptual component of an INRM approach. The internalized impact orientation (guiding star) steered the Zimbabwe case to develop an initially implicit, later explicit, strategy on how to achieve broad impact. The strategy and approaches, methods, and activities were adapted regularly in response to the outcomes, both intended and unintended. Impact monitoring and assessment were internalized processes to learn, reflect, and then readjust to improve the performance of all actors involved. The focus was on learning; thus monitoring and self-evaluation were integral parts of the action research loop at different levels. The guiding question in designing impact monitoring was: "who wants to learn what and at what level?" For example, farmers may monitor their plans, activities and experiments, and any social implications; researchers/facilitators monitor the effectiveness of their interventions in enhancing these processes among farmers). For each of the superimposed learning loops of different actors and learning objectives, a clear set of performance criteria can be defined during the planning stage.

The impact monitoring and assessment consisted of three elements: process monitoring, outcome monitoring, and documentation of the process and outcome. This was carried out in the field mid-season and when farmers and researchers together evaluated activities and technologies in the field through annual reviews, self-evaluation in communities, and in the teams. This self-evaluation led to readjustments of the strategy and replanning of activities.

Process documentation ("writing the journal") was central for self-learning; to demonstrate the quality of process implementation and impacts and/or outcomes; and to ensure that the rationale for adaptating the planning framework was transparent and understood by headquarters and evaluators. Without sound process documentation and analysis, external evaluators might have found it easy to criticize the "non-fulfillment of the logframe commitments," and eventually derail the direction of the program. The documentation also built confidence within branches of the partner organizations toward increasing autonomy in adapting the planning framework.

Lessons and insights from monitoring and evaluating the program in Zimbabwe and South Africa can be summarized as:

1. The need for a genuine impact orientation at the start of the project cycle, a strategy for impact being a first step. Often research projects that do not even have a clear impact strategy are evaluated on the basis of an impact they never set out to achieve, which in itself is not consistent. It often appears that far too much time and energy are invested in impact assessment instead of developing and improving the strategy for making a real difference.
2. The need for monitoring and adaptation of the "plausible impact strategy" and the process. To reduce complexity of attribution of effects, Kuby (1999) constructs an "attribution gap" in impact assessment in R&D. Because innovation is a social process with many actors, it is practically impossible to assess effects of certain activities beyond a given level; too many factors beyond the control of a program dilute the attribution. Therefore, programs can be held responsible for their planned outputs and outcomes, but not for broad impact. To bridge the "attribution gap," Kuby pleads for a "plausibility bridge." In our experience, this plausibility bridge is the strategy developed in the interdisciplinary sequence that we have described and the process designed to get there, both of which need to be regularly monitored and readjusted to remain plausible.

This does not mean that R&D interventions would be released of their responsibility. They would have a much greater responsibility for their local process outcomes, strategy, and contribution to bringing other actors together. Intervention performance would be measured through quality criteria related to process implementation and strategic orientation/ adaptation, in contrast to the present impact indicators. If the impact is difficult to attribute in more open-ended processes, more focus needs to be placed on quality process inputs. Quality criteria and standards for process implementation, as well as competency development, will have to be developed.

A true learning system in interventions would aim to become self-referenced. In other words, the capacity to learn, reflect, and readapt the strategy and action is the process to be achieved. Once self-referenced, the system will be able to reflect self-critically concerning the meaning of its actions, and will be less likely to make serious mistakes. External evaluation is still required and useful, but learning systems perpetuate their own performance improvement. These are the basic characteristics of adaptive management.

Performance indicators of such systems with high adaptive capacity need to broaden beyond technology to other dimensions such as enthusiasm, empathy, confidence, self-esteem, understanding, creativity, values, and the social energy (Soedjatmoko 1986) displayed by farmers when articulating and demonstrating the solutions they found to their problems. In Zimbabwe, these were indicators for an increased adaptive management capacity that were recognized and accepted easily by evaluators during visits because they reflect human- and value-based criteria. However, it was difficult to make them objectively verifiable and quantifiable, which might not be the appropriate approach to assess constructivist learning processes. Ultimately it is the management aspect in INRM (human dimension) that makes the wheels turn. INRM science needs to take this more into account.

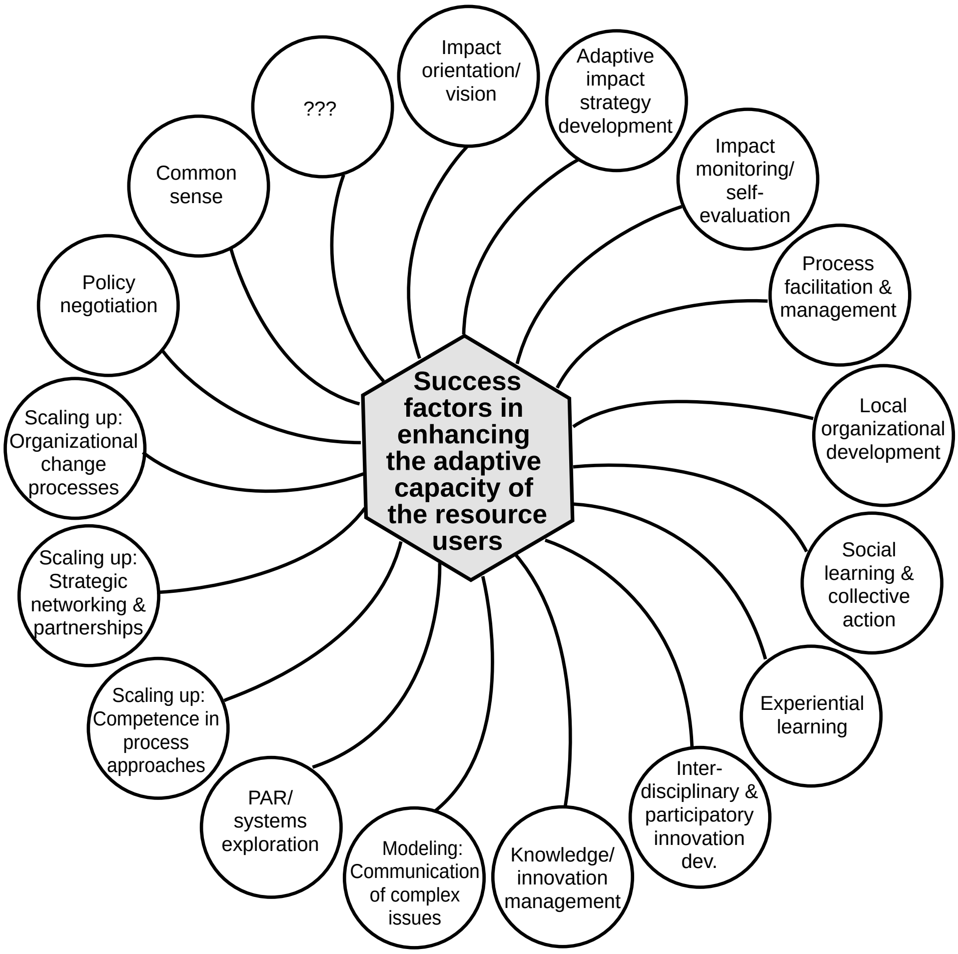
There are still many open questions in this framework of assessing performance and quality of research. Core criteria would be quality of strategy, process implementation, and the research process, rather than the impact (e.g., attitude to scaling up, a plausible strategy, an impact orientation, guiding principles, effectiveness of coordination and the convening role, clarity of the value system). All these performance criteria are derived from the process and learning paradigm in INRM and replace the conventional understanding of "impact." In brief, INRM might imply a shift in emphasis from impact assessment to performance, quality, and strategy monitoring and assessment.

Synthesis: a conceptual framework for INRM

The lessons and success factors described in this paper, together with other factors that were not treated in detail (e.g., policy negotiation, knowledge/innovation management), form a foundation for an emerging framework for designing INRM interventions. The framework, in the form of a "wheel" (Fig. 4), combines and links the critical conceptual and methodological success factors in a systemic way. This implies that none of the elements can be dealt with in isolation, but different elements might be relevant in different stages of the process. The implementation process design and management will define which element will be required, when, and how in developing the adaptive capacity of the main actors. One example of the design is Fig. 1, but different sequences might be developed for different contexts. This flexible framework is based on the understanding of innovation as a social process, applying the constructivist perspective as discussed. It operates on the principles of systems thinking in rural livelihoods and through participatory learning approaches.

The core value of INRM interventions is local ownership where participation is understood as emancipation of rural resource users. Intervention aims to be inclusive, accountable, transparent, and to enhance openness from all actors to social learning and collective action.

Figure 4. The main elements/success factors in INRM R&D interventions.



CONCLUSIONS: FUTURE CHALLENGES

The INRM focus on enhancing the adaptive capacity of the resource user system changes the role not only of research, but also of the whole innovation system, including extension, rural knowledge management, and service delivery. Conventional divisions of linear institutional mandates do not appear effective to address complex and diverse needs of INRM and other spheres of development. Within this broader framework, the roles of international vs. national research in INRM, research in general vs. extension and other development agencies, and other key players (e.g., private sector, farmer organizations) need to be revisited to build an effective, synergistic institutional arrangement for innovation and service delivery. If individual actors are linked in a broader network where interfaces between actors are well defined, their individual effectiveness can improve substantially. Our South African experience showed that platforms of service providers and stakeholders on which a joint vision, roles, relationships, and approaches are worked out, can contribute greatly to the development of functional innovation systems. R&D programs can work toward this in a persistent way and can achieve results step by step. Researchers can take a convening role, accompanying the process by action research to develop workable modalities and methodologies.

A core issue in INRM is the facilitation role, which is demanding and requires a high level of competency. It is unrealistic to think that every researcher can become a good facilitator. The individual who plays this role will need to be negotiated and agreed upon. Development agents who facilitate action learning processes at local levels and researchers who carry out studies on these processes must be fully engaged. Such situations leave the development agents as "guinea pigs" in an insecure position. Unless researchers engage themselves emotionally in participatory action research, they limit their ability to understand the dimension, and thus their ability to contribute effectively.

The implications for the structure and governance of international and national research organizations are also challenging. Moving from discipline-based "silos" to interdisciplinary teams, with sound competencies for process-oriented action and systems research is one challenge. Another task is to match flexible client needs with centralist, top-down planning procedures and their hierarchical and control-oriented management styles and organizational cultures. Without substantial organizational development over several years, involving structural and cultural/behavioral approaches and the development of strategic leadership (van Maurik 1999), these changes are not likely to come about fast enough. Ultimately, this might become a question of survival for many R&D organizations.

None of these challenges threatens preconditions for the operation of INRM R&D. Both INRM and the new institutional arrangements for innovation and service systems are conceptually and in practice still evolving through early stages. Considerable experiential learning is required to develop workable arrangements and approaches. If many R&D organizations would actively engage in this process, even through small steps, joint learning could promote rapid change. Better indicators, performance criteria, and standards for "adaptive capacity" and "process implementation" will help to move the approach forward for implementers and planners. Ultimately, the focus on competency in process approaches will make INRM interventions successful.

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4.

The Adaptive Decision-making Process as a Tool for Integrated Natural Resource Management: Focus, Attitudes, and Approach

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ABSTRACT

Integrated natural resource management (INRM) and its many closely related approaches are generally considered to be more effective than single-disciplinary approaches for managing the complex resource issues currently facing many countries. INRM approaches aim to integrate several disciplines and involve different stakeholders operating in their own subsystems across different spatial and temporal scales. These approaches focus on identifying management strategies for sustaining natural resource stocks and flows of goods and services as well as their underlying ecological processes. Changes in the behavior of consumers and producers and in the allocation of resources among uses, users, time, and space will be necessary to achieve sustainable development. To accomplish this, changes in focus, attitudes, and approaches to research and management will also be necessary. This paper argues that the key focus of INRM should not be the natural resource itself, but rather the interactions of humans with each other and with their natural environment, and the decisions they make about using and managing resources. Such decision-making processes aim to identify and implement action-oriented strategies and to apply economic and noneconomic instruments that motivate behavioral changes, allowing for different responses to various economic imperatives. This process should be guided by constructivist philosophy and supported by rigorous cross-disciplinary research and active stakeholder participation. It must be compatible with dialectic decision making to reflect the different views and objectives of the stakeholders, the presence of incomplete information, and, at times, the fact that researchers have only a poor understanding of the dynamics of subsystems and their

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interactions. There must also be iterative, regular monitoring and fine-tuning of the management strategies chosen. We prefer to call the entire process an adaptive decision-making process (ADMP). Here we propose a four-phase ADMP illustrated by projects in Fiji and Thailand, both of which are supported by the Australian Centre for International Agricultural Research. The role of research, researchers, and other stakeholders in the ADMP is also discussed.

KEY WORDS: adaptive decision-making process, bioeconomic models, commodity research, decision support system, integrated natural resource management.

INTRODUCTION

Traditional resource management policies and strategies are commonly based on reductionist approaches within the paradigm of a single discipline. Management strategies of this type are largely " ... reactive, disjointed, and for narrow or limited purposes ... " with " ... ineffectual or unsatisfactory, often undesired, management outcomes ... " (Born and Sonzogni 1995:168). These methods are generally ineffective in explaining real life with its complex interactions and uncertainties. Researchers practicing such strategies tend to regard current global resource and environmental issues as "wicked problems" that are impossible to formulate in a definitive manner (Rittel and Webber 1973, Margerum and Born 1995, Bellamy and Johnson 2000).

There is an increasing consensus about the need to find an approach to resource management that encourages environmentally friendly economic development by treating economic growth and environmental management protection as a continuum that crosses the boundaries of various scientific disciplines (Costanza and Jorgensen 2002, Belsky 2002). The need to develop a process for formulating and implementing a course of action that explicitly takes into account social, political, economic, and institutional factors is also acknowledged. Such a process must be inclusive and fully address the scale and scope of environmental and human issues and their consequences (Dixon and Easter 1986, Cairns 1991, Born and Margerum 1993, Born and Sonzogni 1995, Lovell et al. 2002, Gündel et al. 2002, Hagmann et al. 2002).

Such realizations have led to a gradual but fundamental shift in the resource use and management paradigm. Integrated approaches to resource management have been advocated in many fields, such as river basin management, regional planning and ecosystem management (reviewed by Born and Sonzogni 1995), coastal zone management (Cicin-Sain 1993), wetlands management, and oceans management (Costanza et al. 1999). This emerging management concept has been known by at least 36 alternative terms (Downs and Gregory 1991), including "integrated catchment management," "integrated environmental management," "ecosystem management," and "systems analysis." In this paper, we use the term "integrated natural resource management" (INRM).

Although INRM has been heralded as *the* approach to addressing resource use and management, adopted by agencies and communities in developed countries, and advocated by many international development donor agencies, it does not yet have a systematic methodology. As part of the conceptual development of and based on their experience with INRM, theoreticians and practitioners alike have outlined elements and principles that are integral to the process. It is generally accepted that any systems approach adopted should:

- integrate multiple disciplines,
- span spatial and temporal scales, and
- involve multiple stakeholders in planning and implementation.

However, the application of INRM still poses significant problems even when all of the key elements are in place (Gunderson et al. 1995, Gunderson and Holling 2002, Bellamy and Johnson 2000). These problems are related mainly to the predispositions of stakeholders, researchers, and technical experts as well as managers, farmers, and other end users (Resource Assessment Commission 1993, Lynam et al. 2002).

Because of these problems, many researchers are attempting to further their understanding of INRM, with peer-reviewed publications as a measure of their success. They identify important research problems viewed from within the paradigms that they themselves use to structure research (Kuhn 1970), and based on a positivist philosophy (see Guba 1990). The researcher/inquirer adopts a noninteractive position, and analysis is regarded as value-free. Methodologically, the researcher states a hypothesis and sets out to test (falsify) it empirically. However, achieving practical outcomes is rarely the goal of researchers, which creates a problem when research results are linearly transferred to end users. Managers who have narrow, legislatively mandated terms of reference, duplicate each other's roles, and act inconsistently represent a different set of problems (Resource Assessment Commission 1993). End users are also reluctant to alter their behavior without incentives compelling enough to bring about changes in their fundamental decision making.

To address these problems effectively, all the stakeholders, including users, researchers, and managers whose decisions and/or activities influence actual outcomes, would have to make significant changes in their behavior, and probably in their attitudes as well. Furthermore, changes are required in the scale of analysis and action, which could be at the level of the plot, the farm, the community, the region, or even the nation—whatever works. These modifications can be developed by farmers (farmer experimentation), scientists, and/or the private sector (Hagmann et al. 2002, Lovell et al. 2002). All the stakeholders, including researchers, must be involved in developing strategies for change. These strategies will also require changes in the way research is identified, developed, and conducted as well as in the behavior of managers. The types of strategies that lead to alterations in end-user behavior would also need to be reviewed, so that individuals are given incentives, rather than directed, to change.

In this paper we argue that, to adequately reflect these concerns, INRM should be seen as an iterative and adaptive decision-making process guided by constructivist philosophy. Decision makers should be encouraged to make dialectic choices from among management strategies that focus on changing people's behavior to achieve specific outcomes, rather than relying on the specific inputs required for traditional resource management.

The objectives of this paper are:

- to provide a practical adaptive decision-making process (ADMP) and
- to illustrate its application using two case studies in which the ADMP framework was used to identify research issues and to implement participatory research in support of stakeholder-based decision making.

THE ADAPTIVE DECISION-MAKING PROCESS (ADMP)

The adaptive decision-making process (ADMP) is a problem-focused, action-oriented participatory process aimed at producing use and management strategies that stakeholders agree with and feel like they "own." This process recognizes multiple stakeholders who have different values and knowledge systems and use multiple paradigms (Lynam et al. 2002, Oglethorpe 2002). It acknowledges the need for a dialectic decision-making process supported by rigorous single- and multidisciplinary research. Consequently, there are three themes inherent in the ADMP: (1) participatory action research, (2) the use of a user-friendly decision support system (DSS), and (3) dialectic, stakeholder-based decision making underpinned by analytical rigor.

Constructivist philosophy

In constructivist philosophy, " ... realities exist in the form of multiple constructions, socially and experimentally based, local and specific, dependent for their form and content on the persons who hold them ... " (Guba 1990:27). Thus, any inquiry is value-bound, and these values influence a researcher's choice of problem and interpretation (Tacconi 2000). The recognition of different realities suggests that no one understanding is complete, and that no one solution can be optimal. This is particularly true when there is a great degree of uncertainty, and when decisions need to be made despite inadequate information. To achieve this, stakeholders need to embrace a collaborative dialectic process of interaction, investigation, and testing. The real challenge is to use this approach for effective resource management.

Participatory action research

Participatory action research requires the active involvement of all the stakeholders in the entire research–extension–development process and the acknowledgment of their multiple realities (Okali et al. 1994, Cornwall and Jewkes 1995). Stakeholders learn through their experiences and modify their actions accordingly (Chamala and Keith 1994, Hagmann et al. 2002). Key characteristics of the action-oriented research process include:

- problem-focused research that responds to local priorities;
- a methodology with an interdisciplinary focus that includes every stakeholder's knowledge system;

- the use of more than one methodology;
- triangulated data collected by researchers and stakeholders;
- analyses carried out by researchers from different disciplines using their own theoretical constructs, paradigms, and disciplinary tools;
- results and information that are interpreted through a dialectic process;
- actions that are integral to the process; and
- final results that are shared and owned by all the stakeholders.

Decision support system (DSS)

A decision support system (DSS) is an integrative analytical tool that describes key processes and spatial and temporal connections within and between human and biophysical subsystems from a systems perspective. It uses a multidisciplinary approach to provide a definitive representation of a system, using mathematical algorithms where relevant. Multiple management objectives are recognized and built into the evaluation framework (Kersten et al. 2000, Lynam et al. 2002). A DSS comprises data sets, key analytical models, and a user interface, and is central to the dialectic decision-making process.

Dialectic decision-making process

Dialectic decision making assumes that there are many different interpretations based on different scientific paradigms, experiences, and value systems that cannot easily be reconciled. No one interpretation may be complete, and, as a result, many realities are possible. This process thus " ... elicits and refines hermeneutically ... with the aim of generating one (or few) constructions on which there is substantial consensus ... " (Guba 1990:27). Decisions are based on the knowledge systems of all the stakeholders and on sound judgments supported by rigorous analysis. These decisions are achieved through interactions between stakeholders. This type of decision-making process is aided by the use of a DSS.

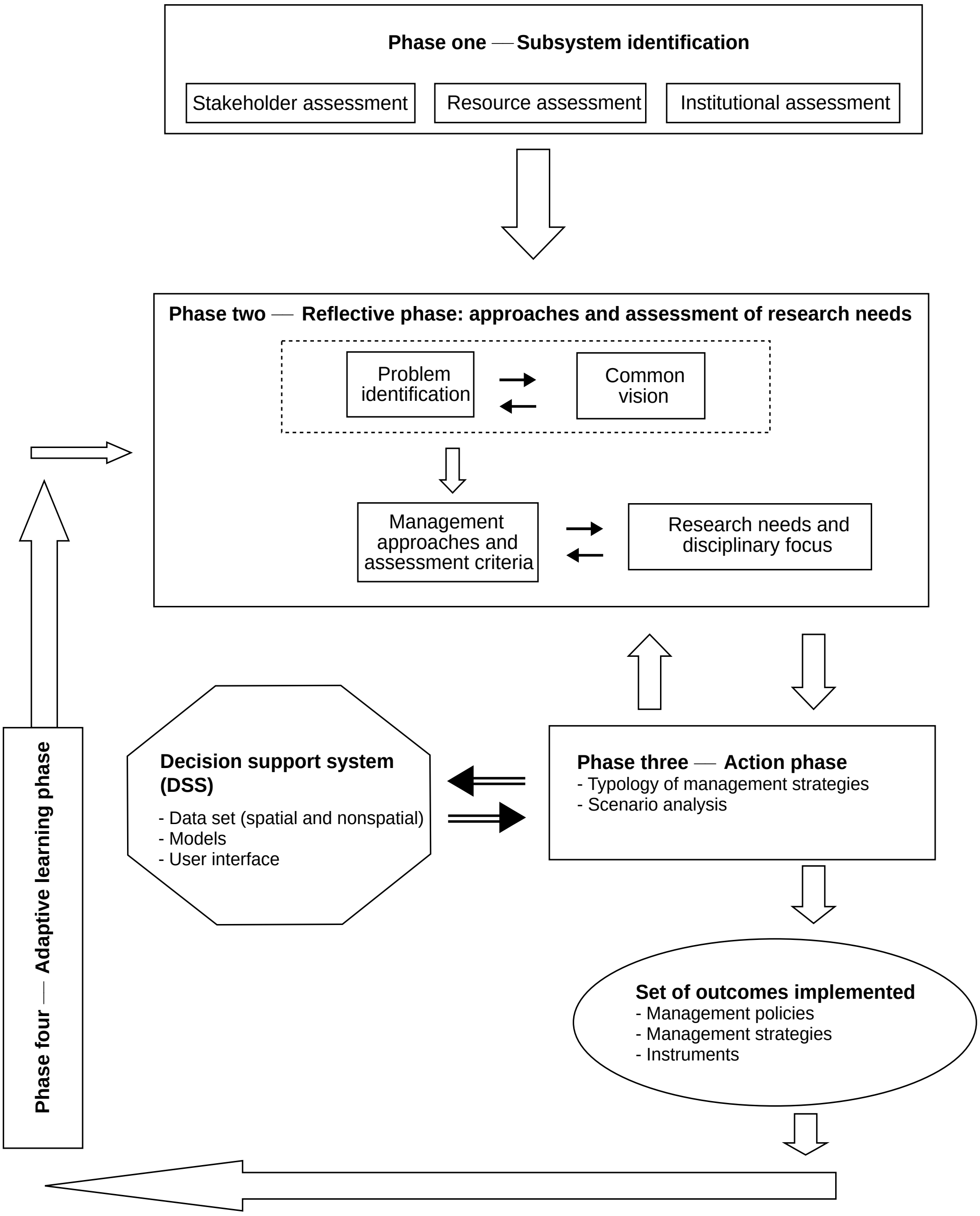
Operationally, the ADMP comprises four phases: (1) subsystem identification, (2) reflection, (3) action, and (4) adaptive learning (Fig. 1). Although a four-phase ADMP is recommended, the boundary between one phase and the next is flexible, and more than one phase may be undertaken at the same time.

The phases of the ADMP

Phase one: Subsystem identification. The following three assessments are carried out in this phase:

- a stakeholder assessment, which identifies key resource owners, users, and managers at all levels of government, existing patterns of decision making, and the contexts in which stakeholders interact;
- an institutional assessment of the rules and regulations that govern activities within the ecosystem and of other institutions that may indirectly affect the system. This stage also

Figure 1. The adaptive decision-making process (ADMP).



identifies traditional institutions that may be relevant, as well as the management instruments used by the different agencies involved, including indigenous communities; and
- a resource assessment that uses traditional science and indigenous knowledge to provide a preliminary inventory of relevant biophysical and ecological flora and fauna. It also considers the dynamics of the natural processes that contributed to the current status of the environment as well as the functional processes and interactions between key components of the natural system.

Phase two: Reflection. The aim of this phase is to identify priority problems and establish a common vision, select the overall management approach and assessment frameworks to be adopted, and determine the research needs and disciplinary focus by means of participatory action research and dialectic decision-making processes. Researchers play an active role in this process by working with other stakeholders and using their technical and analytical skills to help them understand the effects of human activities on natural dynamics within the legal and institutional contexts of observed reality. The agreements reached during this phase and the data gathered and analyzed are included in the design of the DSS, which is built as part of the action phase.

As mentioned above, the initial goals of this phase are to identify problems and establish a common vision. A clear understanding of the underlying management issues and general agreement on the desired outcome are critical to any decision-making process that attempts to choose a path for development and management. The stakeholders, with their different perspectives, will together define the problem statement, arrive at a common vision about the desired outcome, and identify the appropriate management approaches and the set of management criteria that will be used to choose from among alternative policy options and/or management strategies. Information generated by individual disciplines and across disciplines, as well as indigenous knowledge, should be integrated into the process to develop detailed descriptive and causative inferences about the:

- nature and scope of the specific problems, issues, or concerns;
- existing value systems and patterns of interaction between owners/custodians, users, and managers;
- interactions between existing natural, economic, and social systems and possible cause-and-effect relationships and linkages between human activities and ecological functions and processes; and
- spatial and vertical boundaries of relevant interactions, based on ecological and/or economic considerations.

If complete information is available on the effects of human activities on ecological processes and economic values, and if the integrity of the underlying ecological processes is not threatened, then market mechanisms can be used to encourage an optimal allocation between competing uses during this phase. This assumes that market values reflect all the costs and benefits of the system, and that all the necessary information is freely available.

However, this is often not the case. Resources may exist for which property rights cannot be assigned, which leads to “missing markets.” In these situations, market-based mechanisms cannot reliably encourage efficient or ecologically sound outcomes. Under such circumstances, it is useful to develop an evaluative framework to help the stakeholders agree on some way to objectively assess the impact of their activities on the ecological system.

The management approaches and evaluation frameworks chosen help to determine the research needs. The problem or issue itself will dictate the types of single- or interdisciplinary analyses and skills required. Depending on the research subobjectives (exploration, description, understanding, explanation, prediction, evaluation, and/or assessment), then inductive, deductive, retroductive, and/or abductive strategies may be used (see Blaikie 2000:100–127 for details). The research team should be drawn from appropriate disciplines and should normally include at least a biophysical scientist, a social anthropologist or community specialist, and an economist with experience in natural resources, agriculture, or environmental issues.

Phase three: Action. In this phase, the stakeholders agree on the management strategies they will use to resolve the resource problem based on their knowledge of what motivates and influences the actions of individual decision makers. Management instruments may include legislation, agreements, market-based strategies, institutional changes, and/or education (Panayotou 1998, Dover 1999). These instruments may meet a specific target and/or self-regulate. The strategies identified by the ADMP should always incorporate incentive mechanisms for change. This allows the stakeholders to adopt strategies for which the benefits outweigh the costs and the risks remain within agreed-upon safe, minimum environmental and social constraints. To guide the stakeholders, a DSS is built, and the researchers use it to help develop scenario analyses.

A DSS generally consists of:

- a set of biophysical, social, and economic data;
- a set of integrated analytical, simulation, and/or optimization models derived from individual disciplines;
- an output module for the spatial and/or nonspatial depiction of expected future outcomes; and
- a user-friendly interface that enables relevant stakeholders to perform “what if” scenario analyses.

The DSS serves three purposes: (1) stakeholders gain a better understanding of the problem in a way that attempts to detach them from their previous inclinations; (2) decision makers may objectively compare the effects of different value systems, different world views, and a range of possibilities based on sound analysis; and (3) the DSS may increase the chance of finding a shared vision or acceptable solution (Kersten et al. 2000, Lynam et al. 2002). Different scenario analyses represent different management strategies, policy options, and/or institutional settings aimed at changing decision-maker behavior to meet the desired goal. Each scenario can be considered a unique depiction of a future strategy and may be analyzed using the DSS. This type of scenario analysis can also contribute to conflict resolution.

In any multidisciplinary environment, a conflict of interests, values, and approaches is inevitable. This can occur despite good intentions and agreement about desired outcomes, the management approach, and the evaluation framework. Conflicts and disagreements are often unavoidable and must be resolved. Differences may arise because:

- many different activities may be contributing to the observed problem,
- a single activity can have many different impacts,
- there are connections within and between land-based and aquatic components of the ecosystem,
- activities may have indirect and synergistic or cumulative effects, and
- relationships may be nonlinear (Antunes and Santos 1999, Lovell et al. 2002).

In the face of uncertainty, incomplete understanding, and different value systems, stakeholders should pool their knowledge and be flexible and willing to arrive at a consensus, or at least recognize these differences, which can then be analyzed using dialectic processes to reach some form of agreement. Many different models of conflict resolution are available. However, bargaining and dialogue are superior to authoritarian decision making for complex problems involving uncertainty and competing interests. Buckles and Rusnak (1999) also argue that conciliation, negotiation, and mediation are more likely to produce a "win-win" solution. A DSS may help in the resolution of conflicts, particularly those involving values, management approaches, and strategies.

Phase four: Adaptive learning. It is important to treat the process of examining prospective management strategies as a series of management policy experiments. This emphasizes the element of surprise in the search for sustainable development (Janssen and Goldsworthy 1996, Holling et al. 1998, Lee 1999, Hagmann and Chuma 2002). The management strategies selected in the action phase are now implemented and monitored in an iterative manner (Fig. 1). The results of these experiments indicate the extent to which these problems are manageable, and which strategies are useful. Regardless of how the results are interpreted, this phase becomes one of adaptive (or experimental) learning.

This learning process is central to the ADMP. May (1992) describes three types of learning:

- instrumental policy learning about the viability of specific instruments or programs;
- social policy learning about social constructions of policy problems, the scope of policy, or policy goals; and
- political learning, during which stakeholders become more knowledgeable about policy process and negotiating skills.

Users of the resource are also key learners. They learn by observing the results of their actions and analyzing cause-and-effect relationships based on their newly acquired knowledge; their findings are then fed back into the decision-making process.

APPLICATION OF THE ADMP: ACIAR CASE STUDIES

Two projects are presented to illustrate the lessons learned by applying the ADMP. The first assesses the effects of reforms in the international sugar market and defines appropriate responses for the Fiji sugar industry. The second concerns a framework for integrated water resources assessment and management in the upper Chao Phraya in Thailand. These two projects were chosen to emphasize that the ADMP is relevant whether the underlying research is commodity-based or concerns natural resource management per se. These projects also demonstrate that the ADMP can be applied when stakeholders need to make decisions about either sociocultural or institutional constraints, as in the Fijian case, or biophysical or ecological limitations, as in the Thai case. These two case studies make it clear that this artificial distinction is part of the problem that needs to be considered in INRM research and development.

Although in neither of these projects have all the phases of the ADMP been completed, the Fiji sugar project illustrates how the process was implemented in its early stages, whereas the later phases of the ADMP are best illustrated using the Thai context. The action learning phase has not been completed in either of these case studies.

The Fiji sugar project

Phases one and two of the ADMP were carried out simultaneously. Preliminary discussion and literature reviews revealed many stakeholder groups in the sugar industry who had a direct interest in and/or whose decisions were likely to influence industry outcomes. Internationally, the World Trade Organization and developments in the European Union Common Agricultural Policy have a direct impact on the Fiji sugar industry. The Sugar Protocol of the European Union has guaranteed Fiji specific levels of exports and prices that are often two to three times the world price. This, together with a productivity decline over the last decade, provided the overall institutional context for research and the scenario analysis.

Domestically, the stakeholders include owners of native lands, which account for more than 70% of all Fijian land under sugarcane; sugarcane growers, predominantly of Indo-Fijian origin, who grow sugarcane on leased land regulated by legislation; a milling company monopoly that owns all four mills; and the sugarcane harvesting groups (Table 1). In addition, the Ministry of Planning, the Ministry of Agriculture, Forestry and Fisheries (MAFF), and, more recently, the Ministry of Sugar are involved in the industry.

To initiate a participatory process, it was crucial to obtain the endorsement of the most influential government official, the Permanent Secretary of the Ministry of Planning, who was also the Secretary of the Sugar Commission of Fiji. Discussions later included MAFF, the Fiji Sugar Cane Growers Council (which represents all those involved in sugarcane

Table 1. Institutional arrangements affecting the Fiji sugar industry.

• Agricultural Landlord and Tenant's Act	• a maximum 30-year, non-renewal tenure arrangement on native land, the majority of which will expire between 1997 and 2005
• Crown Lands Act	• crown land leases
• Sugar Industry Master Award	• formalizes the relationship between growers, sugarcane cutters, transporters and millers • stipulates distribution of sugar proceeds between growers and millers • stipulates payment rates for transportation, sugarcane harvesting, etc
• Sugar Industry Tribunal Act	• covers industry disputes, including sugarcane harvesting arrangements and transportation arrangements

production), and the Fiji Sugar Corporation (the sole sugar miller). After the project implementation meeting, efforts were made to keep the Native Land Trust Board (the custodians of indigenous land) informed, with the hope of involving it more actively at a later date. One year after the project began, the Land Trust's full cooperation had still not been secured, and this may take some time because of recent political events. The Native Land Trust Board finally agreed to share some of its data late in 2001, well over 5 years since the project idea was first mooted!

Discussion with the stakeholders identified the management issues that required analysis. Given the huge challenges facing the industry, it was not difficult to arrive at a broad consensus on priority issues. There was general agreement that impending trade negotiations with the European Union were the major concern and that land tenure was the most critical domestic issue. More than 95% of all land leases are due to expire by 2005. If these leases are not renewed, as has been threatened, and the land reverts to the indigenous landowners, the sugar industry will be further jeopardized due to the lower productivity of farms that are managed by indigenous Fijians.

There were, however, different opinions about how to address these issues. Before the ADMP concept was introduced, the Sugar Corporation had concentrated on improving the efficiency of transportation and milling. In contrast, research at the Fiji Sugarcane Research Centre was focused on farm-based fertilizer and pesticide trials, farm management trials, and breeding varieties to suit different soil conditions. Researchers from MAFF were interested in assessing sugarcane land-use capabilities, whereas the Lands Department was developing land information systems based on geographical information systems (GIS). These different stakeholder groups did not interact, and thus did not achieve the synergistic benefit of an integrated approach.

Following discussions that lasted almost 12 months, the key stakeholders endorsed the use of the ADMP approach. They acknowledged the value of integrated research, using a nested scale of analysis (Fig. 2) to address the problems facing the sugarcane industry.

Figure 2. Nested scales of analysis.

Scale		Analysis [Tools]
INTERNATIONAL		International trade [trade model, political economics]
NATIONAL		Economy/industry-wide impact assessment (computable general equilibrium model)
REGIONAL • Economic region • Biophysical catchment	IMPACTS FEEDBACK	Land-use suitability [crop suitability models, land-use models, bioeconomic model]; spatial variability [GIS]
LOCAL • Farm household system		Household profitability (on-farm and off-farm activities) [household income and expenditure model]
• Agricultural activities of households		Farm activity model [farm model]
• Specific crop		Biophysical crop-specific/ crop model

Staff from the Fiji Sugarcane Research Centre agreed that there was a need for integrated bioeconomic research. MAFF acknowledged the merits of combining their work with that of the Lands Department, and agreed to join the research team, thus bringing together a land-use specialist, a crop scientist, an agricultural and resource economist, and a trade economist. The Sugar Corporation, on the other hand, became involved only after the merits of the project were no longer in dispute; the corporation also needed to be reassured that the project leader was apolitical at a time when the country was divided along ethnic and political lines.

Not all issues were resolved easily; some required extensive dialogues over long periods of time, and others are still unresolved. For example, because the Lands Department and MAFF operate on different scales, it has still not been possible to reconcile their outputs. Issues related to the scale of analysis and the appropriate degree of accuracy must still be addressed, as must some issues between the bioeconomist and the land-use specialist; discussions of these subjects are continuing. It may be possible to resolve these problems once the users of the research clearly indicate the scale at which they want the analysis and results to be expressed.

Only when the recently appointed Chief Executive Officer of the Cane Growers Council fully endorsed the ADMP project did researchers gain access to Council data and information. The new CEO is working closely with the research team and has asked to see the results of key analyses of the expected effects of expiring land leases on landowners, sugarcane growers, and the sugar industry as a whole. The Minister for the Sugar Industry has also sought similar information.

The results of the analysis of land tenure options have been made available to the bipartisan Agricultural Landlord and Tenant Act Task Force, the key forum for the land tenure issue. The research team is continuing its discussions with the Sugar Commission, the Growers Council, and the Minister for the Sugar Industry, and there have been requests from these bodies for additional scenario analyses of alternatives for land tenure reform. However, negotiations over the renewal of leases have stalled because of recent political events in Fiji.

Stakeholders will be able to undertake scenario analyses using the DSS with minimal input from technical staff. The key components of the DSS design are currently being developed. To guide this development, potential users, including key government agencies, the Growers Council, members of the Sugar Commission, and the Fiji Sugarcane Research Centre have been asked to identify the issues they would like to address in the near future.

The Thai project

At first, the Thai project did not fully embrace the ADMP process. The project began as a catchment management project, with a greater focus on the scientific challenges to individual disciplines. It was not until late in the first phase and early in the second that it became outcome-oriented and incorporated decision makers into the process. Researchers from different disciplines were almost halfway into the project when they finally started to see the linkages and appreciate the synergy that would result from bridging the disciplinary divide. This project has completed three of the four phases of the ADMP.

Phases one and two were undertaken concurrently because of difficulties related to the diversity of stakeholders in Thailand. After a preliminary literature review and stakeholder discussions, it became apparent that the key issues involved land and water resource allocation, together with the effects of government policies and management strategies. Three government agencies are actively involved in management within the catchment area. The Department of Land Development is responsible for developing catchment management plans, the Royal Forestry Department implements forest conservation strategies, and the Royal Project Foundation has an active role in agricultural extension. These agencies are represented at national, provincial, and local levels. A number of environmental nongovernment organizations, activist academics from Thailand, farmers, and farmer organizations are also involved in resource management.

However, not all stakeholders were interested in the ADMP project because of their experiences with earlier academic projects, which did not produce useful results. For this reason, the Department of Land Development was deliberately chosen as the key government stakeholder, because it expressed the most interest. The challenges were then to implement the ADMP and design a DSS-based process that could meet the needs of the Land Department without limiting the future involvement of other stakeholders. The project team then had discussions with the rural householders who live in the catchment area and are the primary stakeholders. As the project progressed, other stakeholders joined when they saw that the DSS developed as part of the project could be useful in their own efforts to devise suitable management strategies.

Although households are the main decision makers in the catchment when it comes to issues related to the allocation of inputs such as family and hired labor, capital, and land (Walker and Scoccimarro 1999), water is managed communally, as in other regions of northern Thailand. Weir management committees allocate water and organize labor for the maintenance and repair of the weir infrastructure (Tanabe 1994).

It was evident after a number of stakeholder meetings that their priority concerns were not the same as those previously identified by the government. Downstream agricultural communities were worried about the effects of changes in land cover on the availability of water, in particular, about the possibility of flooding and drought caused by upstream forest clearing for agriculture. The Land Department was interested in identifying land uses that suit underlying biophysical conditions and meet socioeconomic criteria. Individual agricultural households were concerned about their livelihoods. The demand for water for dry-season cropping has increased, and there were proposals for new water storage facilities.

Research needs evolved as the project progressed. Consequently, although the project began with a core research team comprising a hydrologist, an economist, and a social anthropologist, it expanded over time to include a crop modeling expert, a land-use specialist, a soil erosion expert, and a DSS specialist.

The large number of stakeholders had many different views and objectives. Appreciating their roles in the catchment area and understanding the ways in which other factors affected household decision making were crucial issues for the project team, whose objective was to recognize and incorporate these varied views. For example, farmers were interested in their own financial performance and were not necessarily concerned about downstream implications. National policy makers tended to view the catchment area as a whole; some of them focused on overall land and water use, whereas others were more interested in the distribution of water use by household within the catchment area.

In the third phase, the key objectives were to identify a typology of management strategies, determine the assessment criteria that were important to the different stakeholder groups, develop a DSS, and analyze possible management scenarios.

Much of this phase was implemented by the researchers, who had regular interactions with other stakeholders to validate assumptions, check information, and seek input about management objectives, strategies, and assessment criteria. They also tried to determine how to present the results in the form that would be the most useful to the stakeholders. The researchers used standard discipline-based methodology to collect and analyze data, develop analytical models for scenario analysis, and construct the DSS. A brief overview of the different components is provided to demonstrate and emphasize how the DSS, which is the core of the ADMP, was built using the most rigorous single- and interdisciplinary methodologies, models, and tools.

In the upper Chao Phraya catchment area, a number of management approaches have been used, including command and control regulation of particular activities, market intervention to promote alternative crops or subsidize input use, interventions in capital markets, and public investment in irrigation infrastructure. These policies, implemented by a variety of agencies with specific objectives, have had both intended and unintended consequences for the socioeconomic and biophysical systems.

As part of the process of determining the various objectives of natural resource management in the catchment area, stakeholders have identified assessment criteria that reflect their own interests and goals. These criteria include household performance, variations in household performance among different farming systems, the distribution of resource use among communities within the catchment area, and land cover and its associated effects on the hydrological regime. Having a range of indicators that reflect biophysical and socioeconomic processes in the catchment area makes users confront the consequences of policy intervention for both human and natural systems.

The Thai DSS recognized the nested operational scales of stakeholders and made it possible to feed production decisions from the local level to the wider regional and national scales (Fig. 2). In turn, the human and natural resource systems of these wider scales affect the local level, commonly through changes in commodity prices or environmental conditions. Given the links between these scales, different analytical tools are used to accommodate the precision required at each scale; these tools range from crop simulation models and household bioeconomic models to catchment-level, physico-bioeconomic models that link hydrological and household-based bioeconomic models. It is important to note that this integration of disciplines and interests is immensely complex. To address this, the DSS integrated various components heuristically in such a way that those components and interrelationships deemed most likely to underlie the cause of a problem could be explored first.

Biophysical and socioeconomic data sets collected from different sources, including indigenous knowledge, formed part of the data module in the DSS and were used for three purposes: (1) as data for the modeling tools, (2) to provide information to users, and (3) to produce model outputs in spatial and nonspatial forms. Spatial data layers in the DSS included soil maps, catchment and administrative boundaries, digital elevation models, and land cover and zoning maps. These data layers were overlaid in various scenario analyses.

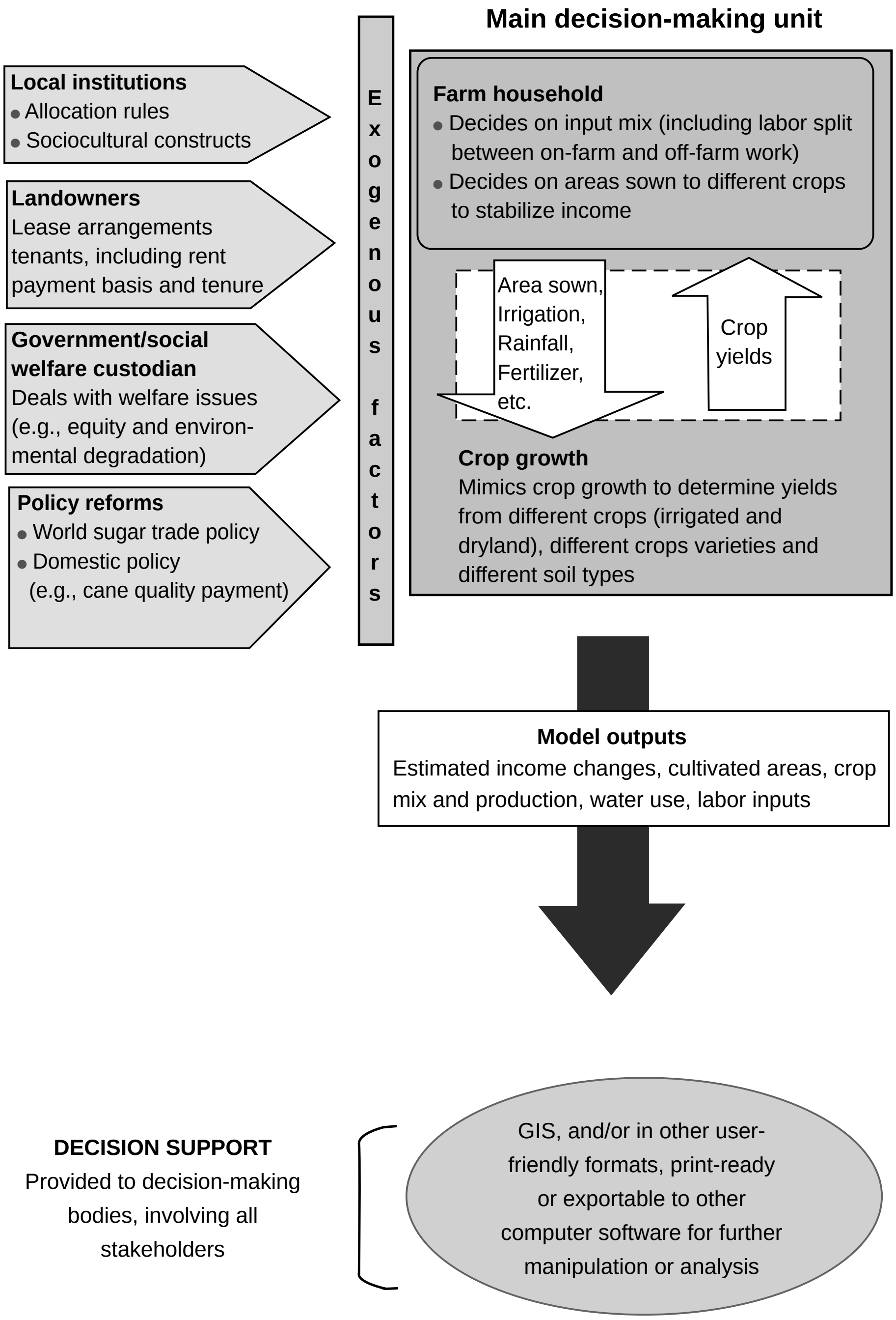
The design of the DSS was not easy, because methods for integrating data (particularly spatial data) and modeling tools are in their infancy. Although off-the-shelf software exists for spatial data manipulation and modeling, few packages incorporate both. As a result, software had to be designed especially for the DSS application.

To fully take into account the impact of policy reforms or institutional restructuring, it was crucial to understand the interactions between stakeholder groups within their altered operational settings. The socioeconomic and environmental effects of change will ultimately depend on decisions that stakeholders make in the field. To assess these effects, the DSS attempted to capture stakeholders' decision-making behavior within the context of the constraints imposed by natural processes and the existing legal and cultural arrangements.

The DSS is thus composed mainly of a biophysical and socioeconomic model (referred to as "the model" in the following discussion) that can explain cause-and-effect relationships and predict the effects of interactions within the system. It also includes a GIS system that is capable of spatially depicting the summary characteristics of linked databases and the simulation and optimization results of the models. The model represents stakeholder groups as discrete modules, each with characteristic decision-making behaviors and patterns (Fig. 3). These modules are interrelated to the extent that their production and consumption decisions affect each other, with the combined impact of decisions made (or not made) determining the likelihood of achieving their envisioned future.

The core of this DSS is the farm household as the main decision-making unit or resource management unit (RMU). Households were classified into groups based on their ownership of high-quality paddy land and access to irrigation, the two most important factors

Figure 3. Sample structure of the biophysical and socioeconomic model.



that determine household decisions. This classification resulted in 5–10 RMU types per region of agricultural activity (Walker and Scoccimarro 1999). Embedded in the farm household model is a crop model for analyzing the bioeconomic viability of various farming practices. This allows decision makers to assess the environmental feasibility of adopting best-practice farming methods and planting high-yield crop varieties as farmers respond to challenges in their operational settings brought about by policy and institutional changes or anticipated climatic conditions.

Although farmers are the main managers of land and water resources, other parties, including local and national governments and nongovernmental agencies, influence their decisions. In general, these other stakeholders were represented as auxiliary modules, and the choices they make feed into the main RMU as exogenous factors. The impact of other groups was also incorporated by explicitly modeling their decision-making processes. For example, weir management committees are key decision-making units who determine rationing during periods of water shortage. Charges and fines are levied on households who do not obey these rules. Weir management committees are responsible for the repair and maintenance of the weir, for which they draw upon household labor. Households often contribute labor based on how much irrigated land they own or pay an equivalent quantity of cash. In some cases, the committees also negotiate with upstream committees. A weir allocation module was included in the DSS to mimic the current rules used for water allocation. DSS users are able to manipulate the allocation rules by changing policy scenarios. Government policies are also treated as scenarios within the DSS. To allow for differences in objectives, the economic efficiency of government policies was not evaluated at the outset, but this could be assessed later using the DSS.

The DSS is characterized by a highly intuitive user interface that allows decision makers to explore alternatives by changing the values and data in the model. The interface guides nontechnical users through the stages of accessing and manipulating data and developing and assessing scenarios. The DSS was designed to allow future users to identify information gaps, update information, and evaluate critical assumptions or uncertainties; it can also accommodate changes in information and assumptions as the ADMP takes the stakeholders through different stages of social learning. The aim is for researchers and users to be able to incorporate new data and collaboratively define new modeling requirements and refinements (Allen et al. 1996). The results can be summarized in tables, plotted, or collated into an exportable text file, depending on stakeholder needs.

Whereas there is no specific format for designing a user interface, the following principles were considered to be important:

- a format that the stakeholders are comfortable with,
- the availability of on-line help and tutorials,
- easy access to all components of the data and models,
- the ability to interface with other software,
- a format that allows for transfer between computers, and
- the provision of different ways to present the model outputs.

The interlinked models in the DSS were used to assess many management scenarios, and the results were presented to the key stakeholders at workshops. Topics covered included the implementation of forestry regulations, the introduction of crops through agricultural extension, the construction of facilities for storing water, and investment by households in more efficient irrigation systems. Scenarios were assessed using a range of indicators that captured the broad socioeconomic and biophysical processes. Indicators reported for these regions included water supply, water diversion, crop yields, and household performance. Household indicators included gross margins, income from cash crops, on- and off-farm income, and shadow prices of constraining resources. The results of various scenario analyses were presented to different stakeholder groups. The fourth phase of the project will be implemented in 2001–2002.

CONCLUSION

Integrated natural resource management (INRM) that integrates multiple disciplines across spatial and temporal scales and involves stakeholders in key decisions will probably be more effective than the single-disciplinary management approaches of the past. However, for INRM to succeed in practice, it must focus on how people make decisions and how they interact with each other and with their natural environment.

First, all the stakeholders involved will probably have to change their behavior to allow for the planning, research, and implementation of management strategies across traditional and legislatively mandated roles and disciplinary biases. Second, constructivist philosophy should guide a dialectic decision-making process supported by rigorous individual or interdisciplinary research. Third, the specific problem should dictate the scale, scope, and disciplinary mix of the research, and the desired outcomes should be identified through participatory action research, which may require a spatial-analytical framework of hierarchical scales of analysis from local to global. Fourth, research should be integrative and synergistic, crossing disciplinary boundaries and bridging gaps in the perceptions, values, and perspectives of different stakeholders. Actions and policies should be developed in a participatory manner and implemented at different scales to bring about the outcomes that have been identified as desirable based on the decisions that stakeholders actually make in the field. These cycles of behavioral change followed by the search for appropriate management strategies then occur iteratively, with continuous adaptive learning as the cornerstone of the decision-making process.

Thus, the ADMP essentially consists of four cyclical, iterative phases, with each cycle facilitating the selection of more appropriate management strategies and helping to change the behavior of the stakeholders. Every cycle provides an opportunity for learning as long as the stakeholders adapt their decision-making processes to the results obtained. In such a process, researchers play a vital supporting role by using their analytical ability and theoretical understanding to aid in identifying useful questions and by using DSS-based interdisciplinary analysis to help stakeholders negotiate desired use and management strategies.

The ADMP is not easy, because conflicts are inevitable between stakeholders with different views about the nature of the problem, expected outcomes, the research and development strategies needed to achieve the outcome, and the scale. The two case studies presented here demonstrate that reaching a consensus is likely to require time, resources, and commitment on the part of the key stakeholders involved.

ACKNOWLEDGMENTS

The origins of the ADMP framework can be found in the two-tiered, macro-environmental standards approach (MESA) adopted in Kosrae by Lal and described in an unpublished (1990) report that later formed the basis of Australian Centre for International Agricultural Research (ACIAR) projects on Integrated Water Resource Assessment and Management (IWRAM) in northern Thailand and the Fiji sugar project. Michelle Scoccimarro is part of the ACIAR Thai project research team, which includes Andrew Walker, Claude Dietrich, Pascal Perez, Sergei Schrieder, Tony Jakeman, and Nick Ardlie. The views and interpretation of the project are those of the authors and not necessarily those of the rest of the Thai project team. Finally, comments from two anonymous reviewers and the editor helped improve the paper, and their inputs are gratefully acknowledged.

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5.

Negotiation Support Models for Integrated Natural Resource Management in Tropical Forest Margins

Meine van Noordwijk[1], Thomas P. Tomich[2] and Bruno Verbist[1]

ABSTRACT

Natural resource management research has to evolve from a focus on plans, maps, and regulations to an acknowledgment of the complex, sometimes chaotic, reality in the field, with a large number of actors making their own decisions. As outside actors, we can only try to facilitate and support a process of negotiation among the stakeholders. Such negotiation involves understanding the perspectives of all stakeholders, analyzing complementarities in views, identifying where differences may be settled by "science," where science and social action can bring innovative alternatives for reconciliation, and where compromises will be necessary to move ahead. We distinguish between natural resource management problems at village level, within country, or transboundary, and those that relate local stakeholder decisions to global issues such as biodiversity conservation. Tree-based systems at plot or landscape level can minimize conflicts between private and public interests in local environmental services, but spatial segregation of functions is an imperative for the core of global biodiversity values. The complex agroforests developed by farmers as alternatives to food-crop-based agriculture integrate local and global environmental functions, but intensification and specialization may diminish these non-local values. For local biodiversity functions, a medium-intensity "integrate" option such as agroforests may

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be superior in terms of resilience and risk management. Major options exist for increasing carbon stocks by expanding tree-based production systems on grasslands and in degraded watersheds through a coherent approach to the market, policy, and institutional bottlenecks to application of existing rehabilitation technologies. Agroforestry mosaics may be an acceptable replacement of forests in upper watersheds, provided they evolve into multistrata systems with a protective litter layer. Challenges to INRM research remain: how should the opportunities for adaptive response among diverse interest groups, at a number of hierarchical levels, be included in the assessment of impacts on the livelihoods of rural people?

KEY WORDS: Indonesia, adaptive learning, adaptive options, agroforests, integrated natural resource management, land-use change scenarios, negotiation support models, quantitative impact assessments, scaling rules, stakeholders, sustainability assessments, tropical forest margins.

INTRODUCTION

Izac and Sanchez (2001) describe the paradigm shift for international agricultural research from a focus on germplasm and technology development targeted at increased productivity, as such, to "integrated natural resource management" (INRM). INRM, in their view, aims to identify land-use practices that increase production while maintaining natural capital and continuing to provide ecosystem services at local and global scales. Once such practices have been identified, their adoption by larger numbers of farmers can be facilitated by a combination of dissemination approaches and changes in policies. The complex agroforests, developed by farmers in the forest margins of Indonesia, form a prime example of systems that combine local and global functionality and in which removal of negative incentives derived from existing policies has become the major target of INRM intervention (Izac and Sanchez 2001, Abel et al. 2002). However, even in this agroforest example, it is not clear why and how farmers can afford to, or are motivated to, care for longer term and externally set objectives, including biodiversity conservation and an increase of terrestrial carbon stocks. The fact that the farmer and external objectives partly coincide in these systems forms no guarantee for the future, if the alignment is "accidental" rather than based on shared values and common perceptions of the likely impacts of change.

Stakeholders other than farmers aim to modify farmer decisions. Although spatial planning and regulations about those land-use practices that are allowed have some impact in countries with strong institutions and good governance, the reality in many tropical countries is otherwise. In common with most "central planning" philosophies, many "development" projects have an overly optimistic view of their possible impact in modifying decisions by millions of rural households and the individuals that constitute them, on how to manage the rural landscape to satisfy their livelihood requirements. Introducing the "natural resource management" terminology, as such, will not make a difference. In this contribution to the debate on international agricultural research support for INRM, we want to focus on:

1. Who are the managers implied in the M of INRM?
2. What is the scale at which the various natural resources can be managed?
3. To what degree can the objectives of the farm household, and other local, regional, national, or international stakeholders, be met by integrated land-use patterns as alternatives to spatially segregated ways of addressing multiple functions of land?
4. How can the various stakeholders overcome the prevailing sense of conflict?
5. How can research play a role by providing negotiation support to the various stakeholders in natural resource management?

The views and concepts presented here were developed in the context of the "Alternatives to Slash-and-Burn" program of research on options for land-use change in the margins of the tropical forests (Tomich et al. 1998*a*, *b*, 2001, van Noordwijk et al. 1998*a*). We will summarize lessons learned in this program, which targets one of the greatest challenges in the debate over global natural resource use: finding ways to conserve the functions and existence of tropical forests while providing sustainable livelihood options for poor farmers in the forest margin.

THE M OF INRM: RECOGNIZING AND SUPPORTING THE MANAGER

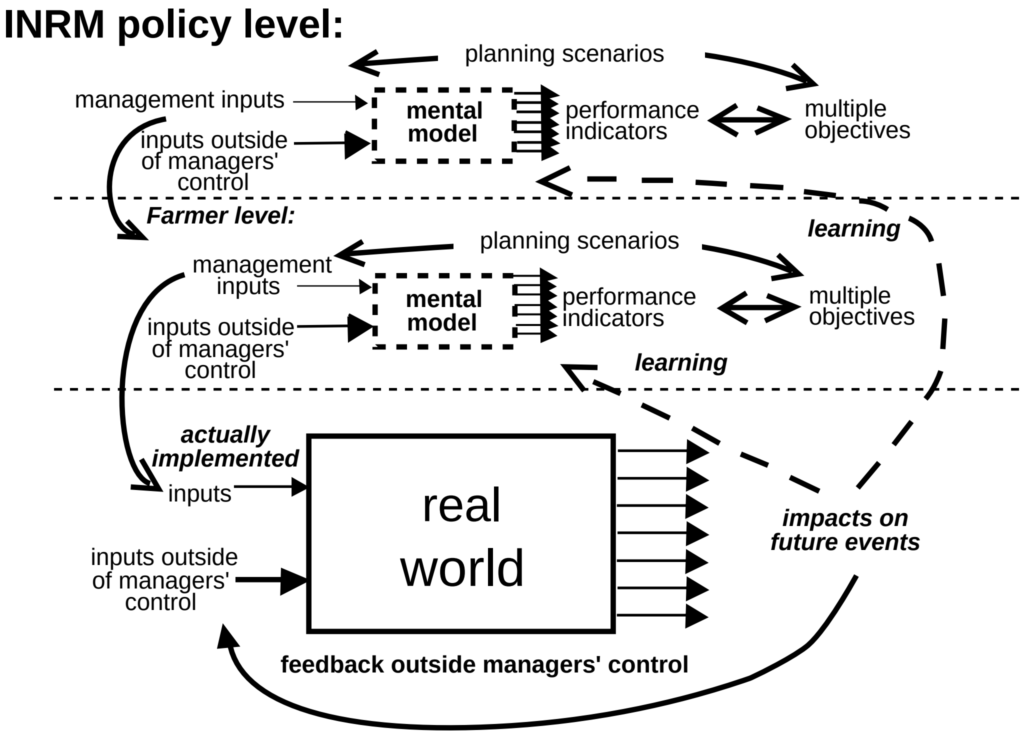
The overall objective of INRM research and development activities is to help managers at various levels do a better job of managing natural resources. We subscribe to the view that "management" of natural resources involves taking and implementing decisions that will modify the way in which the agro-ecosystem functions internally and the way it responds to external factors (Lynam et al. 2002, Cain et al. in press). These management decisions are generally taken on the basis of managers' objectives and a mental model that approximates how certain actions will influence performance indicators of the system (Fig. 1).

In an abstract sense, the various steps in this cycle can summarize the targets of INRM research:

1. Identifying clearer, more realistic, and/or more encompassing objectives, and constructing better performance indicators that reflect the way these objectives are met;
2. Improving the mental models of all managers, based on understanding how outputs and outcomes are related to inputs, and how multiple causes can lead to similar effects; this is the primary entry point for new technologies that enlarge the array of options from which farmers can choose to influence their agro-ecosystem;
3. Making better use of the mental models for planning how to obtain desirable impacts on the multiple management objectives for minimum inputs and management efforts;

4. Improving implementation of these management plans and scenarios;
5. Improving evaluation of the current state of the real world system;
6. Determining how the factors outside the managers' control influence the system; and
7. Learning better how the real world actually responds to the change, including the feedback created by ecological, economic, social, and political interactions within and across scales.

Figure 1. Management of natural resources involves a mental model of how the real world responds to influences by the manager (thin arrow), as well as influences outside the managers' control (thick arrow), and how this overall response is reflected in performance indicators that will (partially) satisfy a set of multiple objectives. The contrast between the expected system performance and objectives may lead to a change in the managers' inputs into the real-world situation. Actual experience may lead to learning, in the sense of modifying the mental model, and changing the scenarios and plans. Because the real world involves many layers of "managers," there will be considerable feedback outside of the managers' control. The diagram shows a "national policy" management level superimposed on a "farmer" management level, superimposed on the real world.



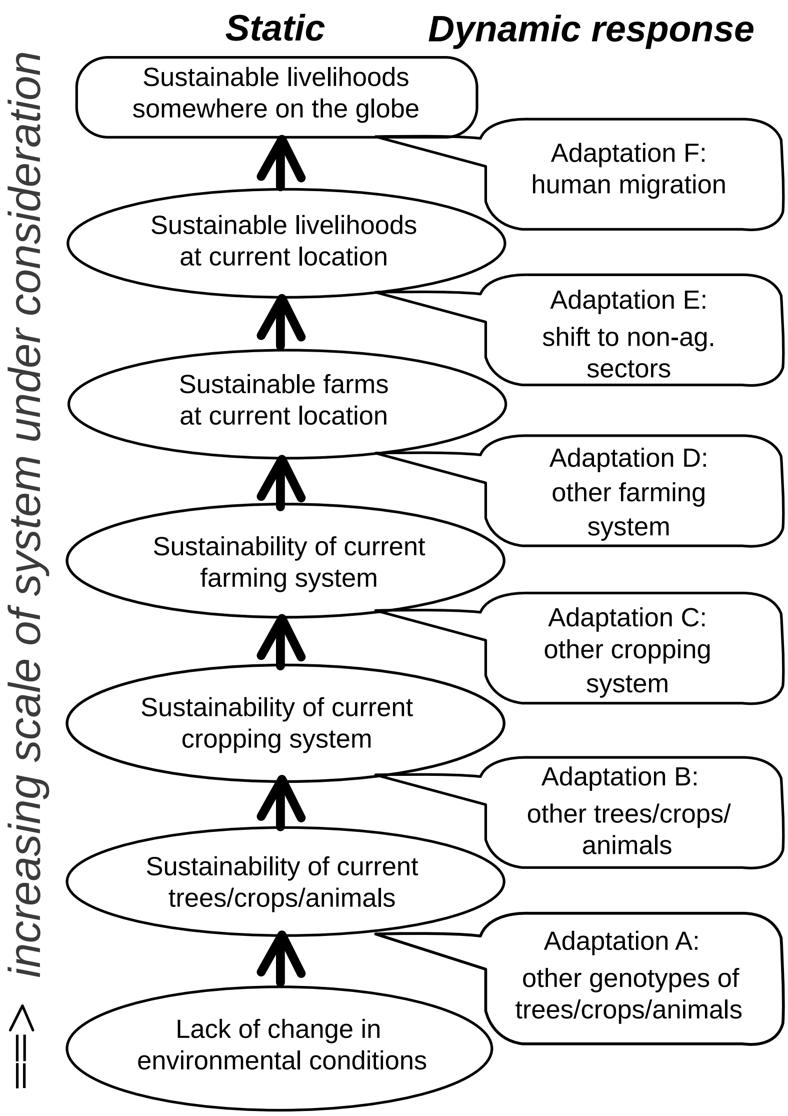
An analysis of the weakest elements in the current management cycle may help us to focus on the domains with the largest potential for immediate or medium-term improvement. Agricultural systems aiming at full control over all factors that influence crop growth for maximum yield require more labor and chemical inputs than systems that, to a certain degree, work "with nature" and can lead to higher returns to labor, better financial performance, and fewer negative environmental effects. Yet, a no-input agriculture (that harvests whatever happens to grow) allows only low returns per hectare and consequent human population densities of hunter/gatherer communities, even though it may lead to quite acceptable returns to labor. Similarly, at the national scale, a paradigm of full control, involving plans, maps, and heavy-handed manipulation of citizen behavior cannot claim much success, nor can a complete laissez-faire approach. The search is for effective and efficient government interventions that incorporate the likely response of decision makers at lower hierarchical scales into the design and implementation of interventions.

In the past, agricultural research has been largely based on designing interventions, such as technologies, germplasm, and external inputs, that lead to a predictable increase in yields in well-defined situations, and on demonstrating the value of these technologies to farmers. This technology approach, based on a "full-control" paradigm, can certainly claim to have had successes. However, it drew criticism because its focus on yield led to an agricultural system with undue negative impacts on sustainability and other performance aspects; had little positive effect on the farmer as a resource manager, in a more complete sense; and worked against the inherent variability and diversity of real systems. The new paradigm of INRM is one of "adaptive learning" by farmers, supported by outside actors who themselves are learning in the process (Tomich 1992, Hagmann et al. 2002). Adaptive learning is closely linked to issues of sustainability.

Sustainability at any level of complexity, from cropping systems to the level of the planet, can be based on the sustainability of its components, or on adaptations, the agility in finding and introducing new components (Fig. 2). Existing sustainability indicators appear to focus on the "persistence" axis, because the adaptive capacities at the levels from crop genotype to farming system are more difficult to assess. Sustainable livelihood options outside agriculture will have to form the escape route for the majority of today's rural population, as it has already done in the "developed" world in response to agricultural transformation (Tomich et al. 1995, Campbell et al. 2002). Research on adaptive capacity must differ in character from that of the sustainability of existing systems. The latter has specific land-use practices as its target and can do experiments and make models of longer term behaviors. Adaptive capacity research has to consider the range of options available and the way in which these options themselves change over time and differ between stakeholders.

Taking the "manager" seriously implies trying to understand the mental model of ecological relationships that underpin farmer resource use and investment/care decisions. An effective toolbox for mapping these mental models now exists (Sinclair and Walker 1998, Walker and Sinclair 1998, Walker et al. 1999). Farmers' ecological knowledge often complements current ecological science in interesting ways, and contributes to decision rules for management, along with many non-ecological factors.

Figure 2. Adaptive capacity as the missing link between sustainability (persistence) at different levels of organization.



THE NR OF INRM: AT WHICH SCALE CAN THE VARIOUS RESOURCES BE MANAGED?

Natural capital consists of many resources, each with its own renewability, dynamics, and movement. Where management refers to a specific spatial domain, movements of resources in and out of this domain set boundary conditions for management. If "scaling up" implies the consideration of larger spatial domains, it is likely that changes in management will be needed at scale transitions. Each type of natural resource may have a typical scale at which it can be meaningfully managed, depending on the patterns of lateral flow relative to the local stocks of the resource (Lovell et al. 2002). This scale, however, depends not only on the resource, but also on the situation. Groundwater may be a resource that is used, replenished, and thus managed at village scale (as in the Zimbabwe example of Lovell et al. 2002), or it may be part of aquifers that span hundreds of kilometers and may have the management complexity of large surface streams and rivers. The spatial correlation of rainfall is relevant for the way in which risks are reduced by access to plots some distance apart (van Noordwijk and Ong 1999), and also for predicting surface run-off and its soil transport capacity at above-plot level (van de Giesen et al. 2000).

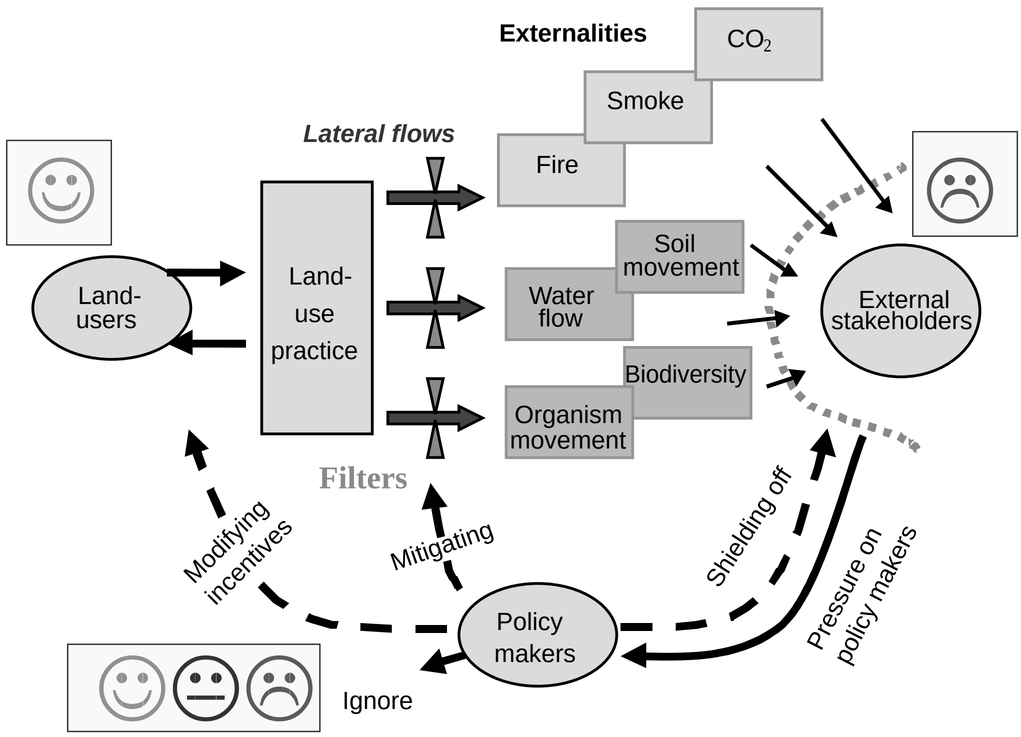
In much work on "scaling up" naïve extrapolations of measurements and management recommendations are made on an area basis. For example, plot-level measurements of sediment loss are translated to statements that "erosion is one of the main causes of nutrient loss from Africa," whereas, in fact, very little sediment reaches the seas or oceans in African rivers. Plot-level erosion leads to a considerable lateral flow, impoverishing soil in one place and enriching it in another (van Noordwijk et al. 1998*b*). Scaling issues, in this sense, critically depend on lateral flows of entities such as organisms, fire, smoke, water, sediment, nutrients, people, money, and ideas, and determine the degree to which the overall scaling relationship differs from area-based ones (van Noordwijk 1999*b*, *c*). Many external effects of land-use change are based on modifications of lateral flows of soil, water, air, fire, or organisms (van Noordwijk et al. in press). To this list we can add people, money, and ideas. Lateral flows imply that area-based scaling is not appropriate. For example, if human migration is defined as people crossing boundaries at village, district, national, or continental scale, the number of migrants, or proportion in the total population, will decline strongly with increasing scale of consideration. At the global scale, migration is zero, just as is net loss of sediment by erosion.

Biodiversity is also a concept with a complex scaling relationship, because the richness of taxonomic or genetic entities at any scale depends both on the richness at a smaller scale and on the degree of similarity between these units (Douglas 1999). The time dimension causes an additional complexity because the objective of long-term survival of populations cannot be directly observed, and has to be inferred from current size of the populations and their internal genetic diversity.

The term "filter" is used here in a generic sense to mean anything that can intercept a lateral resource flow (Fig. 3). Typically, filters occupy a small fraction of the total area and have a large impact per unit area occupied. They can thus be regarded as "keystone" elements of a landscape. Closely coupled to the issue of filters and flows is the question of whether spatial pattern matters for natural resource management. When external impacts of land-use practices derive from lateral flows, the causality of impacts on external stakeholders of plot-level land-use decisions is complicated. Conserving or establishing filters to intervene in such lateral flows may provide attractive options to mitigate the impacts, compared with elimination of the "root cause."

Examples of this type of "mitigation" can be found in the filtering and temporary storage of CO_2 in terrestrial ecosystems that slows the rate of increase of the atmospheric concentration due to fossil-fuel use. It is also seen in the impact of riparian filter strips that mop up the flows of excess nutrients from intensively used agricultural land and reduce their "downstream" impact.

Figure 3. Schematic representation of how lateral flows and filters complicate the cause–effect relationships between plot-level activities (managed by land users on the basis of their objectives) and external stakeholders. There are many options for reducing the impacts on external stakeholders.



Key questions on the way filters function in natural resource management are:

1. How effective are different types of filters for intercepting flows?
2. How quickly will they saturate under high inflows?
3. How fast can the filters regenerate between events?
4. Do filters have a direct value and can they be treated as a separate "land-use practice"?

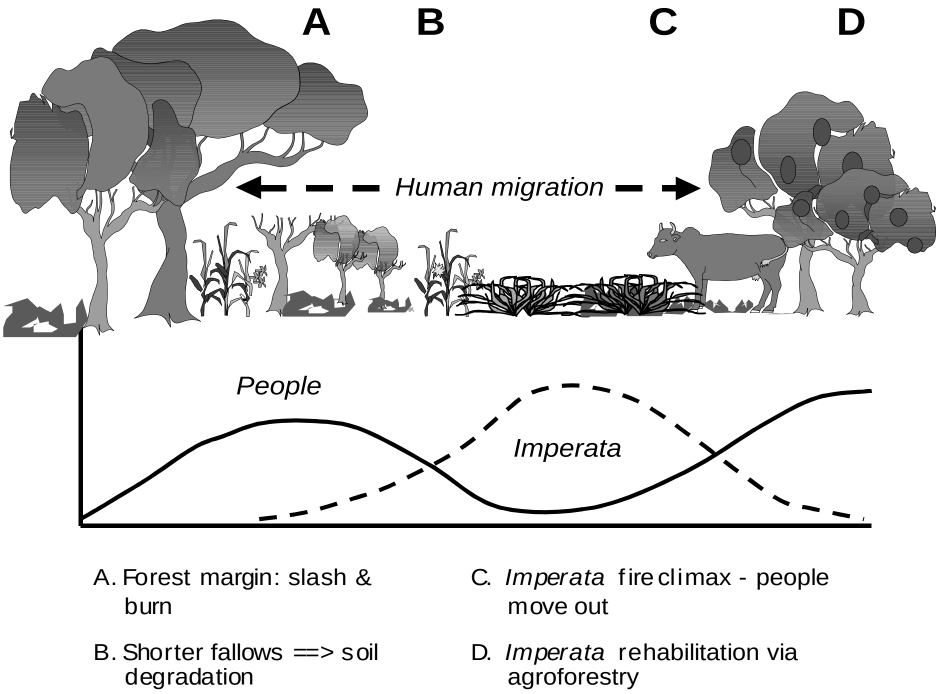
Institutionally, landscape filters may require special attention in natural resource management. Private resource access is hard to secure for linear elements in the landscape far from home and potentially external to the enterprise. Nobody will plant fruit trees in vegetative filter strips along streams, even if they contain fertile soil and have a favorable water supply, unless local institutions secure access to the fruits of those trees.

The lateral flow, or migration, of people is one of the main conditioning factors in natural resource management at scales relevant for policy. People moving into and extending the forest margin are a major source of land-use change, with potentially desirable political and economic connotations for a central government, but may also lead to rapid loss of environmental service functions from a national, regional, or global perspective. Generally, four phases can be recognized in the changes of forests, through a degradation stage to a rehabilitated landscape where planted trees reappear (Fig. 4). Rules, such as taxes and administrative restrictions on the sale of logs and wood, aimed to reduce the forest degradation stage, may be a major constraint in the rehabilitation stage, as they reduce the incentives to plant trees. Unfortunately, this relationship applies particularly to indigenous trees, rather than to introduced species. There has been much debate on the conditions under which the availability of options for more intensive use of agricultural or degraded lands can reduce the pressures on forest conversion (Jepma 1995, Kaimowitz and Angelsen 1998, Tomich et al. 2001). The "Alternatives to Slash-and-Burn" program was built on the expectation that such a relation indeed exists.

THE I OF INRM: INTEGRATE OR SPATIALLY SEGREGATE FUNCTIONS?

For most land-use and natural resource-management problems, both "integrated" and "spatially segregated" solutions exist, and each may have appeal to different stakeholders (van Noordwijk et al. 1997*a*). Although "integration" has a general appeal, similar to that of "agroforestry," critical analysis is needed to decide whether it is really superior to segregated solutions. Similarly, agroforestry as a science has its roots in the often naïve expectations that close associations between trees and crops can not only serve multiple functions, but also serve these functions better than can a spatial segregation of agriculture and forestry. With an increased understanding of competition that typifies many of these intimate mixtures (Sanchez 1995), the definition of agroforestry and the focus in agroforestry research have evolved

Figure 4. Schematic land-use transformations from forests ("more people, fewer forest") via *Imperata cylindrica* grasslands to rehabilitated lands with various agroforestry options ("more people, more trees") (after van Noordwijk 1994).



from plot-level interactions between trees, soils, crops, and animals, to the way in which landscape elements, including trees and forest patches, interact to produce local as well as external "environmental service functions."

For some of these environmental service functions, however, a spatially segregated approach may be better (van Noordwijk et al. 1995). Again, lateral flows and filters are the key to recognizing the options for landscape-level integration of functions that are not compatible at plot level (van Noordwijk and Ong 1999). For example, where high nutrient supply to agricultural crops is not compatible with quality standards for surface or groundwater, a nutrient filter of vegetation around streams and ditches may lead to an acceptable solution. Where crops use less water than the natural vegetation they replaced, and where increased groundwater flows create problems of salinization, as in Western Australia, introduction of trees in specific zones may help (Lefroy and Stirzaker 1999). However, parts of the "charismatic megafauna" of tropical forests, such as tigers or elephants, are not compatible with human objectives in agroforestry, and a clearer spatial segregation is necessary for combining agriculture and biodiversity conservation (Nyhus and Tilson in press).

The first step in the segregate-or-integrate analysis is to define the trade-off function between the degree to which the various pairs of objectives can be met, similar to the practice in analysis of intercropping systems. Concave curves on such a biplot always lead to the conclusion that it is better to segregate the components; convex curves suggest that a combination of functions can indeed be attractive (van Noordwijk et al. 1995, van Noordwijk and Ong 1999). Where the two functions compared have different scale relationships, the shape of the trade-off curve will change. The relative merit of integrated vs. spatially segregated land-use options is essentially a question of scale.

INRM RESEARCH ON ALTERNATIVES TO SLASH-AND-BURN IN INDONESIA: AN EXAMPLE

The original Alternatives to Slash-and-Burn (ASB) perception of the problems in the tropical forest margins was that "poverty causes people to migrate to the forests, but they don't know how to manage the soils and are forced to move on to open new forest, leaving a trail of degraded lands behind." This perception of the problems led to the "Phase 1 hypothesis" that "intensifying land use as an alternative to slash-and-burn can reduce deforestation and poverty." This hypothesis has a local variant in the forest margin. Here, the "more people, less forest" trend can be modified by more intensive forms of agriculture and a landscape-wide action, where stimulating the "more people, more trees" stage may reduce the migration flows into the forest margin and thus contribute to forest conservation (Fig. 4).

The main conclusions of the research in Indonesia (van Noordwijk et al. 1995, Tomich et al. 2001) have been:

1. There is little evidence that the original perception holds true; unsustainable systems used by recent migrants are mostly found under the government-sponsored transmigration programs, which are planned at government level, rather than growing from spontaneous poverty-driven, land-use practices.
2. Farmers have developed agroforests, based on rubber, resin, and other local or introduced trees, as sustainable and profitable alternatives to food-crop production based on slash-and-burn techniques.
3. This opportunity, however, has stimulated rather than slowed down forest conversion in the absence of active boundary enforcement mechanisms for natural areas.
4. In mountain zones, opportunities for migrant farmers to privately plant profitable tree crops such as coffee and cinnamon have hastened forest conversion, with variable effects on forest functions.
5. Current forest conversion is a combination of logging, large plantation-style projects, government-sponsored migration, and activities of both local and recent migrant smallholders. Much of the conversion is planned and sanctioned by government and is encouraged by public policy; small remnants of "shifting cultivation" remain in Sumatra,

but largely in the form of settled fallow rotation, and these do not lead to significant land degradation and people moving onto new forest margins.

6. The land-use systems that follow forest conversion differ significantly in their sustainability, profitability, and impacts on carbon stocks, greenhouse gas emissions, and biodiversity.
7. Although agroforests can maintain part of the biodiversity of the original forests, they are clearly no substitute for full protection of biodiversity in dedicated natural areas and conservation reserves.

The main activities can be summarized (Fig. 5) in the general framework of natural resource management research (Izac 1998, Izac and Sanchez 2001). After quantifying the way in which various land-use alternatives can meet a wide range of criteria that reflect local, regional, national, and global interests, the analysis of trade-offs helped to identify a number of natural resource management conflicts that will require negotiation between stakeholders.

CONFLICTS AND THE NEED FOR NEGOTIATIONS

Conflict management entails clarifying the options from all perspectives, searching for mutually acceptable options or negotiating compromises, monitoring the outcomes, and enforcing compliance. Three types of natural resource management problems can be identified in the margins of tropical forests.

Problems at local level (upland/lowland): watershed and landscape ecological services

Conflicts between local and downstream stakeholders following forest conversion are evident throughout Southeast Asia. Yet some forms of spatial integration of “forest” and “agricultural” functions may fulfill the needs of downstream land use. The conflicts may be based, in part, on misperceptions of forest hydrological functions (Calder 1999) that lead to enforcing rules for “watershed protection forest” outside the domain where it is truly functional. Our key hypothesis in this category of problems is that complex tree-based, integrated systems, at plot or landscape level, provide an opportunity to minimize conflicts between private interests (in production/profitability of land use) and public interests in local environmental services (hydrology, ecology, air quality).

Global–local conflicts of interest in biodiversity conservation

Our key hypotheses in this domain are as follows. For core biodiversity values (including charismatic megafauna), spatial segregation of functions is an imperative, requiring socially acceptable ways of protecting conservation areas. For local biodiversity functions, a medium-intensity “integrate” option, such as agroforests, may be superior in terms of resilience and risk management.

Figure 5. Schematic representation of steps in "integrated natural resource management" taken by the "Alternatives to Slash-and-Burn" (ASB) program in its Indonesian benchmark sites.

Problem analysis

- Rapid conservation on the margins of tropical forests, leads to loss of biodiversity, carbon release into the atmosphere, smoke & haze problems, impacts on watershed functions
- Part of this forest conversion is ***poverty***-driven; life in the forest margin is full of risk; strong perceptions on forest squatters prevail and they have little or no voice in the public debate
- Local solutions that appear to be promising, such as the complex agroforests that have replaced crop-fallow rotations, are not recognized at policy level; current ***policies*** may hinder these solutions and aggravate problems

==> Need for integrated analysis of impacts of broad range of land-use alternatives on local, national and global benefits

Enhanced biological productivity

- For locally relevant representatives of major land-use systems, develop descriptions of productivity on a 25-year time frame, labor and other inputs
- Tests how exiting 'improved' tree germplasm can be used and what the constraints are
- Tree * site matching in rehabilitation of degraded lands
- Support farmer experiments on agroforest rejuvenation

Enhanced human well-being

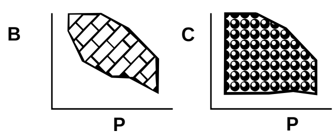
- Risk in forest margins is linked to vertebrate pests, fire, insecure resource access rights and economic shocks; diversity plays a role in managing these risks
- Farmers get a voice in discussions at local policy level, as follow up to participatory surveys
- Reviewing policy constraints on tenure arrangements, securing access under certain restrictions, obtaining recognition for farmer-development options

Enhanced ecosystem integrity and resilience

- Quantification for all land-use categories of their impacts on plot-level above- and below ground biodiversity, time-averaged carbon (C) stocks
- Quantity impacts on water use and sediment flows
- Sustainability indicators that include nutrient cycling and soil organic matter studies
- Quantify smoke production during forest conversion

Analysis of trade-offs, range of flexible options

- Matrix format for synthesizing all attributes of major land-use options
- Analysis of trade-offs, e.g. Biodiversity * Productivity * C-stock
- Zoom in on trade-offs *within* the most promising land-use categories
- Analyze other factors influencing decision making on promising land-use options



Outcomes and feedback

- Policy dialogue at local and national scale on the main outcomes, leading to identification of entry points for intervention
- Policy recognition for agroforests
- Review of trade policies and taxes on farmer-grown trees
- Support to negotiations among stakeholders in access to state forest land and watershed functions
- Analysis of policy options for managing fire and smoke
- Re-evaluation of re-settlement policies
- Re-orientation of existing extension services to appreciate farmer-developed options and resource integration.

Because there is indeed no substitute for spatial segregation of many endangered species and people, socially integrated mechanisms are needed for stabilizing boundaries of conservation areas. These would include tools for conflict management and actual compensation mechanisms based on agreed performance criteria. Stabilizing physical boundaries of protected and reserved areas implies providing farmers, extractivists, and hunters elsewhere with livelihoods at least as good as they could expect in their current situation, or providing shifting incentives toward sustainable use. There is a lack of proven means for either approach.

Major unresolved issues also remain in the relationship between species richness and ecosystem function from a local perspective. Farmers are most likely to perceive reasons to maintain complex and species-rich agro-ecosystems if the direct use value of each element per unit of resource use is approximately the same.

Where past germplasm development efforts focused attention on "priority" elements, they are likely to have increased the contrast in value among the components of the system, and thus to have undermined the rationale for maintaining agrodiversity (van Noordwijk and Ong 1999).

Global–local conflicts between global interests in carbon stocks and local interest in conversion of forest for more profitable land uses

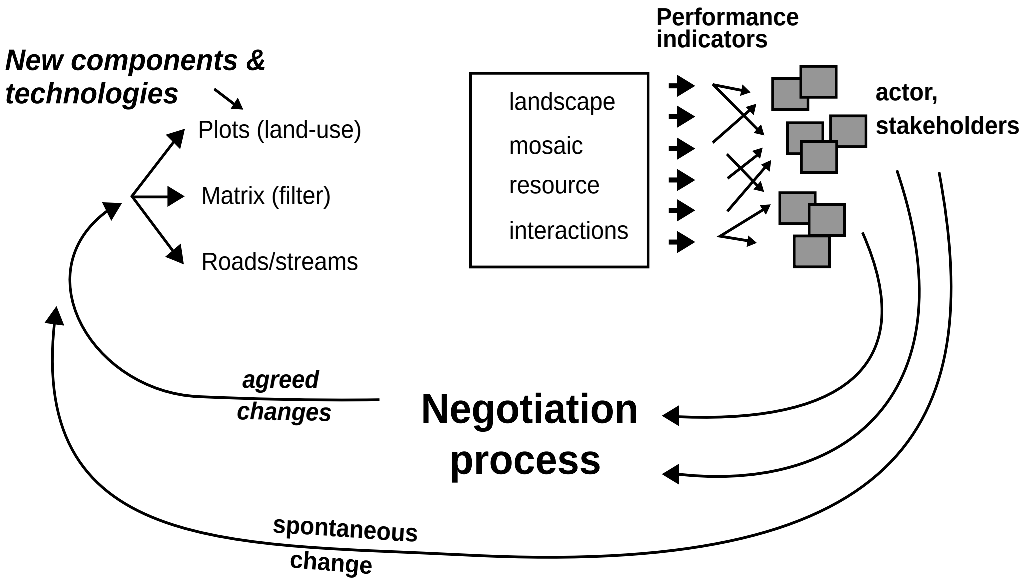
Evidence from ASB suggests that, for the combined objectives of increasing carbon stocks and annual food-crop production, a "segregate" option is superior if it allows for maintaining high carbon stock areas (including peat swamp forests) intact, and intensifying production elsewhere (van Noordwijk et al. 1997*b*). For the combined objectives of farm profitability and carbon stocks, however, production systems based on tree crops provide a sensible "integrate" option. The key hypothesis is that major options exist for increasing carbon stocks by expanding tree-based production systems on grasslands and in degraded watersheds through a coherent approach to the land tenure, market, policy, and institutional bottlenecks to the application of existing rehabilitation technologies.

This type of INRM issue implies (1) a need for institutional and policy reform to eliminate existing disincentives for planting trees, and (2) a need for compensation mechanisms or other means to increase incentives for planting trees.

HOW DECISION SUPPORT EVOLVES INTO NEGOTIATION SUPPORT

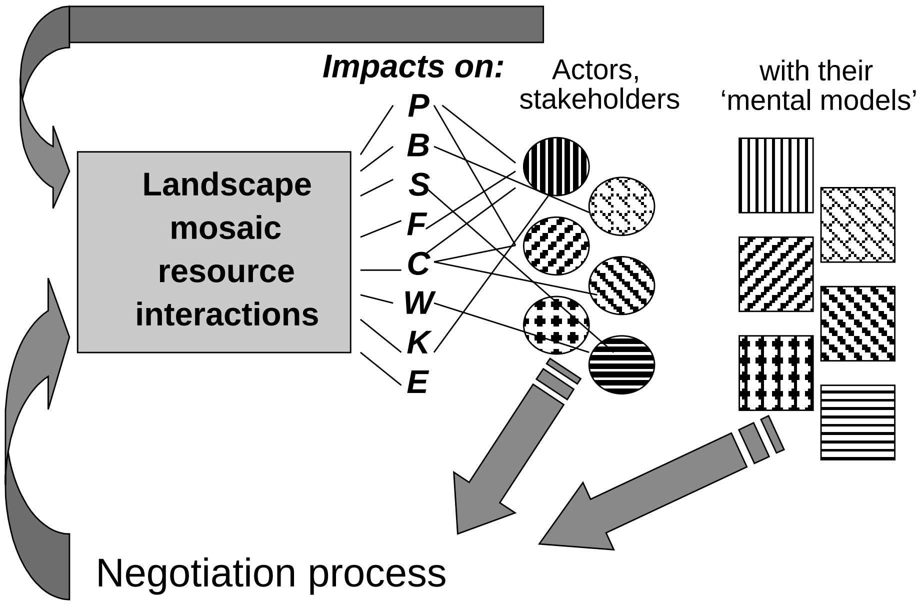
The real-world human impact on natural resources derives from a large number of individual decisions, made with different access to sources of knowledge and information, with different technical means to organize exploitation, and with different objectives, constraints, priorities, and strategies. The best we can hope for is a process of negotiations among stakeholders that leads to modification of the individual decisions to produce superior outcomes from the broader social perspective (Fig. 6).

Figure 6. Schematic representation of the main elements of natural resource management "action research." This approach relates the predicted impacts of landscape-level changes in land use, channels, and/or filters to the range of performance indicators that is considered to be relevant by the actors and other stakeholders of this landscape. It facilitates a process of negotiation that may lead to changes in the way actors manage various parts of the landscape.



The term "decision support model" may suggest that a single management entity will seek a solution that optimizes the way in which multiple objectives can be achieved, and then will make decisions to be imposed on the various actors and stakeholders. We prefer the term "negotiation support models" for constructs that help to obtain a common perspective on the "if this, then that" relationships for a range of possible future landscapes. To function adequately, the "negotiation support model" itself will have to be the subject of negotiation and shared development efforts among stakeholders (Fig. 7). In this view, the main role of research and development organizations is to help in developing the tool as a predictive system, as well as in the process of stakeholder consultations and negotiation, acknowledging the existing inequity in access to resources and information, wealth, political power, and social status (Lynam et al. 2002, Cain et al. in press).

Figure 7. Modified scheme (compare with Fig. 6) indicating that all stakeholders, including the researchers, will enter the negotiations with their own mental models of the real world and the impacts of activities on the performance indicators in which they are interested. These indicators include: *P,* productivity or profitability; *B,* biotic interactions or biodiversity; *S,* sustainability; *F,* fire or smoke; *C,* carbon stocks and net emissions of other greenhouse gasses; *W,* watershed functions or the regular supply of clean water; *K,* knowledge that can be used to update the various mental models; and *E,* ethical or aesthetic values.



INTEGRATED MODELS

During the first two phases of the ASB project, it became clear that "watershed protection functions" of forests and the way in which they change after forest conversion are a major source of conflict in Southeast Asia (Tomich et al. 1999). Because these issues are based on the lateral flow of water and sediment, they have challenging scale relationships and involve distances beyond those at which local institutions can be expected to cope (Lovell et al. 2002). Because several hierarchical layers of stakeholders are involved, a complex negotiation process is likely to be necessary, and a model of how the real-world landscape functions may be a helpful tool in this process.

Integrated system models can first serve as a common framework of analysis that clarifies the type of information required from the various participants of the research program. Second, and perhaps more important for the implementation phase, is the function as a discussion tool. Different scenarios outlined by the various stakeholders can be clarified qualitatively in a first approach. Possible future changes can be examined and discussed, possibly generating the basis for overcoming present conflicting interests to obtain a better collective future. Disciplinary research can offer the necessary "building blocks" to make quantitative simulations with a certain probability and precision. In the development of simulation models, a "top-down" approach that starts with the overall problem and gradually adds detail as required can be distinguished from a "bottom-up" approach that starts with available knowledge and insights on component behavior and seeks integration and "emergent properties" at a higher level of integration.

Some progress has been made, e.g., by the FLORES group using a "bottom-up" approach to model development (Vanclay 1995). A village-level model of shifting cultivation (FALLOW; van Noordwijk 1999*a*, in press) also builds up landscape-level predictions from the way in which households are supposed to manage the various plots within the simulation domain. Explicit scaling relationships can be built into such an approach. Many issues remain unresolved, however, especially regarding the amount of detail required to simulate individual decision-making processes and the collective action within and among rural communities. A diversity of approaches may also be needed to provide options for location-specific attempts to develop a support model for locally relevant natural resource management negotiations.

A top-down approach using a system description, which still allows for the incorporation of individual stakeholders' interests, was taken for the development of a modeling framework for coastal zone management near Ujung Padang, Sulawesi, Indonesia. The RAMCO-model (Rapid assessment for management of coastal zones; de Kok and Wind 1999) is based on conceptual guidelines provided by Randers (1980), Miser and Quade (1985), and de Kok and Wind (1999). It recognizes eight distinct steps for the design and use of integrated models for policy analysis.

1. Problem formulation, which should include at least one problem definition, its boundaries and constraints, and the various values and criteria used by respective stakeholders.
2. Generation of alternatives.
3. Qualitative system design, which involves the development of a causal relationship diagram or system diagram (see Fig. 8).
4. Quantitative modeling.
5. Model implementation.
6. Model validation (return to steps 3, 4, or 5, as needed).
7. Ranking of alternatives from various stakeholder perspectives.
8. Stakeholder negotiations on the consequences of the various alternatives (return to step 2, if new ideas arise).

The general problem in the new ASB benchmark area in Sumber Jaya, the upper Tulang Bawang watershed in Lampung (Sumatra, Indonesia) can be defined as the perception of unsustainable use of natural resources, leading to conflicts over land use and access rights. A stakeholder analysis is being carried out to confirm or discard some of the initially identified issues and thus to frame the questions that the negotiation support model should try to answer.

The apparently contradictory objectives of the stakeholders in this conflict can be formulated in terms of the values that are considered relevant for watershed management. On the basis of these values and criteria, a more concrete problem definition, and the boundaries and constraints of various alternatives, can be generated, including an initial compilation of the perceived causal relationships. Research to map the "mental models" of all participants in the negotiations, as illustrated in Fig. 7, can help to clarify the service that each stakeholder can actually expect from the watershed. The mental model of a model-builder (an example is given in Fig. 8) needs to be completed and verified with the mental models of the various other stakeholders.

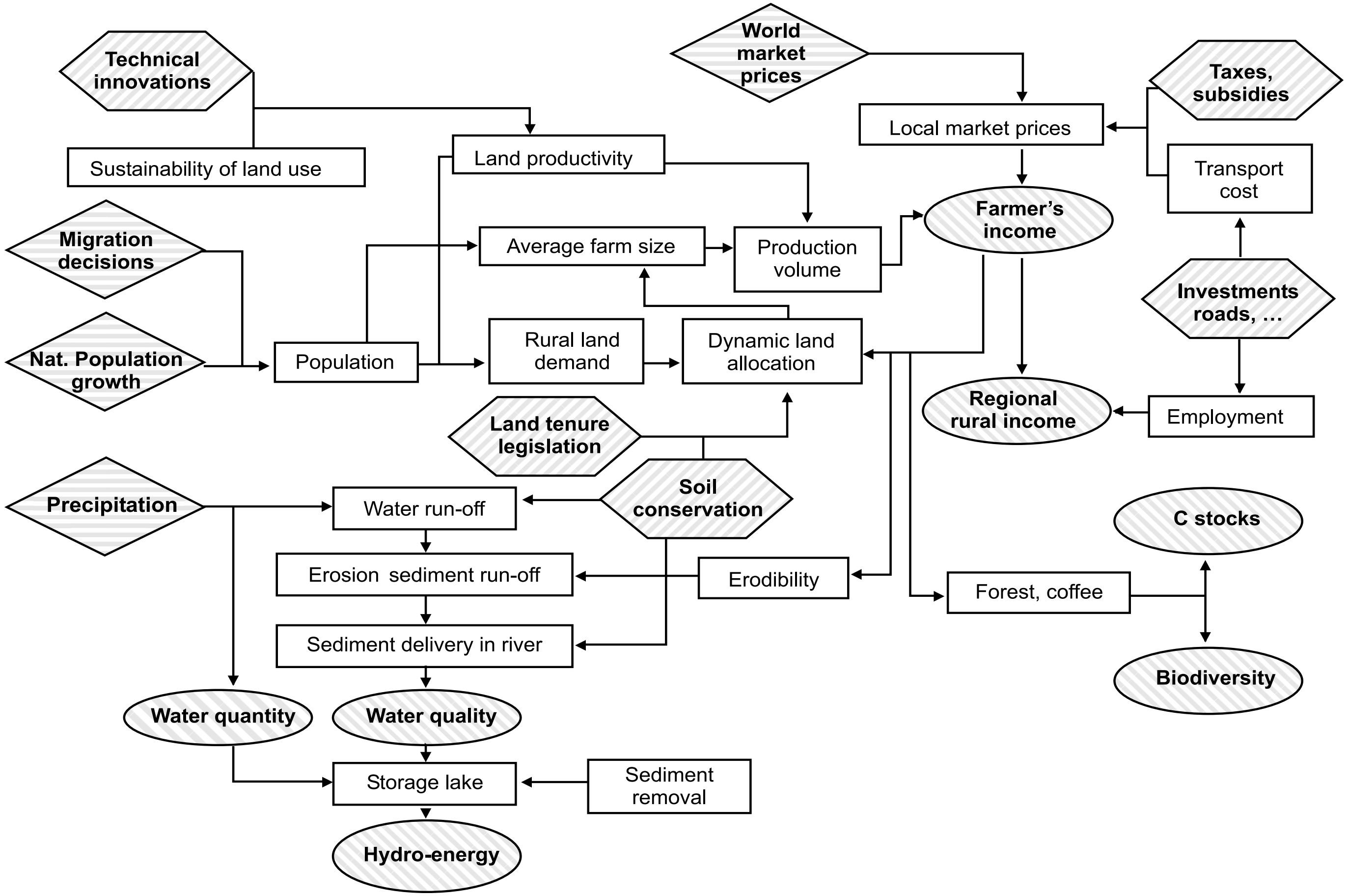
Different "what if" scenarios, based on stakeholder inputs and feedback, will allow an exploration of various possible options. Scenarios need to be developed for fewer or uncontrollable, external parameters such as migration, world market prices, or precipitation. The main objective of this model building is to put stakeholders on a more equal footing and thus help them in negotiating an agreement over future resource use and access rights. The social process to achieve this objective requires a series of confidence-building experiences and a political climate of openness that only recently has developed in Indonesia. The modeling and social interaction will have to be iterative and parallel (not serial), adaptive-learning processes, contributing to the stages of problem definition, evaluation of options, negotiation, and implementation and monitoring of agreed-upon solutions.

CONCLUDING REMARKS

Integrated natural resource management research and development efforts should lead to tangible impacts on the ground. If, however, we continue to evaluate the "impact" of our research and development involvement simply on the basis of the spread of specific technologies, we are likely to misdirect our efforts. Supporting farmers as managers may mean that informed non-adoption or adaptation-beyond-recognition may be better signs of success than adoption of well-defined practices in a context in which social pressure plays a role. If improving the ability of natural resource managers at all hierarchical scales is our target, we should measure our success and failure accordingly, based on the adaptive learning capacity and the way in which we can help to expand this.

The Sumber Jaya case study is still in an early stage and will form a laboratory for INRM research and development efforts. Ultimately, we subscribe to the naïve, positivist view that the quality of decisions and negotiations can be improved by providing better, not necessarily more, information to the various stakeholders so that more alternatives can be generated and evaluated. This optimistic view may not be supported by reality, where, too often, solutions are selected that bear no relation to the officially stated objectives or to the problem. More equal access to information for the various stakeholders and a process in which transparency becomes a requirement in public debate, are essential if the information that we contribute is to be of actual value in the negotiation process.

Figure 8. Initial system diagram of relations in the Sumber Jaya ASB benchmark area in Indonesia; shaded diamonds indicate external variables; shaded hexagons indicate management options for some of the stakeholders; shaded ovals represent key impacts. This qualitative diagram will have to be verified with the various stakeholders. The next steps are the quantitative modeling and a strength–weakness analysis of the various processes.



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6.

The Question of Scale in Integrated Natural Resource Management

Chris Lovell[1], Alois Mandondo[2] and Patrick Moriarty[3]

ABSTRACT

Lessons from integrated natural resource management (INRM) practiced at different scales are reviewed, with a focus on catchment management. INRM is complex, and many interactions have to be addressed. Consequently, the scale of investigation can restrict the generality and utility of the findings. Examples show that temporal, biophysical, and institutional scales can each be critical. Contexts and dynamics associated with particular scales, and interactions or lateral flows that become important with increasing scale, also pose serious challenges. A conceptual framework is presented for scaling issues in INRM and how to deal with them. To benefit many people over large areas within sensible time frames requires considerable political will, investment, and strategic planning from the outset. Only then will an enabling environment be created to meet a range of preconditions identified in previous studies of integrated catchment management, watershed development, common property management, and devolution. This paper focuses on the links between the organizational/human aspects and the biophysical/technical perspective of various scaling issues. In particular, there is a need to reconcile current top-down and bottom-up approaches, both of which are needed to achieve effective delivery in structured programs beyond the scale of a few villages or isolated success stories. Options for bridging this gap are discussed and recommendations are made for research that might be undertaken. Action research is recommended to enable learning-by-doing, and should

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focus at two levels: strategic studies to help create the political and institutional landscapes required for scaling-up; and specific studies of gaps in knowledge, in particular, programs that account for scale issues. These suggestions are illustrated using the example of groundwater management via nested scales of interdisciplinary research.

KEY WORDS: common property management, community-based natural resource management, devolution, going to scale, integrated catchment management, integrated natural resource management, integrated water resource management, participatory watershed development, scaling-out, scaling-up, spatial scale, temporal scale.

WHY FOCUS ON SCALE?

In many countries, governments and development agencies are turning to integrated natural resource management (INRM) as a means of safeguarding the natural resource base and improving agricultural productivity. In national planning, integrated catchment management and integrated water resource management are now synonymous with "integrated management" of land, water, and forest resources at river catchment scales, typically 5000–500,000 km^2. The boundary ascribed in this case is always the physical watershed, or the boundary of the catchment.

In contrast, INRM is also being promoted with community groups and, in some cases, even with individual farmers through community-based natural resource management of common-property, open-access, and privately owned resources in micro-catchments, typically only 5–50 km^2. Social boundaries prevail, and many so-called "watershed development" projects are being undertaken at this scale in developing countries, primarily through nongovernmental organizations (NGOs).

INRM is also central in current thinking on poverty alleviation. The Sustainable Rural Livelihoods Framework (Carney 1998) seeks to improve the lives of poor people and to strengthen the sustainability of their livelihoods. It aims to help people understand and manage the complexity of rural livelihoods through holistic analysis of the five different types of capital asset (natural, manufactured, human, social, and financial), upon which individuals and groups draw to support themselves. INRM is thus being promoted at a very wide range of scales. In all cases, it seeks to address whole agroecosystems, which, by nature, are complex. Thus, many interactions have to be addressed (Campbell et al. 2001).

Gonsalves (2000) defines "going to scale" as "bring[ing] more quality benefits to more people over a wider geographical area more quickly, more equitably and more lastingly." If INRM is to go to scale, this raises the thorny question of making trade-offs between these five quality dimensions of capital, because there are many interactions across scales that must be addressed. This paper is prompted by the growing realization that many people, when working across natural scales of space and time, do not always appreciate the full extent of problems associated with scaling, or the implications when interpreting their results. The objective of this paper is, therefore, to highlight some selected conceptual, as well as practical, issues of scales and scaling in INRM, and to present a conceptual framework for dealing with these issues.

As noted by Schulze (2000), scaling in the fields of hydrology and ecology has been comprehensively reviewed in the past five years, through the many contributions to recent special journal issues of, for example, the *Journal of Hydrology*, *Water Resources Research*, *Hydrological Sciences Journal*, and *Hydrological Processes.* It has also been addressed in other publications by Schulze (2000), Harvey (1997), and Jewitt and Gorgens (2000), the recurring contributions by Beven, Wood, Bloschl, and Becker in the peer-reviewed literature, and in recent books edited by Feddes (1995), Kalma and Sivapalan (1995), Stewart et al. (1996), and Sposito (1998). In the fields of economics, environmental sustainability, and organizational development, seminal analyses of scaling have been provided by Schumacher (1973), Adams (1990), Ostrom (1990), Holling (1993), Lee (1993), and Murphree (2000). Drawing on the lessons from these previous analyses where possible, this paper considers scaling issues that arise in INRM, particularly the disjunction between current top-down (predominantly technical) national programs and bottom-up (predominantly social/ institutional) community-level projects. Three questions underlie the paper:

1. Under what conditions is INRM likely to be successful and to go to scale?
2. What can be done to increase the probabilities of success?
3. What kind of INRM research is needed?

The paper begins by considering why scale and scaling issues arise in INRM. It then presents a conceptual framework for dealing with these issues, using practical examples from around the world to support the logic. The paper concludes with a discussion of the need to reconcile current top-down and bottom-up approaches and the role that research might play in this process.

WHY DO SCALE AND SCALING PROBLEMS ARISE?

"Scale" is defined in the *Oxford English Dictionary* as "relative size or extent." It is a characteristic dimension (or size) in either space or time or both, of an observation or a process, or a model of that process (Jewitt and Gorgens 2000). Intuitively, it is an indication of an order of magnitude rather than a specific value (Schulze 2000).

"Scaling" (up or down), on the other hand, represents the transcending concepts that link processes and actors at different levels in time and space. Scaling, therefore, entails changes in processes and actors, upward or downward, from a given scale of observation. It recognizes the interconnectivity of scales and includes the important constraints, interactions, and feedback (lateral flows) that may be associated with such changes in scale. Included in the concept of scaling are changes in spatial and temporal variability, in patterns of distribution, and in sensitivity (Schulze 2000). Scaling thus goes beyond simple aggregation (up) ("scaling-out," or extrapolation of approaches to sites with similar characteristics) or disaggregation (down) of results at one scale to achieve results at a more desirable scale.

Natural and anthropogenic systems display considerable heterogeneity, which influences the type of processes that dominate and the rates at which they occur. These systems are also hierarchical, with much feedback occurring across overlapping scale spaces (Schulze 2000). Scaling problems related to time, space, institutions, and environments have been addressed by a number of researchers who have proposed various solutions (Table 1). This information can be presented in the form of a conceptual framework or strategy (Fig. 1) to deal with scaling issues in INRM, primarily through very careful problem analysis, coordination of civil and professional science, and iterative learning. The practical examples that follow are provided to support the logic for this conceptual framework.

Table 1. Scaling issues related to time, space, institutions, and environments, and how to deal with them.

Scaling problem	Solution	Further reading
General		
Focus on a single scale may obscure important processes that only become obvious at either finer or broader scales.	Ask questions about cumulative impacts on a broader scale than that being studied. Examine large-scale impacts on a smaller scale.	Schulze (2000)
Temporal		
Change within natural systems occurs at different rates.	Analysis should focus on the interactions between the slow and fast phenomena and monitoring should focus on long-term, slow changes in structural variables.	Holling (1993)
Process scales may be episodic (e.g., rainfall), cyclical (e.g., rainy season, long-term rainfall cycle), stochastic having a certain recurrence interval (e.g., a 1 in 10 year drought occurrence), ephemeral (e.g., stream flow) or continual (e.g., groundwater movement).	The observation scale at which samples are collected and phenomena studied should match the scale at which the processes are taking place. Ideally the process should be observed over a wide extent with high resolution and fine grain to allow any signal within the process to be observed at the appropriate time scale.	Bloschl and Sivapalan (1995); Jewitt and Gorgens (2000); Schulze (2000)
Spatial		
Process scales exhibit spatial extent (e.g., the area over which the rainfall occurred), space period (e.g., the area over which a certain rainy season occurs) and correlation space (e.g., the area over which the 1 in 10 year drought left its mark).	As above, match the observation scales to the process scales.	Schulze (2000)
Dominant processes and physical laws change with scale.	Observations should be made at the scales at which the processes and physical laws are taking place.	Wood and Lakshmi (1993); Harvey (1997)
One process may dominate the response (e.g., rainfall distribution may dominate over land use or institutional performance).	Identify the dominant spatial forcing function of response and observe over a wide extent with high resolution and fine grain.	Bugmann (1997); Schulze (2000)

Table 1. *Continued*

Scaling problem	Solution	Further reading
The elements in a natural system respond non-linearly at different rates, according to different threshold scales and lags, and with varying degrees of feedback.	Isolate those significant elements that explain both the signal and the variance in the response.	Becker and Braun (1999); van Noordwijk et al. (this volume)
Institutional		
The assignment of jurisdiction over particular assets and functions across a spectrum of issues, which may range from local to global.	Strong local jurisdictions, affected by genuine devolution. Jurisdictions no larger than necessary (at levels where such collective problem-solving makes most sense and has most autonomy). Aggregation through negotiated and reciprocal interest and interaction when ecological and functional scale imperatives require larger jurisdictional reach. Jurisdictional size matched to resource base. Constituent accountability. All this takes time and evolution.	Lee (1993); Williams (1998); Murphree (2000)
Jurisdictions imply boundaries, which may be spatial or resource-specific, overlapping or nested in larger systems.	The boundaries should be social, with specification of who has responsibility, who has authority, who has appropriative rights, and what the limits of these rights and responsibilities are.	Lee (1993); Williams (1998); Murphree (2000)
Two contrasting policy thrusts: "big government" (comprehensive authority located at a few nodes across the spectrum of expanding scale requirements) and "small is beautiful" (an approach that seeks to place jurisdictions at local or community levels).	Both are needed. Community-level ownership and decision-making are fundamentally important, but community-level decisions should be made within a wider planning framework. The requirement is for local regime independence within the context of a larger, scalar interdependence.	Schumacher (1973); Adams (1990); Lee (1990); Ostrom (1990); Murphree (2000)

SCALE OF INVESTIGATION: EXAMPLES FROM AFRICA

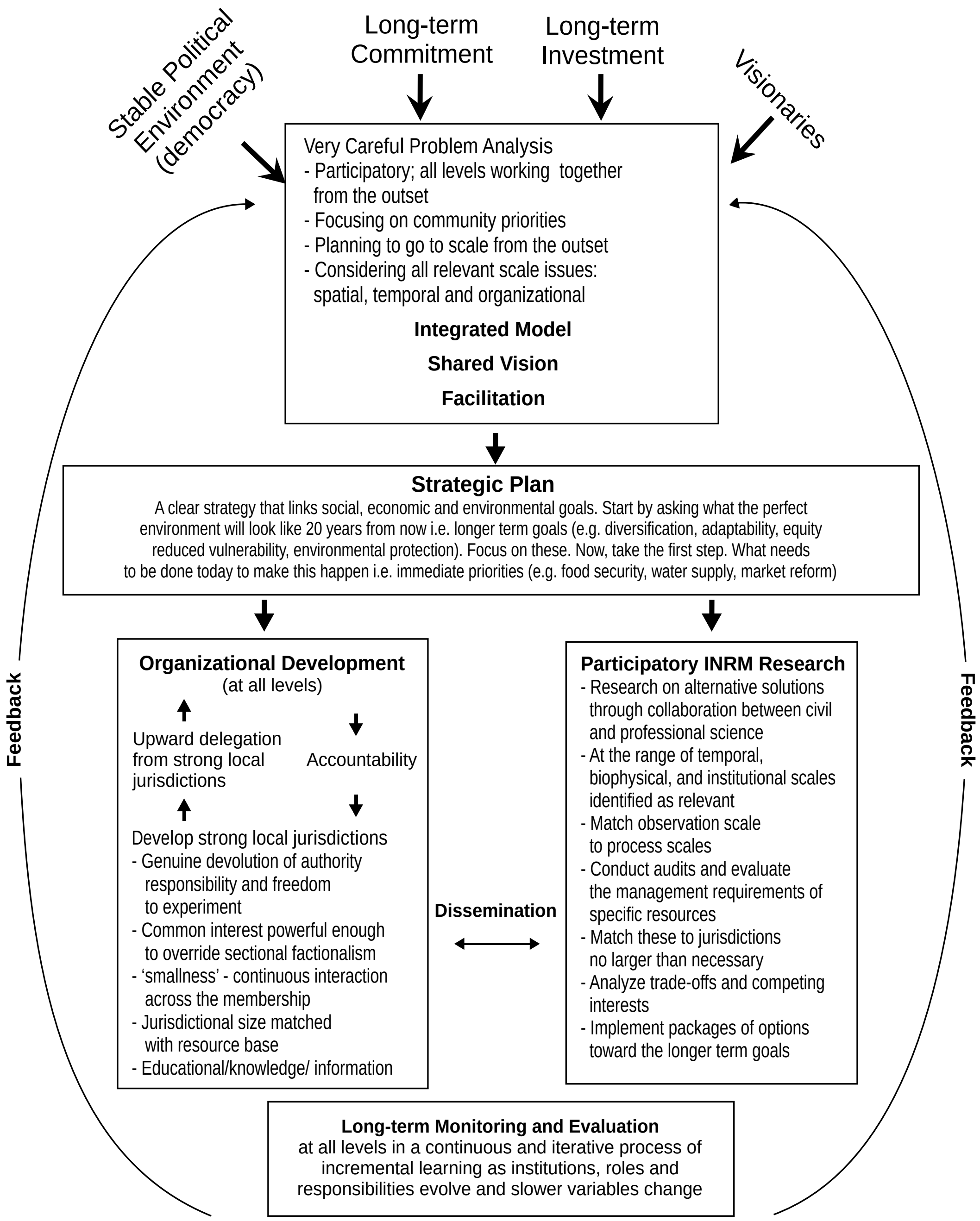
Studies in communally managed dryland areas of Zimbabwe illustrate that temporal, biophysical, and institutional scales of investigation can each be critical and can restrict the generality and utility of findings.

Temporal scale

Over time, change occurs at different rates (Holling 1993, Sneddon et al. 2002). "Slow change" is cumulative (accumulations of human influences on components of their environment over decades and centuries), whereas "fast change" is a sudden alteration in "fast environmental variables that directly affect the health of people, productivity of natural resources, and vitality of societies."

For several centuries before colonization, the indigenous people of Zimbabwe were part of localized territorial groupings, and natural resources were abundant in relation to population (Beach 1980). However, colonial land apportionment brought an abrupt change in tenure and settlement patterns when these people were forced into native reserves, mostly in parts of the country least favored for agriculture (Moyo et al. 1991). Concentrated settlement was rapid, and related environmental change accumulated over decades, while some

Figure 1. A conceptual framework or strategy to deal with scaling issues in INRM.

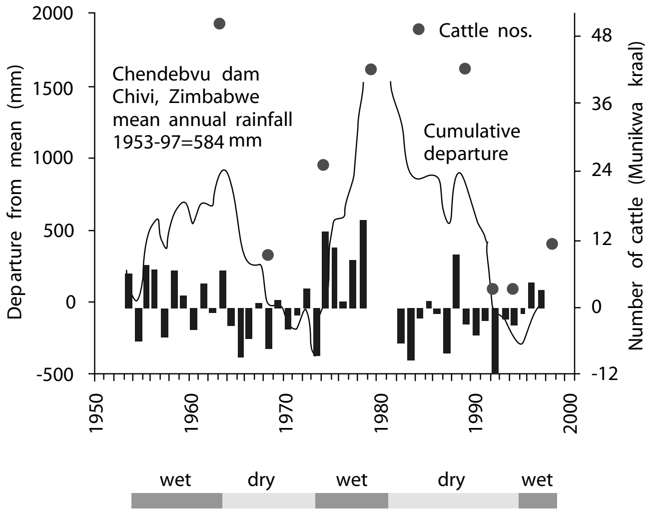


environmental legislation put in place over a century ago has survived even to this day (Mandondo 2000) because institutions exhibit path dependency and do not easily change (North 1990).

Today, 57% of people in Zimbabwe live in the "communal lands" designated during the colonial era. All land is owned *de jure* by the state but, *de facto,* cropping land is owned by families under customary arrangements. Grazing land, forests, and water are managed through common-property arrangements and are apportioned opportunistically through open access or at the whim of traditional leaders. Environmental concern reaches back to the early 1900s, informed by experiences with disasters elsewhere, e.g., the American Dust Bowl of the 1930s. In 1966, there were reports that 50% of communal lands were either badly overgrazed or had little herbaceous cover. In the 1980s, a national survey suggested that > 90% were "severely" deforested, the worst areas being those with the largest livestock and human populations and longest periods of settlement (Whitlow and Campbell 1989). There were also reports of extensive erosion, and many areas began to experience severe water resource problems as groundwater levels fell and water points failed. These observations led to a widespread perception that land management in the communal lands was bringing about general desiccation of the environment.

The Romwe catchment study (Bromley et al. 1999) began in 1992 in Chivi communal land to help resolve the uncertainty. Through a combination of ground-truth measurements, monitoring, and modeling, it partitioned the causes of groundwater decline into rainfall pattern, land-use change, and human abstraction. Rainfall in this region exhibits periods of above- and below-average levels (Chenje and Johnson 1996, Makarau and Jury 1997). This means that areas such as Romwe actually fluctuate between being semiarid and semihumid. The implications for natural resource management are enormous. Village elders recall cattle numbers oscillating in line with departures from mean annual rainfall (Fig. 2; Moriarty 2000).

Figure 2. Cycles of rainfall and cattle numbers in Chivi district, Zimbabwe (adapted from Moriarty 2000).



Similar fluctuations may be expected in grain yield, vegetation cover, erosion, and siltation. Modeling catchment hydrology for this period clearly shows that rainfall is by far the greatest determinant of natural resource status. Long-term trends in groundwater levels reflect cumulative rainfall variation, and the main cause of water point failure in the late 1980s and early 1990s was the extended dry period from 1981 to 1992 (Butterworth et al. 1999). Human impact through land-use change is of only secondary importance (Butterworth 1997), and human impact through present groundwater abstraction is trivial (Table 2). The important implication for INRM is that short projects or “snapshots” are dangerous. In this environment, the temporal scale of investigation must cover (or at least allow projection over) one full cycle of rainfall variability in order to account for natural fluctuations in resource status.

Table 2. The annual water balance of a micro-catchment in southern Zimbabwe (year 1 July–30 June); see Lovell et al. (1998).

		Run-off	Recharge	Change in groundwater storage	Natural groundwater recession	Human use	Balance to evaporation, change in soil moisture and other losses
		mm					
1994/95	rainfall 738 mm	4	38	–34	72	1	695
1995/96	rainfall 990 mm	93	262	+100	162	1	634
1996/97	rainfall 937 mm	84	296	+62	234	1	556

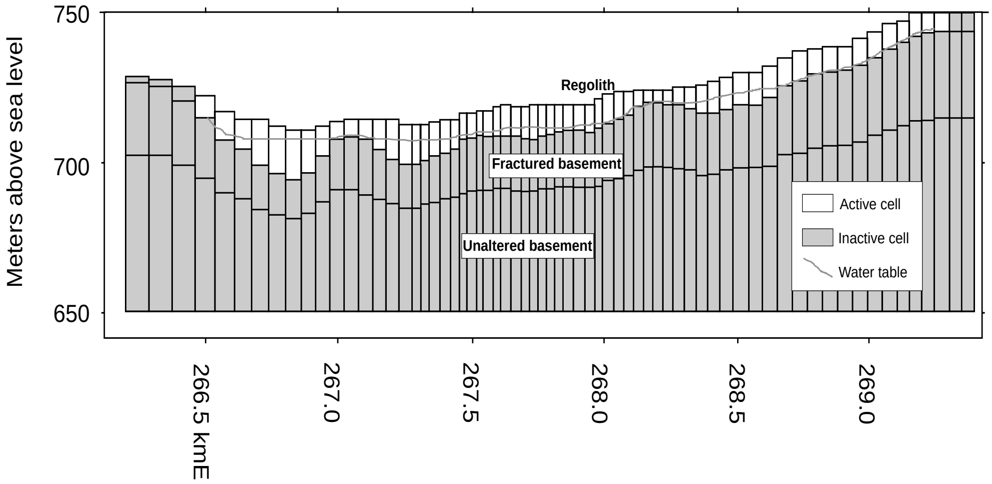
Maximum values of recharge, calculated as rainfall minus potential evaporation and run-off during period of groundwater rise and assuming no lateral flow or change in storage in the unsaturated zone. Specific yield S_y=0.045 for the whole catchment inferred from maximum values of recharge and measured groundwater rise across a network of piezometers. Change in groundwater storage is annual change in groundwater level multiplied by specific yield. Recession is difference between recharge and change in groundwater storage. Balance is rainfall minus run-off, recharge and human use.

Biophysical scale

Biophysical scale, as related to groundwater in Romwe, is driven by the crystalline basement geology. In contrast to sedimentary aquifers, where recharge can percolate to great depths and move over large distances underground, basement aquifers are localized in sump points (Fig. 3). Storage takes place only in areas of relatively deep weathering. The aquifers are relatively small in area, shallow, discontinuous, and seldom match the boundaries of surface water catchments.

The important implication for INRM in this environment is that groundwater management does not have to be applied consistently over huge areas to have a measurable effect. This contrasts with surface water management, where a beneficial effect may often lie hundreds of kilometers from the point of intervention (e.g., where headwaters are managed to improve reservoir performance downstream). For groundwater in basement areas, decisions and actions that have a real impact on the *locally* available resource can be made at the *local*

Figure 3. Section through a model of crystalline basement aquifers showing storage of groundwater in localized weathering (Moriarty 2000).



level. Such decisions include whether to adopt water-harvesting methods to enhance groundwater recharge or rain-fed crop production, or whether to develop woodlots on aquifers rather than irrigated gardens. The correct biophysical unit for management in each case is the groundwater micro-catchment. Although this seldom coincides with an existing institutional boundary, it does at least make micro-catchment management an appropriate strategy in this environment, and is a scale conducive to working with small interest groups, typically numbering in the tens of families rather than hundreds.

Institutional scale

Boundaries are central to INRM because they specify the area over which jurisdictions apply, as well as the roles that particular actors are assigned (Murphree 2000). Specifying jurisdictional zones is, nevertheless, easier said than done, not least because administrative boundaries, infrastructural links, ethnic groups, community limits, and informal networks seldom correspond with physical resource boundaries, to the extent that these can be agreed upon. To complicate matters further, INRM involves the integrated management of a multitude of common-property, open-access, and privately owned resources such as cropland, pastures, forests, and water. Each has an associated complex of often-conflicting interests held by "stakeholders" both inside and outside the particular resource boundary (Nemarundwe 2001).

The choice of institutional scale for INRM conceptually can be made from a continuum of options ranging from "big government" to "small is beautiful" (Murphree 2000). "Big government" is an approach of comprehensive authority located at a few nodes across the spectrum of expanding scale requirements. It arises in response to developing insights about ecological interconnectivity, resource scarcity, and an expanding global economy. It carries with it a strong internal logic; interrelationships of scale are best managed by unitary jurisdiction, or by a few integrated jurisdictions.

"Small is beautiful," on the other hand, is an approach that seeks to place jurisdictions at local or communal levels. Small jurisdictions are more transparent to their constituencies and thus politically acceptable. Controls exerted through local peer pressure are tighter and more efficient than distanced prescriptions on which large jurisdictions have to rely. "Small is beautiful" also carries with it the fact that incentive is the fulcrum for responsibility and the motivation for environmental investments and controls; it requires a clear perception of the links between management inputs and output benefits. Small jurisdictions are better placed to delineate and put into operation these essential linkages. Furthermore, responsibility and authority, which must be linked, can be coordinated under one local institution or explicitly articulated between the limited range of actors involved.

Small units mitigate the transaction costs of organizing for collective action and are generally associated with mutuality of interest and greater social cohesion arising from easy day-to-day contact. However, the "small is beautiful" approach can result in a multiplicity of fragmented jurisdictions that lack coordination when it comes to addressing bigger problems of both a local and trans-local nature. Such problems that cannot be handled in isolation at localized scales are better addressed by larger, unitary jurisdictions, but these are often directed from a remote center, out of touch with local priorities and aspirations. A question, therefore, is whether those at the top should define small units for INRM on the basis of a subdivision of big units, or whether small units based on local interest groups should build into bigger coordinated units (Appendix 1). In the former, communities usually end up with responsibilities for INRM without corresponding authority, making it difficult for local institutions to establish areas of jurisdiction in which there are clearly "insiders" with usufruct rights and management obligations and "outsiders" who can be excluded from direct use. In the latter, lack of capacity in lower- and middle-level institutions, and ineffective links between the two, are often key constraints.

Identifying and negotiating these interests and relationships is a key part of INRM that generally requires external facilitation to advise on organizational development and to help find compromises between potentially conflicting interests (Ravnborg and Ashby 1996). It is inevitable that the solutions, in the form of appropriate institutional arrangements, will be location-specific and resource-specific to some extent. In terms of direct management, the particular user group and its neighbors should determine the appropriate institutional scale. In terms of program development, this must involve at least the scale at which INRM policy can be decided and enacted. In Zimbabwe, this corresponds to the district council.

Scaling-out

"Scaling-out" is sometimes used to define spatial extrapolation of successful approaches to other sites with similar circumstances; i.e., replication at the same scale but at different locations. It may involve a certain degree of adaptation, but essentially involves the same type of system boundaries (Kolavalli and Kerr 2002). It depends on identifying sites with similar circumstances, followed by extension. Harrington et al. (2001) provide examples of tools that can help in this process. These include site similarity analysis through GIS, the use of farmer and land type taxonomies, and simulation models. This form of simple area scaling will rarely be appropriate in INRM, however, without detailed institutional investigations in the proposed extension areas, and without asking questions about cumulative impacts on a broader scale than that being replicated. Similar biophysical areas cannot be assumed to have similar institutional arrangements, local culture, or values, and there will be lateral flows of soil, water, air, fire, organisms, people, money, ideas, etc., across the expanding scales.

The examples of temporal, biophysical, and institutional scale issues that we have given, and their associated physical and social contexts and dynamics, highlight that successful approaches will invariably be location-specific and time-specific, to some extent. Rules or relationships that hold at one scale may not transcend scales, and "successful" approaches at one scale may even cause problems downstream. Van Noordwijk et al. (2001) provide the example of plot-scale erosion that leads to considerable lateral flow, impoverishing soil in one place but enriching it in another, with relatively little actually reaching the scale of seas and oceans.

These scale issues, contexts, and dynamics, and the interactions that become important with increasing scale (e.g., through spatial extrapolation) pose serious challenges and explain the nested scales of interdisciplinary research recommended later in this paper.

SCALING-DOWN AND SCALING-UP: EXAMPLES FROM AROUND THE WORLD

Experience shows that for INRM to benefit many people across large areas requires considerable political will, investment, and strategic planning from the outset (Costanza and Jorgensen 2002, Campbell et al. 2002). Success depends primarily on building relationships, in particular, on community participation, which depends on incentive, which in turn is contingent on the creation of an enabling environment to meet a range of preconditions identified in previous studies of integrated catchment management, watershed development, common-property management, and devolution (see, e.g., Gibbs 1986, Beven 1989, Ostrom 1990, Shah 1993, UNESCO 1993, Clarke 1994, Ravnborg and Ashby 1996, Farrington and Boyd 1997, Farrington and Lobo 1997, Rhoades 1998, Adams et al. 1999, Murphree 2000; C. H. Batchelor, *unpublished manuscript*, C. H. Batchelor, J. Cain, F. Farquharson, and J. Roberts, *unpublished manuscript*, Beaulieu et al. 2002, Kolavalli and Kerr 2002, Gündel et al. 2002). These preconditions or lessons (see Fig. 4) will be discussed in more detail.

Lessons from integrated catchment management and watershed development

Following the United Nations Conference for the Environment and Development (UNCED) held in Rio de Janeiro in 1992, most nations subscribed to new principles for the integrated management of land, water, and forests. Although program names vary from nation to nation, all express similar aims. It should be noted, however, that despite considerable interest and effort, these national programs have rarely delivered. The main reasons appear to be the top-down sector approach taken, a lack of community involvement in the process, and a lack of

Figure 4. Some generalized lessons or preconditions for successful INRM.

Integrated Catchment Management
- Overall strategy that clearly defines the management objectives
- Mechanisms and policies that enable long-term support
- A range of delivery mechanisms that generate the interest and participation of local institutions and communities
- Decision-making and action take place at regional and local levels
- A monitoring schedule evaluates program performance

Common Property Management (Group Management)
- Access to external facilitation to help advise on organization development
- Systematic analysis to identify all stakeholders and ensure their representation
- The operative unit is small enough for local people to participate meaningfully
- Members of the group must benefit directly from the resource
- Constitution (rules and norms) governing management agreed upon defined
- Group membership and resource boundaries are agreed upon and defined
- Compromises for resource sharing negotiated with other user groups using charters of access and compensation mechanisms
- Penalties for infringement of rules and a mechanism to enforce these

The ideal initial development project
- Produces a range of benefits to many people in a short space of time
- Generates cash - lack of income is a huge impediment to new activity
- Creates sufficient incentive for communities to overcome the increased managerial problems associated with joint action
- Builds social capital e.g. provides a meeting place for problem solving and builds confidence in tackling natural resource problems
- Prompt their awareness of the need to protect natural resources in order to protect their initial investment - in some cases this intrinsic awareness may need to be reinforced through environmental education

Devolution of control for natural resource management
- Ratification of community-based organization (CBOs) as appropriate authorities
- Rationalization between customary and modern leadership systems
- Security of tenure
- Access to credit facilities
- Management rules and maintenance arrangements evolved and enforced locally with higher level support
- Revenue from fines, levies and royalties maintained locally
- Conflict management arrangements in place and arbitration available
- Demand-led technical support services with official tariffs where applicable
- Access to environmental education
- Local-level resource monitoring and evaluation
- Open lines of communication between groups and with higher levels of authority

appropriate delivery mechanisms at ground level to generate the interest of local institutions and communities. Indeed, the lack of appropriate delivery mechanisms was identified as the main failing with first attempts to implement integrated catchment management in both Australia and South Africa (Blackmore 1995, van Zyl 1995). The importance of community participation and local development to the success of these national programs cannot be overstated.

In contrast, a recent survey of community-level watershed development projects considered the impact of taking a fully participatory approach (Hinchcliffe et al. 1999):

> *Contrary to common viewpoints, the catchment ... is not always the most rational unit for all activities ... Because neither catchments nor the groups who live among them are homogenous, the nature of their problems and the possible solutions are varied and complex. Prescriptive external solutions have little chance of fitting ... and may be inappropriate or unacceptable to the majority of farmers. Nevertheless, working with common interest groups on contiguous areas of land, whose boundaries may be administrative, social or physical, enables agency staff to provide assistance more efficiently than where individual farms are scattered ... Thus it is not "catchment management" as such that results in improvements in agriculture and livelihoods. Insistence on such a framework may run contrary to communities' needs and priorities ... Rather it is the integration of improved husbandry of land, of crops and of livestock with better interpersonal relations in the context of catchments that produces tangible benefits.*

Twenty-three case studies, ranging from Landcare in Australia to the Aga Khan Rural Support Program in India, present a rich and complex picture of the problems, achievements, and continuing challenges faced by conservation professionals and farmers around the world. The features common to successful projects at this community level include:

- Small micro-catchments with boundaries rarely defined and rarely hydrological.
- Planning units that are collective, i.e., a community-based organization (CBO) rather than individual farmers, with the emphasis on working with people who have something important in common (e.g., caste, blood, class, common dependence, common priority).
- A reasonable degree of social organization through which the necessary critical mass of collective action can be organized. Where this does not exist, it has to be created, requiring significant development of trust and platform building. The social units most appropriate for participation need to be tailored to the particular setting, and the approach may not work where "community" is not the norm and people are devoted to individual actions (e.g., tribals, absentee landlords, landless people).
- Flexibility. A thoroughly predesigned and preplanned project is not considered a good project. Indicators of success focus on adaptation rather than adoption.
- Clearly defined roles for the different organizations: state departments, NGOs, and CBOs.
- Emphasis on introducing government personnel to participatory farmer-to-farmer

extension and on reorienting initial projects and extension approaches away from "treatment" of specific problems toward whole-catchment management focused on livelihood priorities.

- Tangible benefits to participants in a short space of time.
- Group access to finance through credit or other means.
- Highly subsidized by government and donors, with local residents contributing only a small percentage of the value of the development works in cash or as labor. Adequate financial and institutional support is considered critical where authorities are handing responsibility for complex, costly, and conflict-ridden problems back to local people.

Almost without exception, however, these NGO-led projects are small in scale and can be expanded only by repeating the same slow, costly, in-depth techniques in successive villages. Farrington and Boyd (1997) identify three features important to achieve more expeditious replication over wide areas:

- Community participation in local development. This generates a stake in the process and enhances the prospects of effective and sustainable joint action. However, entirely "bottom-up" proposals for improvements limited to the possibilities already known to rural people will not suffice. The process must be open to the wider possibilities known to outsiders and in a format for planning, implementing, and monitoring that allows these outside agencies to verify that public funds have been spent properly.
- Support agency roles that allow the necessary degree of participation for interventions to be planned and function adequately, but that at the same time are rapidly replicated. A criticism of World Bank-supported watershed development, for example, is that despite large amounts of funding on infrastructure, institutional arrangements are rarely adequate to continue maintenance. On the other hand, long-term empowering approaches adopted by some NGOs achieve institutional sustainability in individual villages at the cost of extremely slow replication. A balance is required.
- A clear strategy for scaling-up. Expansion pathways for NGOs are often poorly defined.

Farrington and Boyd (1997) conclude that joint action and participation are central to successful management of natural resources. Replication at any scale larger than a few villages has to occur within a structured program and has to be based on multi-agency partnerships. An alternative to the slow, long-term empowering approach does not emerge from NGOs, meaning that the public sector must undertake exercises in consensus and program building.

In only one setting, the Indo-German Watershed Development Program (IGWDP) in Maharashtra state, India, did Farrington and Boyd (1997) find these preconditions clearly defined at the program design phase (Appendix 2). Farrington and Lobo (1997) discuss the institutional arrangements that have ensured the involvement of all stakeholders. They conclude that the program has generated a technically sound, but at the same time participatory, watershed planning methodology, a coherent transition from capacity-building to full-scale implementation, and a practical framework for field-level collaboration among state departments, NGOs, and CBOs.

Improvements in production form only part of the IGWDP vision. In many respects, a more important part is the strengthening of local people's capacity to draw on civil society. INRM involves essentially political questions within and between villages and with various levels of the administration. Progress cannot be made through local-level resources alone. Government provides technical support services and also much of the fabric necessary, in the form of legal and administrative systems. Local organizations must be able to engage with government in order to draw on these services and systems in ways that meet their needs.

Lessons from common-property management (group management)

Common-property management must be linked to human welfare as the major motivating force. The basic social requirement for achieving this is that the operative unit, the producer/user community, should be small enough for households to participate meaningfully. The question of scale is critical for community cohesion (Murphree 2000). The smallest social organization above the household—the village community—should be able to meet regularly to decide management issues, as was customary in traditional open governance. If a community is too large or too dispersed for free discourse between members, it is preferable that it divides into smaller entities, each of which is then represented by a coordinating body. The economic requirement is that the producer/user community must benefit from its labor through the sale of produce. This economic incentive provides the most important rationale for managing the resource. The institutional requirements are security of tenure for specific user groups, and regulations that evolve and are enforced locally.

Lessons from devolution of control for natural resource management

Williams (1998) and Murphree (2000) discuss the emerging problems of sustainable resource management. Essentially, the challenge is to devise governance arrangements that are supportive of the diverse needs of a variety of users, yet protective of the long-term productive capacity of these resources. The requirement is for local regime independence within the context of a larger, scalar interdependence. New and effective institutional arrangements are needed. A growing recognition of this need is evident. In most countries, state property regimes, in which government officials exercise exclusive decision-making powers, are being de-emphasized in favor of decentralized and participatory management of natural resources. The specific approach used to encourage active local participation varies from one country to another. In some, it has taken the form of legislative reform of land tenure and natural resource management policy conducted over time. In others, land-use planning based on "village territories" has become popular. In all cases, governments have sought to clarify tenure issues and to reinforce the rights of local communities to mange their resources through granting legal recognition and decision-making authority.

RECONCILING SECTOR TOP-DOWN AND BOTTOM-UP APPROACHES

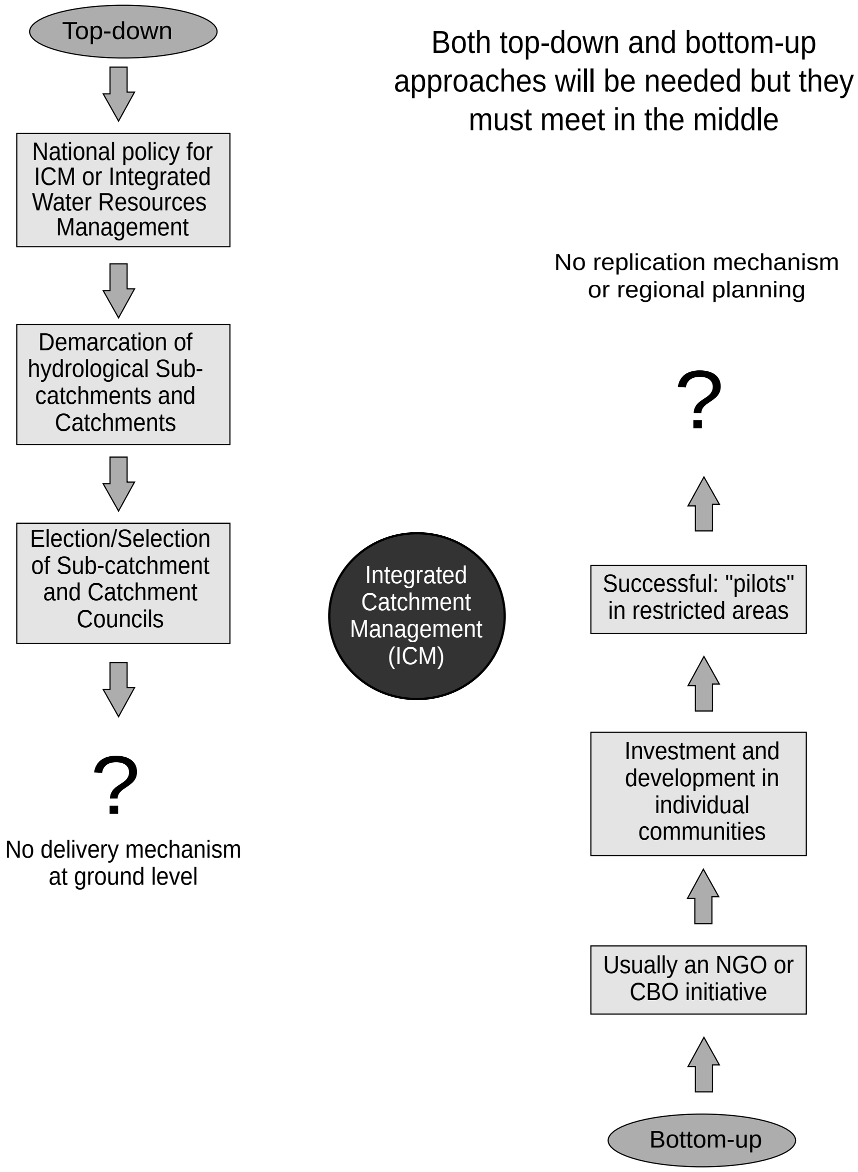
Van Zyl (1995) emphasizes that INRM must be people centered, but also states that:

> *To succeed in managing ... managers must be in a position to see the whole picture, understand the resources, the customers, their needs and aspirations and to make wise decisions in the interests of all. This requires a holistic approach to management that integrates skills in engineering, economics, politics, social and environmental management. It involves the bringing together of various disciplines and the compilation and development of multidisciplinary teams of champions. Due to the ... site-specific nature of (water) resources in terms of physical properties, land use and people involved, it is not feasible to manage ... on a national basis without basing it on logical management units. Because we are dealing with a natural resource, driven by the hydrological cycle, it makes good sense to use river catchments as such units.*

This is INRM as viewed from the top. Although this approach has many benefits, the crucial elements missing are local ownership and the incentive to undertake any INRM strategies that might be developed as part of this top-down approach. An alternative view is from the bottom, whereby INRM is seen as a means of scaling-up community-based schemes to the regional or catchment scale. This approach has advantages in terms of achieving local ownership of the process, but it has disadvantages with regard to structure, regulation, and equity. For example, communities developing projects in headwater catchments are unlikely to put a high priority on ensuring that the resources of downstream users are not adversely affected.

The key issue that emerges is the need to effectively link community-based projects within larger, structured programs. Both are essential, but they must be implemented in a package that meets in the middle (Fig. 5). INRM needs to occur through a structured program that provides overall planning, coordination, and long-term financial support for activities at regional or catchment level. Equally it needs to occur at the scale of the common interest groups on contiguous areas of land whose boundaries may be administrative, social, or physical. At this level, the essential features are the common interest group, the development process that facilitates participation in joint action, and the structured program. The lack of overlap between different physical areas and social groupings associated with the management of different resources can be overcome by this approach, because INRM in this participatory sense is at the scale of the common interest groups. When it is undertaken within a structured program, INRM allows planning for downstream effects.

Figure 5. In search of INRM.



Political will

Bottrall (1992) discusses the dichotomy of simultaneously ensuring both "local ownership" and equitable distribution and regulation of resources at the larger scale. He makes the point that government departments address issues on a fragmented sector basis, and their attempts to promote INRM tend to have high administrative costs (e.g., interdepartmental committees or new multisector units). By contrast, communities find it relatively easy to think and act holistically. The administrative costs of INRM will be kept within acceptable limits only by devolving significant management responsibility to CBOs and, wherever possible, NGO intermediaries. The challenge is to effectively link government departments with each other and with local-level organizations. Interdepartmental committees are a poor attempt, and falter where they are not properly supported by resources specifically allocated by each department.

Government allocations to holistic INRM programs instead of to conventional departmental top-ups would help to facilitate the necessary cross-sector interfacing. The problems of cross-sector/interministerial collaboration should also be easier to overcome through properly established decentralization. However, this requires adequate capacity, especially at lower and middle levels, and genuine social empowerment through devolution of authority, responsibility, and freedom to experiment (Murphree 2000). Authority and responsibility for management must be vested together at the lowest appropriate level and only delegated upward where absolutely necessary. Each level must be functioning properly, and a missing level is essentially a block. Parachuting to community level, for example, as many external NGOs do, will not help INRM go to scale.

Decentralization is thus a precondition for scaling-up, but equally, too much decentralization disperses authority and, simultaneously, any control over forms of authority. Assigning increased authority and responsibility to local users without ascertaining the range of functions of a resource, the diversity of interests among users, and the capability of local institutions to take on these roles, will complicate rather than solve the problems (Williams 1998). Governance arrangements for INRM must be an appropriate mix of local and state institutions. The rights of individuals within legal entities are contractual arrangements that do little to secure property rights in the absence of demarcation, registration, and records, all of which require an institutional framework located in and managed by the state. Local institutions have a comparative advantage in dealing with resource use and preservation issues at community level, but they vary widely in their organizational and management capabilities. State institutions are needed to provide support for the formation or strengthening of these local institutions where they are non-existent or weak. Given the wide variety of users and the complex set of overlapping rights that are continuously contested, the need for conflict mediation will be fairly constant. State institutions will be important in resolving disputes and providing an appropriate legal framework to support and enforce resource use agreements worked out by the different local groups (Ostrom 1990, 1995).

NGO support

The NGO perception of scaling-up recognizes that it is about relationship-building. It is not just replication of technologies or approaches, but expansion of principles and knowledge, such that people build capacity to make better decisions and influence decision-making authorities (Gonsalves 2000). In this respect, scaling-up has power and development dimensions. However, the "learning-process" approach that is adopted generally proceeds through three slow stages: learning to be effective (with emphasis on building interpersonal relationships); learning to be efficient (withdrawal from individual sites); and learning to expand (but focused on local organizational development rather than broader policy and institutional arrangements). The NGO approach tends to be: try a project, have success, then think about scaling-up, including development of relations with the state and how to sustain the momentum, both vertically across institutional levels and horizontally. As we have seen, for local success to go to scale, collaborative planning from the outset between communities, NGOs, and the state is crucial if social change and empowerment of people is to occur in a meaningful and lasting way. The state and NGOs will need to undertake certain commitments to help reconcile current top-down (predominantly technical) and bottom-up (predominantly social/institutional) approaches to INRM (Table 3).

Table 3. Undertakings by government and NGOs to help bridge the gap between top-down and bottom-up approaches to INRM (adapted from Gonsalves 2000).

On the part of Governments	On the part of NGOs
• Provide a stable, supportive and enabling environment and a political culture which allows democratic elections and rule of law • Provide long-term meaningful support to INRM • Implement meaningful devolution of control with institutional capacity building at middle and lower levels • Avoid top-down community manipulation and NGO tension by ensuring that programs are led by and remain focused on community priorities • Provide clear mandates that allow NGOs to participate • Provide clear mandates among state agencies • Develop infrastructure for disadvantaged communities • Provide appropriate technical support • Ensure independent monitoring and evaluation and documentation of lessons learned and best practice	• Forge strategic alliances to generate impact on a large scale • Build up sufficient broad-based community pressure to influence policy • Lobby politicians; invite them to see what is happening in the field and how this fits with their own mandates • Influence market forces and market development • Encourage local champions • Help to construct a shared vision for scaling-up through active participation by all • Strengthen community knowledge and skills in law, planning, decision making, marketing, team building, communication, conflict resolution, natural resource management • Strengthen community understanding of the government system in the scaling-up process • Build social capital (trust/cooperation networks)

The right type of initial development project

Delivery mechanisms now being used with relative success in Australia and India involve financial incentives (Farrington and Lobo 1997, Campbell and Woodhill 1999), but few developing countries have the same financial resources or political will as Australia and India. Kerr et al. (1996) also believe that alternatives to subsidies should be sought in most instances. For developing countries, approaches to INRM are needed that are appropriate to the political setting and that are considerably cheaper. Linking INRM to rural development is one option. However, certain types of development will be more effective than others (Fig. 4). The ideal initial project will satisfy the three basic requirements (social, economic, and institutional) of common-property management. It will focus on a resource of immediate concern to the local people, and one that has the potential to generate meaningful income. It will increase social capital by promoting collective responsibility. It also will build community confidence and institutional structures that will help to address other natural resource problems.

Rural water supply is an example of an ideal project for dryland areas. It is already central to development in these areas, already attracts donor funds, and, in many countries, it already brings together different ministries in an established institutional structure. These are all-important ingredients in scaling-up. The social, economic, and institutional criteria can then be met by developing productive water points (Waughray et al. 1998, Lovell 2000). Unlike conventional water points, these are designed and implemented to provide sufficient water for income-generating projects as well as domestic use. They are public water points, and are implemented in a manner that empowers the local group to own the resource and assume authority and responsibility for its management. Income from production creates the incentive for this management and meets the operation and maintenance costs. In the longer term, reinvestment of this income and the experience of successful collective action create wider benefits to the local economy and the environment through diversification of livelihood strategies and intensification of the farming system.

WHAT KIND OF INRM RESEARCH IS NEEDED?

When considering the contribution that research can make to INRM, one must recognize that the concept itself is a research product, emerging from a series of studies investigating different development paradigms. It has emerged as a model for a universally applicable means of safeguarding the natural resource base and improving productivity. With the wisdom of hindsight, few involved would now question this need for holism.

An important task for INRM research, therefore, is to test and subsequently transform the hypothesis into proven principles that can, with confidence, be applied in practice. The research effort should focus on bringing the INRM approach into operation and on generating understanding by observation. This requires action-research to learn-by-doing within applied INRM programs. The research should address major resource management problems in an ecoregional context. In order to address scaling issues, studies in each thematic program should focus at two levels:

1. Strategic studies that increase knowledge of the preconditions for scaling-up and contribute directly to policy formulation and institutional development. These will concentrate on improved planning, helping to ensure that governments create the enabling environment required to cope with the demands of applying INRM (e.g., piloting genuine devolution where this is not yet enacted).
2. Specific interdisciplinary studies at nested scales that investigate key constraints or gaps in knowledge. These will concentrate on the interconnectivity between scales and on separating and evaluating the influence of factors that are natural and beyond the scope of management (e.g., rainfall variability); reversible by changing local practices (e.g., land management); and external, in that they can only be changed by alterations in policy and institutional arrangements (e.g., legislation, incentives, power relations, resource tenure, civic education).

Table 4 illustrates these suggestions with an example of groundwater management. The process starts with real problems, and how the big issues interact with local situations. These interactions need careful analysis so that the concept of the system is clear before participants embark on small-scale, community initiatives with naïve expectations about later scaling-up. How, and to what extent, do local problems perceived by resource users relate to global (external) issues? What might need to change at the global level to achieve large-scale, long-term success? How will activities at the local level actually contribute to this? In many cases, the required temporal, spatial, and institutional scales of study will be wide ranging.

NRRD (1998) notes that such different categories of research, and the several relevant disciplines needed for comprehensive understanding, will require effective coordination and management. The integration of relevant strategic knowledge from existing sector programs will also be important, as will creation of reliable and enduring partnerships between researchers in different disciplines and between institutions representing different stakeholders, particularly those who will use the knowledge directly.

Although experimentation with scaling-up, community-based approaches that engage multiple stakeholders has continued to grow, much of the experience has not yet been well documented. Long-term monitoring and evaluation will be important for comparative analysis to enable policy makers to synthesize lessons learned and identify principles that can be applied across multiple sites. Education of farmers will also be key. Local resource users generally possess inadequate scientific knowledge to complement their own indigenous knowledge (Williams 1998). A weakness of participatory projects to date has been the lack of scientific rigor in appraising impact. Many projects, from Africa to India, proudly attribute indicators of improved management, such as an increase in grain yield or a rise in groundwater level, to some desired change in social or human capital, such as enhanced sense of community responsibility or improved traditional soil and water conservation. However, they fail to

Table 4. An example of nested scales of interdisciplinary research to address scaling issues.

Problem Analysis: Groundwater decline is a key degradation issue in the 21st century. Aquifer levels have fallen in recent decades in several major grain-producing regions of the world. This decline is popularly attributed to groundwater mining. However, significant gaps in knowledge and understanding of the processes of groundwater decline remain, and limit our identification and implementation of appropriate management actions. This thematic research program will systematically address the issue of groundwater decline in the ecoregions represented by the Punjab of India and the North China Plain.

	Scales of investigation	
Examples of strategic studies	**Spatial/Institutional**	**Temporal (projection in some cases)**
Pilot devolution of control for natural resource management, e.g., through environmental education, capacity-building, village government	user-group; village; ward; council; ministerial	years
Promote collective responsibility for groundwater through programs that support group-based activities and discourage private exploitation	water supply sector	years
With user groups, NGOs and government, apply knowledge gained in the related specific studies to develop and field test appropriate technical, legal, financial, and institutional incentives for effective management	user-group; village; ward; council; ministerial	years
Independent monitoring and evaluation	as above	years; decades
Examples of specific studies		
Model the importance of spatial and temporal variability of rainfall and land management to the reported groundwater decline	field, aquifer, micro-catchment, river catchment	wet year, average year, dry year, “20” year cycle of variability
Partition the decline to natural recession and human use, and partition the natural recession to deep flow, lateral flow and vegetation water use	field, aquifer, micro-catchment, river catchment	year
Simulate the impacts of increasing population and changes in land use and climate	user-group; village; ward; council; field; aquifer; micro-catchment; river catchment	wet year, average year, dry year, “20” year cycle of variability
Cost–benefit analysis of potential macro-economic interventions e.g. import grain from water-rich areas to reduce need for local production	regional; “global”	years; decades

acknowledge the complexity of the natural system or to account for important external factors. INRM research has an important role to play in this regard, in both interpreting and supplying information. The timely availability of appropriate information about the interrelationship between different resources is critical for meaningful participation and decision making by local organizations.

CONCLUDING REMARKS

A lesson to date in INRM is that there are no magic, generic solutions and no quick fixes. To benefit many people across large areas requires considerable political will, investment, and planning from the outset. It also takes time, as institutions, roles, and responsibilities evolve and the slower variables change. Emphasis needs to be on long-term management of resources at all levels, even though this may not be attractive to bureaucrats and politicians who want another glittering initiative (Batchelor et al. 2000).

The process also goes far beyond simple, area-based extension or expansion concepts envisaged by some NGOs. There must be demand for INRM at the local level, it should be integrated with means of enhancing livelihoods, and it needs to be tailored to local conditions. Nevertheless, account must be taken of the "global" as well as the site-specific causes of the problems facing people and the environment (Turton and Farrington 1998).

Within individual scientific disciplines, the expertise exists to deal with these scaling issues. In the development community as a whole, there is also experience of the considerable challenges posed by integrated natural resource management. In this paper, five themes emerge as principles in the search for a strategy that will help to ensure that integrated natural resource management can be achieved successfully at scale:

- the political will to democratize and genuinely empower local communities;
- shared visions across all institutional levels, based on careful problem analyses;
- effective coordination of civil and professional science;
- commitment to a continuous and iterative learning process; and
- long-term (10–20 year) funding for research in tandem with organizational development.

These components raise important questions about how to create the necessary political will, how to facilitate shared visions across all institutional levels, and who should set research agendas. However, without these components, current top-down (predominantly technical) approaches to integrated natural resource management, and bottom-up (predominantly social/institutional) approaches, will remain de-linked, and we will continue with the ineffectual structures and stratagems of "big government" and the well-meaning, but piecemeal, attempts of "non-government."

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APPENDIX 1

The CAMPFIRE Program, Zimbabwe

Although Zimbabwe's natural resource governance structures and processes have for quite some time been "big-government" type—sectorally insular and overcentralized—recent reforms have created hierarchies that appear to address the scale problem. The country's flagship in participatory natural resource management is the Communal Areas Management Program for Indigenous Resources (CAMPFIRE), in which communities are empowered to manage wildlife and benefit from it. The program is based on the concept of the "producer community" as the basic unit of social organization through which communities can be empowered to manage local resources. The original idea was to focus on units at the subdistrict level as the producer communities (R. B. Martin, unpublished report) but, in terms of institutional scale, the program has been variously implemented at the levels of village development committees (VIDCOs), ward development committees (WADCOs), traditional villages, and even entire districts. VIDCOs and WADCOs are structures created under the Prime Minister's directive of 1984, purportedly to give a democratic orientation in the process of planning for local development. However, they are demographically defined administrative units superimposed on traditional villages with which they do not correspond in terms of boundaries, membership, or roles. Although these units have each variously been assumed to represent "community," the "communities" in which the local people have had a major stake in defining themselves and their roles and responsibilities have generally been associated with greater success, particularly where relatively small (Peterson 1991).

APPENDIX 2

Preconditions for scaling-up, defined in the design phase, in the Indo-German Watershed Development Program, India

1. The setting of appropriate criteria for the selection of watersheds, villages, and local-level NGO partners, and the design of local-level collaborative mechanisms

Technical criteria include: notable erosion, land degradation or water scarcity problems; villages located in the upper part of drainage systems; watershed size around 10 km^2; village boundaries corresponding closely with those of the watershed. Socioeconomic criteria include: villages poorer than average; no wide disparities in size of landholding; villages having shown a concern for resource conservation and having a known history of coming together for common causes. As a condition for support, villagers must commit themselves to banning the felling of trees; banning free grazing; undertaking social fencing to protect vegetation; reducing excess populations of livestock; limiting water-intensive crops; contributing voluntary labor to a value of 16% of the unskilled labor costs of the project (landless and single-parent households exempt); starting a maintenance fund; setting up a village watershed committee. In the interests of replication, the IGWDP decided not to work with larger NGOs inclined toward long-term, empowerment-type approaches to group formation.

2. The design of village-level mechanisms for participatory planning, learning, and implementation
Planning by agencies based on external maps failed. The approach subsequently developed relies on consultations with farmers in their own fields, i.e., community mapping, in partnership with external support agencies such as the Forestry Commission. A capacity-building phase of up to one year is undertaken in which a small segment of the watershed (typically 100 ha) is rehabilitated. Funds for this phase (up to US$16,000) are provided by the IGWDP through its technical-support NGO.

3. Design of a sustainable mechanism for screening and funding individual proposals submitted for watershed rehabilitation
The IGWDP has created mechanisms that channel funds to local organizations with as few intermediate steps as possible. It has established a project-sanctioning committee headed by the National Bank for Agricultural and Rural Development. The central role played by this respected national organization in assessing and channeling finance to donor-supported projects is a cornerstone of replicability. Also, local currency can be channeled through this mechanism once foreign funds have dried up.

4. Mobilization of administrative and political support from the early stages
The IGWDP has focused on obtaining political support, first by inviting members of the Legislative Assembly to visit successfully rehabilitated pilot watersheds, then to obtain a Cabinet resolution implementing this devolution of control to village level through joint forest management arrangements in the state.

5. Establishment of channels for drawing on technical expertise in the post-rehabilitation period
The demand from communities for information and assistance to build on their initial success and to start a range of new projects is facilitated in the IGWDP by a watershed organization trust (WOT). This is a body of 29 staff, covering a wide range of social and physical subjects, who help to put NGOs and CBOs in touch with relevant state departments. These links and the go-between role of the WOT are vital.

7.

Delivering the Goods: Scaling Out Results of Natural Resource Management Research

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ABSTRACT

To help integrated natural resource management (INRM) research "deliver the goods" for many of the world's poor over a large area and in a timely manner, the authors suggest a problem-solving approach that facilitates the scaling out of relevant agricultural practices. They propose seven ways to foster scaling out: (1) develop more attractive practices and technologies through participatory research, (2) balance supply-driven approaches with resource-user demands, (3) use feedback to redefine the research agenda, (4) encourage support groups and networks for information sharing, (5) facilitate negotiation among stakeholders, (6) inform policy change and institutional development, and (7) make sensible use of information management tools, including models and geographic information systems (GIS). They also draw on experiences in Mesoamerica, South Asia, and southern Africa to describe useful information management tools, including site similarity analyses, the linking of simulation models with GIS, and the use of farmer and land type categories.

KEY WORDS: Mexico, South Asia, southern Africa, conservation tillage, diffusion of research, environments, geographic information systems, natural resource management, participatory research, scaling out, simulation models, technology transfer.

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THE CHALLENGE

Support for research on natural resource management appears to be approaching a crisis. Increasingly, questions are being raised as to whether this research can deliver the goods. Some feel that it is more concerned with definitions and purity of process than with results. Research on natural resource management must demonstrate its ability to benefit large numbers of poor people across large areas within sensible time frames. The easy assumption that such work is inherently site specific must be overturned. Put simply, we must meet the challenge of accelerating the use of natural resource management practices that improve human well-being.

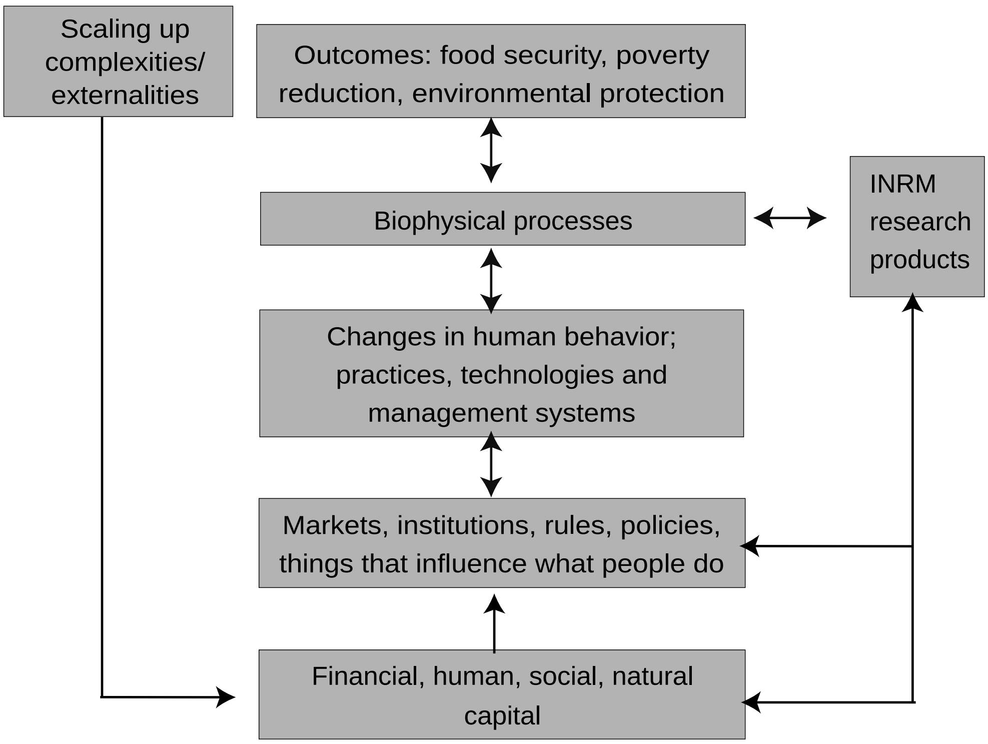
Integrated natural resource management (INRM) research can meet this challenge. Decentralized initiatives, supported by effective institutions and guided by suitable information management tools, can lead to the widespread use of suitable management options from INRM research. This, in turn, can improve agroecosystem productivity and resilience, thereby helping achieve the goals of poverty alleviation, food security, and environmental protection. Behind this is the realization that policies, people's behavior, natural resource management practices, biophysical processes, and system outcomes are linked in cause-and-effect relationships (Fig. 1). Specifically:

- policies, organizations, institutions, and rules affect the behavior of communities and individual farm families;
- people's behavior includes the selection and adoption of natural resource management practices;
- these practices affect plant and animal growth and biophysical processes; and
- biophysical processes result in outcomes that have consequences for incomes, food security, and resource conservation.

This paper discusses some of the concepts involved in and procedures for generalizing and propagating the results of natural resource management research ("scaling out"), with a few forays into the area of externalities and scale of analysis ("scaling up"). It features examples of several methods and tools for accelerating the scale of geographical coverage and impact of INRM practices. Most examples are drawn from collaboration between the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), known in English as the International Maize and Wheat Improvement Center, and research partners in South Asia, southern Africa, and Mesoamerica. Methods and tools illustrated include site similarity analysis through geographic information systems (GIS), the linking of simulation models with GIS, and farmer and land type categories. The selection of examples is illustrative and does not aim to be comprehensive.

These examples show the tools being used in the context of a problem-solving process that harnesses cause–effect links among policies and institutions, farm-level practices, plant and animal growth, biophysical processes, and impacts and outcomes. Strengths and weaknesses of the different methods and tools are discussed.

Figure 1. Integrated natural resource management research furthers the goals of the Consultative Group on International Agricultural Research (CGIAR): food security, poverty reduction, and environmental protection.



Finally, it is argued that these tools are most useful when they provide information in the context of a bottom-up learning process to a wide range of stakeholders who need this information to make decisions. They should never be used for the mere mechanical extrapolation or replication of particular practices.

A PROBLEM-SOLVING APPROACH

Research on integrated natural resource management (INRM) must be capable of solving problems (or seizing opportunities) in ways that improve livelihoods for the poor while conserving resource quality and protecting the environment (Ashley and Maxwell 2002, Costanza and Jorgensen 2002). Understandably, INRM researchers may wish to apply a problem-solving approach (Tripp 1991). Within a problem-solving process, we can distinguish among problem sets, causes, intervention points, and measurement tools.

Problem sets are situations in which agroecosystem performance, i.e., the processes that affect the resource quality or the environment, is unsatisfactory. Examples include low agroecosystem productivity, excessive resource degradation and environmental pollution, low levels of environmental services, low agroecosystem biodiversity, reductions in soil fertility, unsatisfactory water quality for consumers, and excessive greenhouse gas emissions. These problems can be characterized in terms of their costs and consequences, spatial and temporal incidence, and pace of change. They can be recognized and defined by farmers, communities, nongovernmental organizations (NGOs), scientists, and/or policy makers.

Causes are the factors that drive or contribute to problem sets. Typically, many causes at several levels are at work. Causal chains can be long and complex, linking policies, institutions, farmer or community behavior, biophysical processes, and their consequences for livelihoods and the environment (Michaelidou et al. 2002). In other words, policies and institutional arrangements affect people's behavior, people's behavior affects plant and animal growth and biophysical processes, and biophysical processes result in outcomes that cause changes in system productivity and resource and environmental quality.

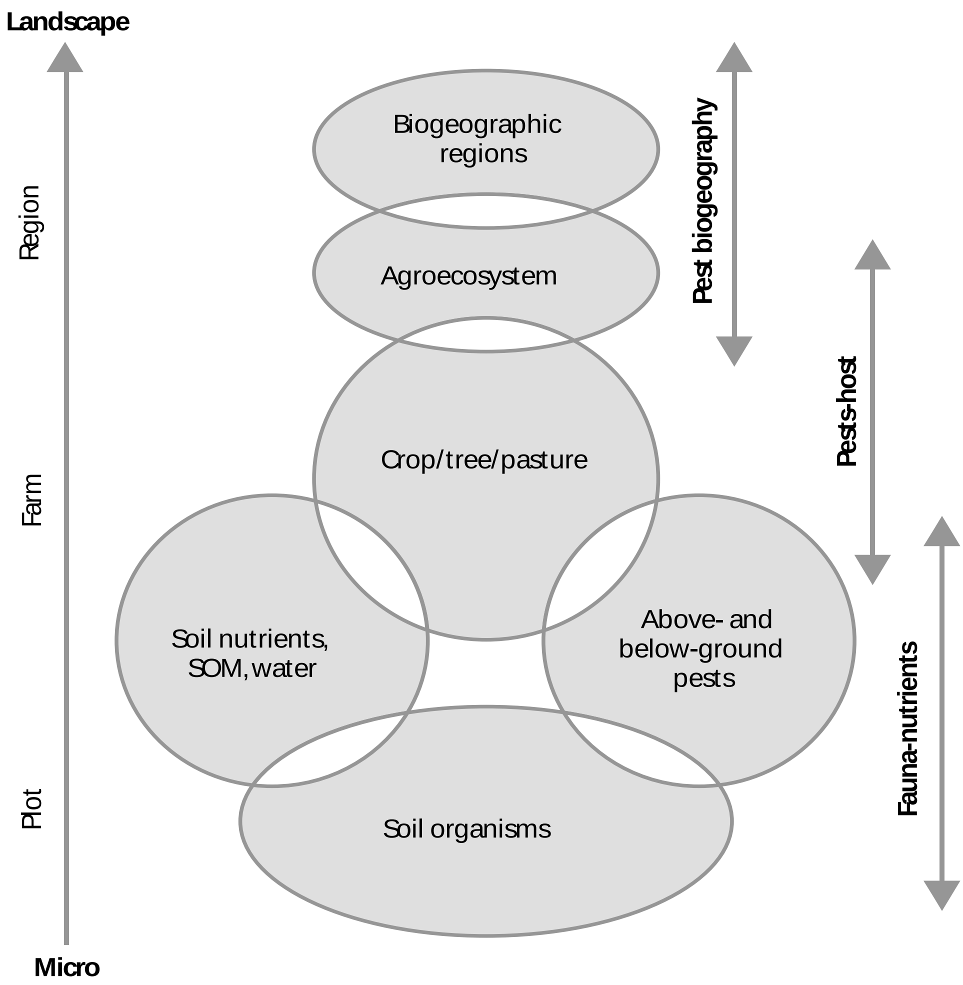
Chains of cause and effect typically link different scales of analysis (Kolavalli and Kerr 2002). For example, regional policies on the burning of crop residues may influence mulch management at the farm level, affecting soil water and organic matter levels and fractions and rates of erosion at the plot level, with consequences for water quality in the watershed as well as for crop yields and family incomes at the farm level.

Intervention points are opportunities for addressing the problem set. They are not restricted to new farm-level technologies; they may also include changes in policies and institutional arrangements, e.g., rules governing community forest management. However, policy change as an intervention is most effective when cause-and-effect relationships are clear, that is, when there is a reasonable likelihood that a change in policies or institutions will modify farmer or community behavior in ways that lead to desired changes in biophysical processes, system productivity, and environmental and resource quality. Interventions, then, can be at any level of analysis: plot, farm, community, watershed, or region. They may be developed by farmers via farmer experimentation, by scientists, by policy makers, or by the private sector (Douthwaite 2002). Early successful interventions have been referred to as "sparks" (Consultative Group on International Agricultural Research 2000).

For example, a problem set may revolve around the siltation of the lowland irrigation infrastructure, leading to substantial productivity losses and heavy public investment in renovation. Causes may include heavy erosion from upland areas driven by policies that encourage communal livestock grazing of crop residues, thus reducing incentives to use these residues as a soil cover. An intervention point might feature policy changes to foster modifications in grazing practices that encourage the use of crop residues as a soil cover mulch to reduce erosion and ameliorate the original problem of siltation.

Finally, measurement tools allow us to understand cause-and-effect links, trace and even anticipate the consequences of interventions, and understand biophysical processes at any scale of analysis. Indicators of sustainability fall into this area, as do most modeling approaches. In this vein, ecosystems analysis provides an analytical framework that makes it easier to understand the consequences of changes in both short- and long-term states at a range of scales (Craig et al. 2002, Luzadis et al. 2002, Lovell et al. 2002). The processes can be linked conceptually within a framework (see Fig. 2), and the effects of given scenarios can be quantified using simulation models linked to spatial and temporal databases through GIS.

Figure 2. Biophysical processes at different scales of analysis. SOM stands for "soil organic matter."



Of course, most models still need to be refined in the critical areas of edaphic and pest (insects, pathogens, and weeds) interactions and constraints. Ecosystems analysis can provide two critical services at relatively minor cost: (1) assessment of both genetic and environmental productivity and sustainability and (2) a framework for impact assessment and the definition of problem–cause relationships, especially those involving biophysical processes, and how those relationships affect system productivity and sustainability. INRM will fail if we do not have a problem focus and include plenty of work to identify intervention points; we cannot simply conduct academic work on measurement tools.

SIMPLE INTERVENTIONS IN COMPLEX SYSTEMS

Natural resource management practices as implemented by resource managers such as farmers, communities, fishers, and forest dwellers are typically complex. Rules governing the use of land and water resources or forest or fishery stocks are usually complicated and difficult for outsiders to understand. However, intervention points, including new technologies or practices for resource use, can be relatively simple. Interventions are usefully seen as options or alternatives for exploration by resource users, who can best judge the attractiveness of an option by testing it under local circumstances.

However, even for simple interventions the consequences of widespread adoption can be hugely complicated. The introduction of relatively simple options can significantly change farming or resource management systems and their accompanying biophysical processes and system outcomes.

For example, farmers who deal with irrigated crop systems use complex practices to manage soil fertility and water quantity and quality. These include managing crop residues, fertilizers, and farmyard manure; arranging for biomass transfer from outside the farm; choosing alternative fuels for household use; deciding among alternative uses for canal and tubewell water; making decisions related to the timing and frequency of irrigation; and selecting crops for well-drained vs. poorly drained areas, among other things (Fujisaka et al. 1994). However, the introduction of a relatively simple practice such as zero-tillage crop establishment can improve the timeliness of sowing, increase the efficiency of water and nutrient use, reduce water pumping, stop groundwater depletion, reduce fuel use, drastically lower carbon emissions, change crop rotations to take advantage of the earlier grain-crop sowing, and change soil chemistry and soil health via new rotations (Hobbs and Morris 1996). Some of these consequences, e.g., changes in the quality and quantity of groundwater, may become apparent only at higher scales of analysis.

A good understanding of ecological, biophysical, economic, and social processes is needed to anticipate, model, assess, and manage such changes. Otherwise, farmers and scientists alike can only react to changes as they unfold.

THE NOTION OF SCALE

The role of integrated natural resource management (INRM) in "delivering the goods," that is, in fostering improvements in the livelihoods of large numbers of the poor, is often referred to as scaling out. This phrase conceals as much as it clarifies, because the notion of "scale" is perceived in many different ways, among them:

- scale of analysis: from plant to plot to farm to watershed to region;
- scale of intervention point: high-level interventions such as policy changes, adjustments in institutional arrangements or property rights, and the fostering of collective action vs. lower-level interventions such as farmer experimentation or extension for specific practices;
- scale of investment in intervention strategies: small vs. large investments in extension, farmer experimentation programs, or efforts to provide information to policy makers;
- scale of community empowerment: the number of communities able to undertake their own research and adaptation through processes for local learning;
- scale of geographical coverage of an INRM practice: whether it is limited to a village or watershed or has attained regional or national relevance;
- scale of impact: for example, the extent to which desirable outcomes, e.g., improved system productivity and resource quality, have been achieved through INRM research.

In principle, these scales are linked. Greater impacts are generated from higher levels of investment in suitable intervention strategies, or from more efficient use of these investments through greater reliance on community empowerment, leading to expanded geographical coverage of suitable practices.

This paper focuses on ways to augment and accelerate the scale of geographical coverage and impact of INRM research. It emphasizes efficiency and effectiveness in generalizing and propagating research results through the replication, dissemination, and adaptation of technologies or practices. These technologies may comprise plausible promises, malleable prototypes, or well-defined practices (Douthwaite 2002). If INRM research products are not scaled out, we will have failed in our goal of contributing to poverty alleviation, food security, and environmental protection.

Sometimes, though, to augment and accelerate INRM research impacts, we must also assess and manage positive or negative externalities, unexpected complexities, or unintended consequences that emerge at higher scales of analysis from the widespread adoption of new resource management practices. This is because consequences that emerge only at higher scales of analysis may either reinforce or undermine the desired outcomes. For example:

- improved efficiency of water use at the plot level may not, in fact, lead to improved water use at the level of the whole irrigation system;

- changes in land use or crop management on hillsides may improve or possibly downgrade the quantity and quality of water available to downstream users;
- more efficient fishing practices used by one person may destroy fish stocks if used by everyone;
- local rules and incentives may be undermined by regional or national policies; and
- institutions that seek to control rather than manage biophysical processes may not foster adaptive capacity, possibly exacerbating rather than solving problems.

Effective scaling out, then, also requires attention to the other notions of scale: scale of analysis, scale of intervention point, and scale of community empowerment.

SCALING OUT AND COMMUNITY EMPOWERMENT

Much current thinking on scaling out integrated natural resource management (INRM) research steers clear of the notion of spatial extrapolation of specific practices. Rather, the emphasis is on community empowerment and scaling out as a learning process. A recent workshop report (Consultative Group on International Agricultural Research 2000) describes this well:

> *It is not technologies that are scaled up, but processes and principles behind the technologies/innovations. This is consistent with the belief that scaling out is not just replication but adaptation and learning that is flexible and interactive ... Scaling out is really about people—of communicating options to people, of a balance between introducing options and involving farmers' ability to adapt to changing contexts ... Scaling out as a development process rejects the cookie cutter approach. [It] ... achieves large numbers and wide area coverage through multiplication with adaptation ...*

We agree with these conclusions. Bottom-up farmer experimentation and community empowerment are fundamental to scaling out INRM practices. However, these bottom-up approaches will be more effective when their outcomes are widely shared. Surely farmer experimenters are likely to be interested in trying out exciting practices developed in similar communities facing similar problems.

Although scaling out is largely a bottom-up process whereby research outcomes are widely shared, our experience suggests that the use of information technologies such as the methods and tools described below can help "smarten" and focus the process.

ELEMENTS OF SCALING OUT

What can be done to foster the effective scaling out of suitable natural resource management practices? We suggest some activities below, several of which involve improvements in human and social capital.

- *Generate more attractive products.* Regardless of how it is done, scaling out is easier when practices are less risky and more profitable, and meet other resource management objectives. Participatory research increases the chance of identifying attractive options.
- *Balance supply-driven approaches with resource-user demands.* Demands from resource users must influence the kinds of resource management options developed through research and the kinds of options to be scaled out. However, they cannot express a demand for practices with which they are unfamiliar. Scaling out, then, must include ways for users to become familiar enough with new options to judge their attractiveness under local conditions.
- *Use feedback to redefine the research agenda.* As information accumulates on technology performance and attractiveness and how policies and institutions influence them, integrated natural resource management research can and should be adjusted accordingly.
- *Encourage support groups and networks for information sharing.* Community groups, cross-community networks, alliances of networks, study tours, and scientific exchanges can all can help resource users as well as scientists better understand the performance of alternatives and options under different conditions.
- *Facilitate negotiation among stakeholders.* With multiple-function, multiple-user resources, trade-offs in resource use may lead to conflicts among stakeholders. Negotiation and conflict management among stakeholders may be helpful in resolving conflicts and encouraging the use of suitable practices.
- *Provide information of use to those who are establishing policies and developing institutions.* Scientists can provide helpful information for policy formulation and institutional development. For example, if adaptable institutions are needed to review new resource management practices, this should be made clear. Policy makers may welcome new information on how resource management practices can help them meet economic and social goals. New policies and institutions can influence human behavior, including technology adoption.
- *Make sensible use of information management tools such as GIS and modeling.* When practices that raise agroecosystem productivity, improve resource quality, and ameliorate environmental consequences are discovered or developed, there is an understandable interest in seeing that these practices or their adaptations are used more widely. Adding a spatial dimension to the problem-solving process can help make this happen. This results from the simple recognition that practices may be equally attractive to different farmers or farming communities that face similar problem sets, are driven by similar

causes, and are governed by similar factors with regard to adoption behavior. This is not a plea for top-down mechanical extrapolation of technology; rather, it is the recognition that stakeholders can use the information provided by spatial analysis when making decisions.

For example, in a certain community, a green manure cover crop may smother weeds, free up labor, improve water use efficiency, reduce the need for external inputs, raise yields, and improve farm family livelihoods. Research may suggest that this practice is most attractive in locations where the cover crop is climatically adapted, soil fertility is within a certain range, land use intensity is low (allowing a cover crop/grain crop rotation), and marketing margins are high (making external input use unprofitable). Spatial analysis that combines data on the climate, soils, population density, crop distribution, and transport infrastructure can identify large areas in other communities that might benefit from this practice. This outcome can be shared with NGOs, research and extension institutions, farmer groups, and policy makers for use as they see fit. This may encourage NGOs or farmer groups to experiment with and adapt the practice, or at least to evaluate its attractiveness under local conditions.

INFORMATION MANAGEMENT TOOLS FOR SCALING OUT: EXAMPLES

The following sections provide examples of information management tools of potential use in scaling out integrated natural resource management (INRM) practices. Most examples are drawn from CIMMYT's collaboration with a range of partners in South Asia, southern Africa, and Mesoamerica. The selection of examples is illustrative, not comprehensive. The methods and tools discussed include site similarity analysis through GIS, the linking of simulation models with GIS, and the use of farmer and land type categories. Although, in most instances, the tools and methods show considerable promise for use in scaling out INRM practices, on-the-ground experience remains insufficient. The strengths and weaknesses of these methods and tools are presented in Table 1.

Site similarity analysis through GIS

A recurring question in efforts to scale out promising interventions is how a practice developed at one location will perform over a broader range of environments. Geographic information systems (GIS) can address such concerns, allowing scientists to share relevant results with colleagues elsewhere, to find new sites for testing and adapting discoveries, and to design more effective research programs. One simple GIS-based approach is to identify areas that are similar to a given location, using criteria relevant to the problem at hand (Corbett et al. 1999).

To identify regions suitable for the introduction and adaptation of wheat production practices that might show promise for conditions in Bolivia, a GIS was used to identify sites similar to key research locations in the country's two major wheat system environments

Table 1. Relative strengths and weaknesses of tools and methods for scaling out.

Tool or method	Strength	Weakness
Site similarity analysis.	• Simple tools available. • Conceptually accessible.	• May over-simplify. • Criteria for similarity often subjective.
Interfacing GIS with models.	• Allows examination of time trends, including climatic risk. • Can express outputs in terms of specific variables of interest to stakeholders.	• Dependent on quality of data. • Dependent on quality of model. • Requires specialists to implement.
Land type and farmer categories.	• Outputs are conceptually accessible. • Outputs can be used by extension workers and farmer experimenters.	• Outputs may be too subjective. • Data acquisition is labor intensive. • May ignore interactions across land types within a household.
Participatory extension; e.g., whole family training.	• Outputs are readily accessible to farm families. • Can be scaled up in terms of organizational capacity required for implementation.	• Deals only with the family as a unit, does not extend to collective action at the community level. • Does not have an explicit spatial dimension.

(Hodson et al. 1998). In the highlands, wheat is grown on summer rains in numerous valleys and small plateaus. In the eastern lowlands, the crop is sown on residual soil moisture as temperatures drop and become more favorable for wheat. Zones of similarity were defined using the GIS-based Spatial Characterization Tool (Corbett and O'Brien 1997) by specifying the latitude and longitude of a given research site and then selecting criteria for similarity based on ranges of precipitation, potential evapotranspiration, and temperature. For the highlands, zones were based on the favorable 5-month growing period, and for the lowlands, the coolest quarter was used.

There were scattered zones of similarity in the highlands of Bolivia, Peru, Colombia, and Venezuela. Extending the analysis to Mexico, Central America, and Africa resulted in the identification of additional areas with similar climates, notably in Mexico and Ethiopia (Fig. 3). For lowland sites, the largest regions outside of Bolivia were in two substantial but disjunct areas of eastern and southwestern Brazil. To extend the analysis to a complete farming system scenario, similarity zones for the rainy season were identified to account for the times when crops such as maize, cotton, and soybean were normally sown and harvested. This allowed researchers to narrow regions of similarity to a single area in eastern Brazil (Fig. 4).

Figure 3. Zones of Bolivia, Peru, Colombia, and Venezuela that are climatically similar to two Bolivian highland wheat production sites for the 5-month optimal crop growth period (± 20% similarity for precipitation and evapotranspiration, ± 10% similarity for maximum and minimum temperature).

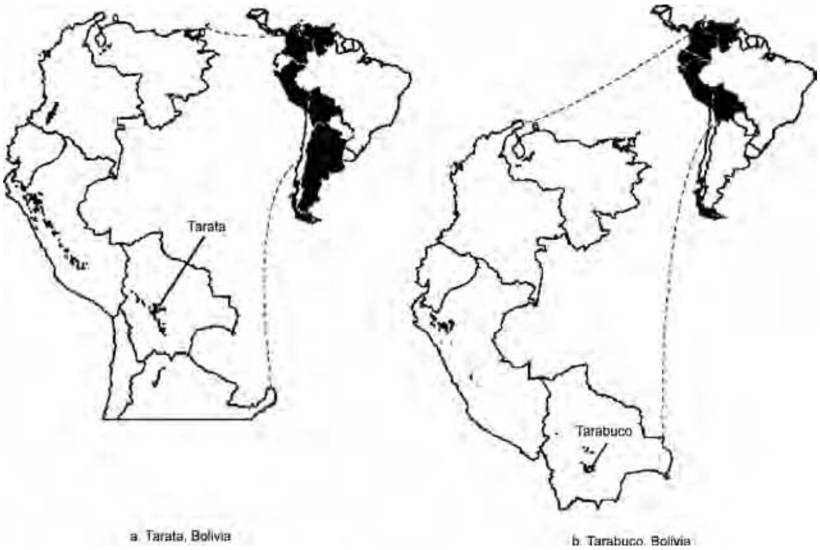
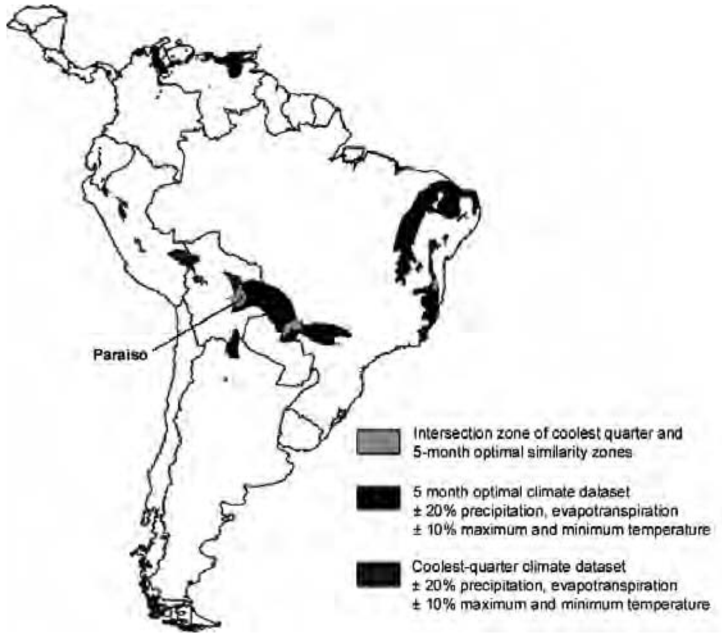


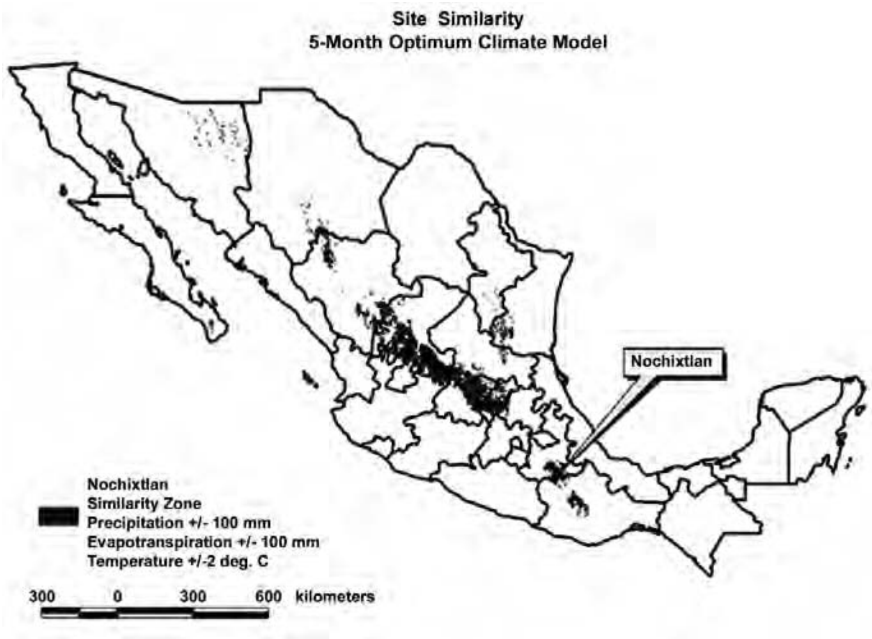
Figure 4. Zones that are climatically similar to the lowland wheat production site, Paraiso, Bolivia, for the coolest quarter of the year, the 5-month optimal crop growth period, and the intersection zone of both.



This specific analysis has yet to be tapped to scale out INRM practices. However, it has now become clear that researchers and farmer experimenters in the defined areas of Bolivia, Brazil, Mexico, and Ethiopia are addressing similar problem sets with similar interventions, and would benefit from sharing research information and results.

In a different application and on a different scale, farmer experimenters in the Mixteca region of southern Mexico, one of the country's poorest areas, used site similarity analysis to identify locations elsewhere in Mexico with climate and soil conditions similar to their own (Fig. 5). This information was then used to plan a study tour of research and farmer experimentation in these similarity areas. The farmers returned home with several ideas that they have begun to test, among them the use of crop residue mulches and drip irrigation for fruits and vegetables (J. C. Velásquez, 2000, *unpublished manuscript*).

Figure 5. Areas throughout Mexico that possess climate and soil conditions similar to those of Nochixtlan, a village in the Mixteca region.



Interfacing models with GIS

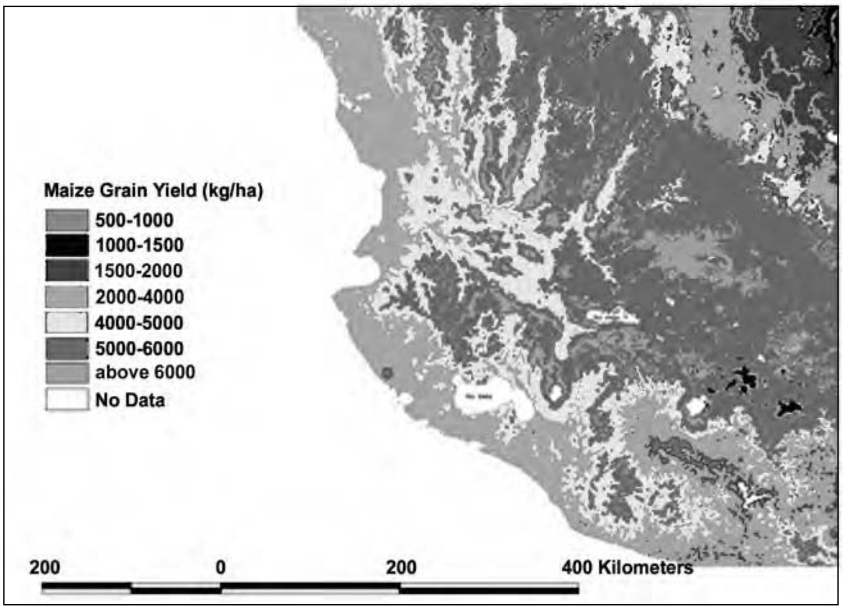
More complex comparisons may be beneficial to address some situations. Stakeholders may want to examine trade-offs for different scenarios. For example, are the productivity gains from conservation tillage likely to entirely offset the value of crop residues for animal feed? How will system performance vary over time, particularly in extremely dry or wet years?

Process-based simulation models can "grow" a virtual cropping system over many seasons, quickly and inexpensively. The output, in effect, extends the reach of science beyond the practicable time horizons of most research programs, while making it possible to examine variables that are difficult or costly to monitor at the field level (e.g., nitrogen leaching and volatilization). By interfacing GIS with simulation models, researchers can develop simulated performance surfaces that portray the likely biophysical consequences of a technology over space and over time (Hartkamp et al. 1999).

Using this approach, CIMMYT scientists examined how the performance of conservation tillage with residue retention might vary over space and time in western Mexico (Hartkamp 2000). Two key factors in the simulations were weather and soil type. Through collaboration with the International Fertilizer Development Center, a residue retention module was added to the Decision Support System for Agrotechnology Transfer suite of crop models (Tsuji et al. 1994).

Outputs from simulations (Fig. 6) were compared with experimental results and with the researchers' own experiences. Using the resulting maps, researchers and decision makers were able to assess the simulated effects of conservation tillage on run-off and erosion, organic matter, soil structure, and moisture conservation. For each soil type, maps produced using the simulations show differences across the region in the biophysical performance of the practice. Impacts can be expressed in terms of various factors, including yield, stability, biomass, and the organic carbon and nitrogen use efficiency of the soil. The methodology thus shows promise for providing information for a range of stakeholders; the maps and other outputs can help NGOs, farmer groups, and researchers determine where conservation tillage may be most appropriate for farmer experimentation and adaptation.

Figure 6. Simulated 12-year average for maize grain yields under a conservation tillage system (maize-fallow with 33% residue retention) in the state of Jalisco, western Mexico, produced using Decision Support System for Agrotechnology Transfer models linked to geographic information system databases.



Land type and farmer categories

The GIS-based applications described above emphasize regional, national, or international comparisons that can be used to guide scaling out. However, more modest tools and methods that feature comparisons across farms can serve the same purpose. It has long been known that many farmers recognize different land types within a farm. These land types frequently follow the toposequence. When problems, causes, and intervention points are specific to land types, scaling out activities can be guided by the typology. When land types are replicated across large areas of the landscape, efficiencies in scaling out can be considerable. Often, of course, farmers with different resource endowments use different management practices for the same land type. Consequently, measures to foster scaling out must also consider farmer categories and cross-land type interactions within farms.

In the rice–wheat systems of the Indo-gangetic Plains, rainfall, water control, and soil texture tend to follow an east–west gradient. However, water control and soil texture in specific locations are also influenced by land type, i.e., lower, middle, and upper terraces, within a toposequence. Even though a land type may be known by different local names in different parts of the Indo-gangetic Plains, its characteristics, uses, and management are often similar (Harrington et al. 1993). Lower terraces are characterized by heavier soils and relatively poor drainage and are more likely to be devoted to long-duration, traditional rice cultivars. Middle terraces have somewhat lighter soils and fewer drainage problems and are typically sown to modern rice and wheat varieties, at times mixed with other crops. Upper terraces have the lightest soils of all and tend to have greater agroecosystem species diversity. Here rice and wheat are sown, as well as pigeonpea, sugarcane, and vegetables.

The usual problems of rice–wheat rotations in the Indo-gangetic Plains, in particular, late sowing, high costs for tillage and establishment, low water and nutrient use efficiency, soil fertility decline, reduced agroecosystem species diversity, salinity and sodicity, waterlogging, and excessive water pumping leading to groundwater depletion, unfold differently in each land type. Similarly, intervention points change across land types but also by farmer category.

To give one simple example, it has become clear that the establishment of wheat after rice is best performed by inverted-T, zero-till seed drills drawn by four-wheel tractors for larger-scale farmers and on upper terraces. However, for smaller-scale farmers on middle and lower terraces, wheat establishment typically is best performed by surface seeding (Hobbs et al. 1998). In this practice, presoaked, pregerminated wheat seed is broadcast into a standing rice crop as water is being drained off. The presoak is a manure slurry that makes the seed unappetizing to birds. If the timing is right, soil moisture substitutes for tillage in reducing soil strength, so that roots follow the water down the profile. In both zero-till and surface seeding, there is considerable room for farmer testing and local adaptation.

In another example, farmers in southern Zimbabwe distinguish among “vlei” bottoms (wetter areas where rainfall accumulates through natural drainage), homestead gardens (with soils that benefit from crop residues, leaf litter, household waste, and farmyard manure), and toplands (with soils of low fertility and low water-holding capacity, relatively distant from the household). These different land types are managed very differently with respect to crop selection and rotations, the application of organic and inorganic fertilizers, soil fertility management, and so on (Z. Shamudzarira and C. Vaughan, 2000, *unpublished manuscript*). In addition, farmers with many draft animals manage land types differently from farmers with few draft animals. Nevertheless, these land types and farmer categories are replicated across much of southern Zimbabwe and adjoining areas of South Africa and Mozambique.

Exciting practices for addressing important problems, once characterized in terms of land type and farmer category, can be shared widely with farmer groups, NGOs, researchers, and other stakeholders in areas where these same land types and farmer categories prevail. Once again, the intent is to make the exciting practices available as new options to be mixed into local learning processes, not just for "cookie-cutter replication."

A FEW WORDS ON EXTERNALITIES

The heart of scaling up is anticipating, modeling, monitoring, and assessing positive or negative externalities, unconsidered complexities, or unintended consequences that emerge at higher scales of analysis from widespread scaling out, and then contributing to the management of these factors. This may require the use of implicit, explicit, or even mathematical models and an understanding of the interactions among humans, institutions, and ecological processes. In a very real sense, an understanding of consequences "at scale" can be used as feedback to redefine the elements of scaling out to minimize undesirable externalities.

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8.

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

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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 bringing 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 borne by the research projects themselves. We raise the concern that these activities may not be widely replicable if such costs are not reduced or borne 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.

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, Campbell et al. 2002, Cain et al. in press). 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, Beaulieu et al. 2002, Michaelidou et al. 2002). 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, van Noordwijk et al. 2001).

Faced with such daunting complexity, many have advocated an adaptive approach to managing ecological systems (Holling 1978, Walters 1986, Rogers and Bestbier 1997, Oglethorpe 2002). 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, Cain et al. in press). 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. In 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 then 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.

CASE STUDIES

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.

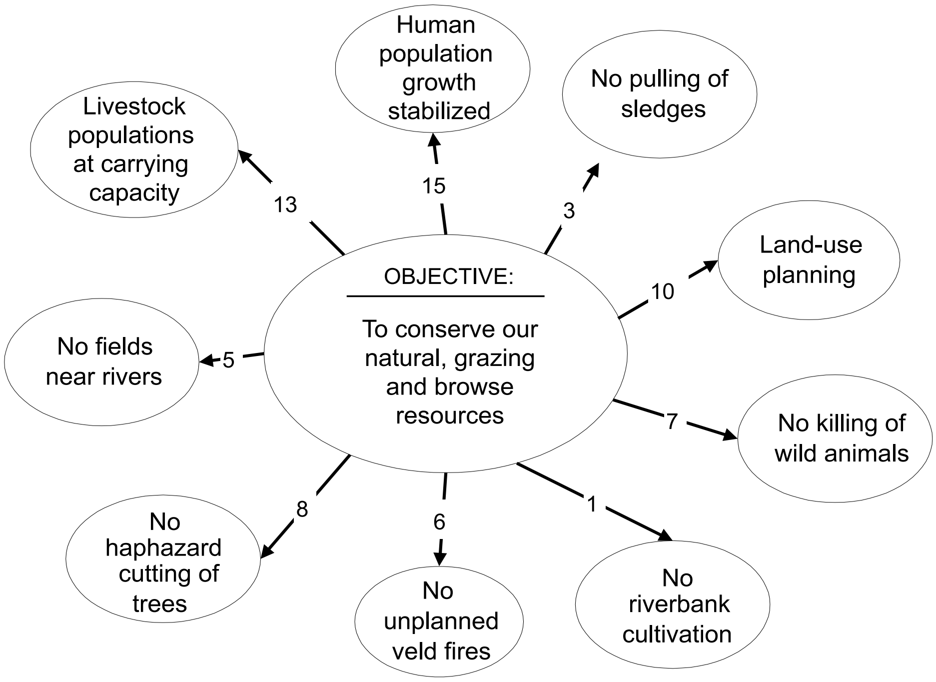
These initially broad objectives were not appropriate for developing actual interventions; they were rather a basis for local policy-level goals. Thus, a second workshop was held to identify which of the objectives were most important and, subsequently, to develop a more refined set of objectives that 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.

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."

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



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).

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

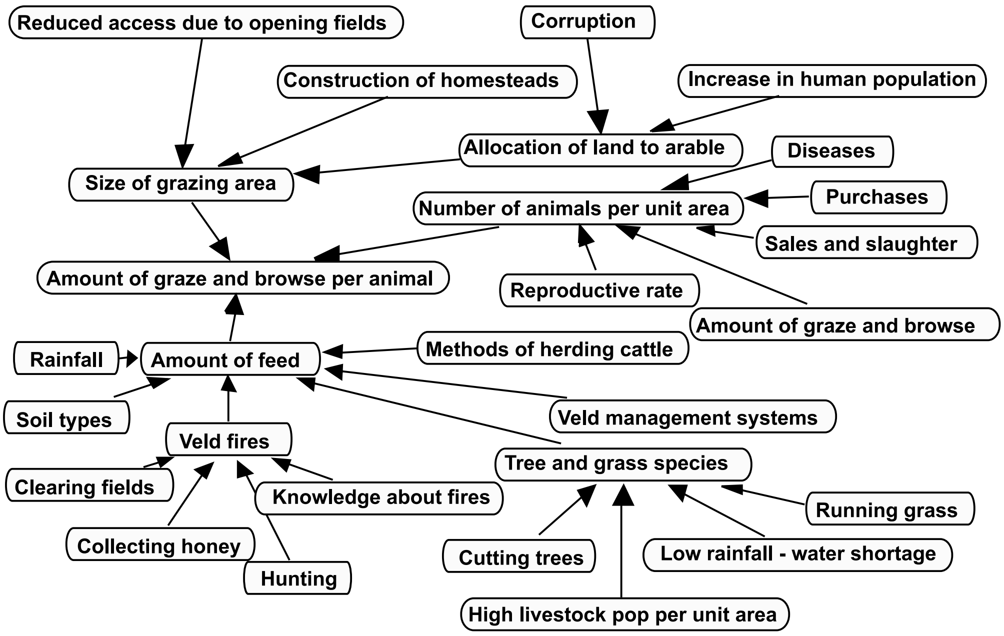


Figure 3. Factors affecting the local acceptance of management plans developed through the research process. Numbers on the spidergram arms indicate the relative importance of each factor at each level; the least important factor is always scored with 1.

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 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 considered 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 multi-agent system).

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).

Figure 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).
>
> *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.

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.

Figure 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.

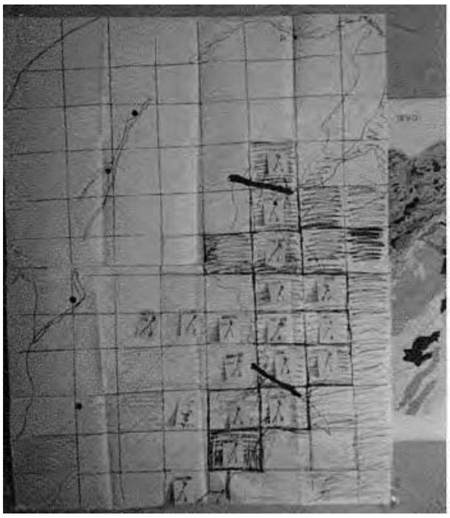


Figure 6. General algorithm of the role game and the model. At each time step (monthly), all agents look for a good place to make crops or to harvest pasture. The agents represent the actors, who may be farmers or herders. At time step 1 (July, in reality), they look for a good place for the wet season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

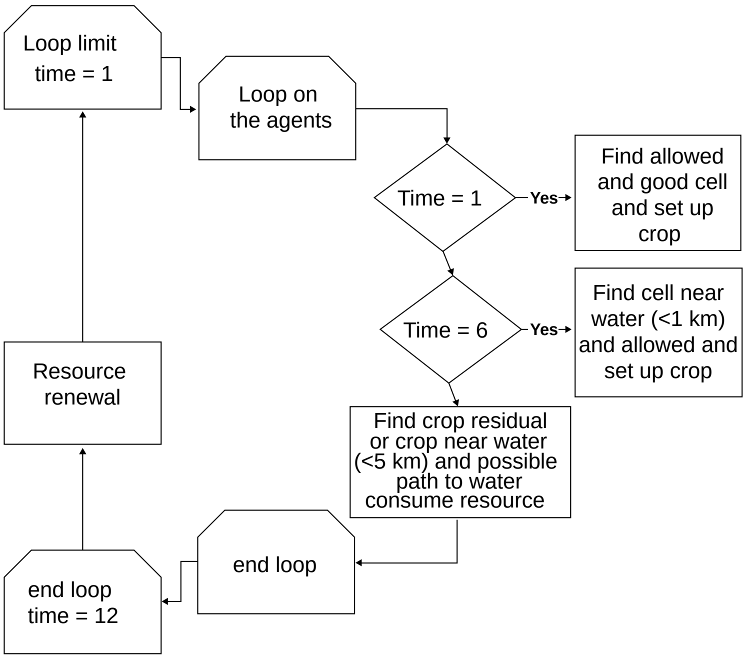


Figure 7. The initial map of Ngnith village, Senegal. The lake is in dark gray and water holes are dark gray dots. The other shades of gray represent the soil quality.

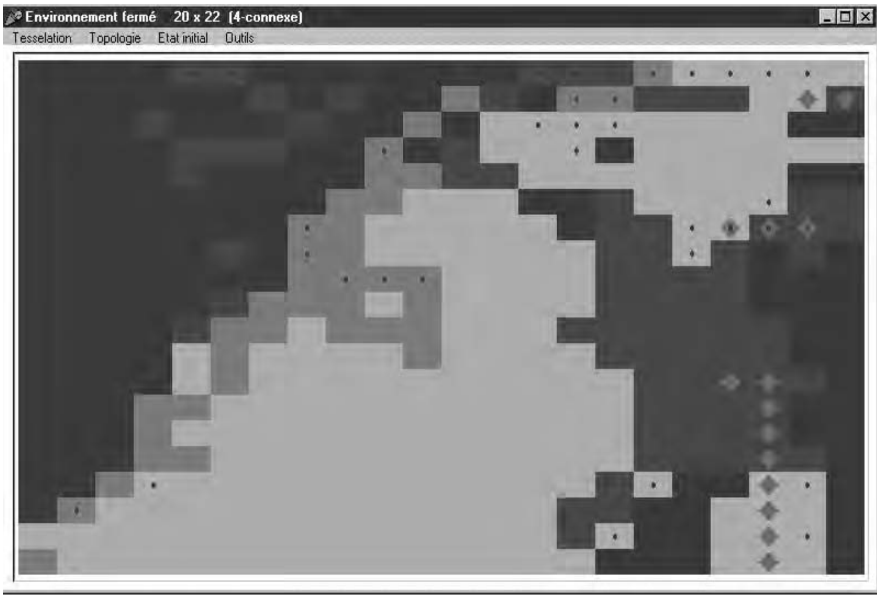
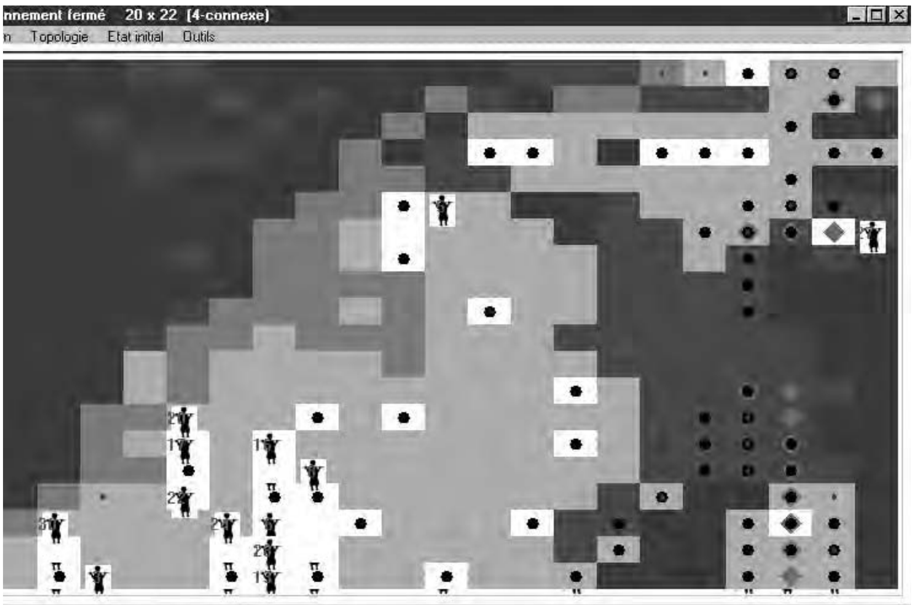


Figure 8. End of a yearly simulation. Black dots are the crops and white dots are areas where resources have been consumed. On this screen copy, one can see that the herders who have no access to the lake go west.



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.

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9.

Spatial Modeling of Risk in Natural Resource Management

Peter G. Jones[1] and Philip K. Thornton[2]

ABSTRACT

Making decisions in natural resource management involves an understanding of the risk and uncertainty of the outcomes, such as crop failure or cattle starvation, and of the normal spread of the expected production. Hedging against poor outcomes often means lack of investment and slow adoption of new methods. At the household level, production instability can have serious effects on income and food security. At the national level, it can have social and economic impacts that may affect all sectors of society. Crop models such as CERES-Maize are excellent tools for assessing weather-related production variability. WATBAL is a water balance model that can provide robust estimates of the potential growing days for a pasture. These models require large quantities of daily weather data that are rarely available. MarkSim is an application for generating synthetic daily weather files by estimating the third-order Markov model parameters from interpolated climate surfaces. The models can then be run for each distinct point on the map. This paper examines the growth of maize and pasture in dryland agriculture in southern Africa. Weather simulators produce independent estimates for each point on the map; however, we know that a spatial coherence of weather exists. We investigated a method of incorporating spatial coherence into MarkSim and show that it increases the variance of production. This means that all of the farmers in a coherent area share poor yields, with important consequences for food security, markets, transport, and shared grazing lands. The long-term aspects of risk are associated with global climate change. We used the results of a global circulation model (GCM) to extrapolate to the year 2055. We found that low maize yields would become more likely in the marginal

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areas, whereas they may actually increase in some areas. The same trend was found with pasture growth. We outline areas where further work is required before these tools and methods can address natural resource management problems in a comprehensive manner at local community and policy levels.

KEY WORDS: crop modeling, dryland agriculture, global change, global circulation model, maize, Markov models, MarkSim, natural resource management, risk, southern Africa, spatial modeling, weather simulation.

INTRODUCTION

Agriculture is full of risk and uncertainty. Risk has been cited as contributing to slowed technology diffusion, fragmentation of landholdings, and price instability (Walker and Ryan 1990). It has a profound influence on decisions because it may strongly modify choices from among a set of alternatives. At the household level, risk and uncertainty can lead to substantial production instability with flow-on effects on income levels and food security. At the national level, agricultural production instability can have enormous social and economic impacts affecting all sectors of society (Alexandrov and Hoogenboom 2001). These factors influence decisions taken in agricultural production that directly affect the economic feasibility of resource management options.

Many methods and tools have been developed to try to deal with or minimize risk. Crop simulation models, for example, are excellent tools for assessing the weather-related production variability associated with particular strategies for the management of agricultural enterprises and natural resources. Simulation results can be used in a wide variety of other analytical frameworks, such as economic surplus and mathematical programming models, to provide information to a range of decision makers (Thornton and Wilkens 1998, Thornton and Herrero 2001, Hartkamp et al. 2002, Gijsman et al. 2002).

Traditionally, point models such as CERES-Maize have been run on long data sets of daily weather available from existing or historical meteorological stations. Stochastic weather simulation is often used to augment the data where historical runs are not long enough (Richardson 1985, Jones and Thornton 1993, 1997, Heinemann et al. 2002, Mavromatis et al. 2002). The results from runs on such data may be used to interpolate and map characteristics of the model output. However, the modeled processes are intrinsically nonlinear and this approach is fraught with difficulties. It would be better to map the modeled response by running the model for each point on the map. This is now feasible using MarkSim (Jones and Thornton 1999, 2000). MarkSim is an application available on CD-ROM that will generate synthetic daily weather files for use with models such as CERES-Maize. The model can be run for each distinct point on the map by estimating the third-order Markov model parameters from interpolated climate surfaces. The relevant characteristics can be extracted from each model run and can be readily mapped in the study area.

A characteristic of this approach is that each point is evaluated in isolation. However, the realism of a general crop failure is never simulated. Off-site effects of the stochasticity of climate are largely underestimated; in the real world when you have a shortage of domestic food or cattle feed, your neighbors are usually similarly affected. When a harvest is good, the market price plummets. This has real implications for national and regional infrastructure, communications, and resource management on a broad scale.

METHODS

For the study, we chose a window in southern Africa extending from 22º E to 42º E and from 23º S to 5º S, covering an area of about 38,000 km^2. This window covers the southern part of Tanzania, Malawi, much of Mozambique, and all of Zimbabwe, and extends west from the Indian Ocean to include Zambia, the southeastern part of the Democratic Republic of Congo (DRC), and small portions of Angola (Fig. 1). We chose this area because of its overall single, well-defined growing season and the considerable spatial variability in total annual rainfall. The following subsections briefly describe the models, databases, and methods that enable us to generate various maize and pasture risk scenarios for this region.

Figure 1. The study area in southern Africa, 22° E to 42° E, 3° S to 23° S (the southern part of Tanzania, Malawi, much of Mozambique, and all of Zimbabwe, extending west from the Indian Ocean to include Zambia, southeastern Democratic Republic of Congo (DRC), and small portions of Angola).

CERES-Maize

CERES-Maize is a model that simulates the growth, development, and yield of the maize crop. It was designed to use a minimum set of soil, weather, genetic, and management information. The model is run with a daily time step and requires daily weather data (maximum and minimum temperature, solar radiation, and rainfall). It calculates crop phasic and morphological development using temperature, day length, and genetic characteristics. Leaf area index, plant population, and row width provide information for determining the amount of light interception, which is assumed to be proportional to biomass production. A water and nitrogen balance submodel provides feedback that influences the development of growth processes (Ritchie et al. 1998). CERES-Maize has been widely used in North America and in the tropics and subtropics (Tsuji et al. 1998). The model has also been successfully validated and applied at many sites in our study window (see, e.g., Muchena and Iglesias [1995] for Zimbabwe, Thornton et al. [1995] for Malawi, and Schulze [2000] and Durand and du Toit [2000] for southern Africa). To run CERES-Maize, we need data on daily weather, the soil profile, genetic coefficients for the variety simulated, and information on the crop management.

MarkSim and weather data

Over the last few years, we have developed and extensively tested a third-order Markov rainfall model (Jones and Thornton 1993). Being able to model outlying rainfall years satisfactorily is particularly important in studies aimed at quantifying production system risk. A Markov model works by randomly sampling a series of events where the probability of observing an event depends on the occurrence of previous events. A third-order Markov model takes into account events occurring over the previous three days. We have found that, whereas a lower order model is often sufficient for temperate climates, the third order is necessary for many tropical climates. This simple model should be able to simulate the variance of monthly and annual rainfall for sites in the tropics and subtropics, but even the third-order model falls short of reality. The MarkSim rainfall generator makes good this deficit by means of annual random resampling of certain of the model's own parameters.

Jones and Thornton (1997) showed that patterns could be discerned in the parameter values that were typical for certain types of climate. The model can thus be used to interpolate rainfall data for places where they do not exist. Regression models were developed that predict the Markov model parameters within certain restricted climate sets (Jones and Thornton 1999). The MarkSim system identifies the climate set relevant to any required point on the globe, using interpolated climate surfaces, and evaluates the model parameters for that point. The climate surfaces used are the 10 minutes-of-arc surfaces fitted at Centro Internacional de Agricultura Tropical (CIAT), based on the National Oceanographic and Atmospheric Administration (NOAA) dataset TGOP006 (NOAA 1984), using inverse square distance weights for spatial interpolation, and a standard lapse rate model to correct temperature for elevation effects. These surfaces are based on historical data from stations having more than 10 years of record taken from the period 1920–1990. Therefore, they are not standard climate normals, but compensate for the lack of time standardization by including more stations.

Jones and Thornton (2000) describe the program in detail. Hartkamp et al. (1999) have shown that inverse distance weighting methods perform as well as thin-plate smoothing and co-kriging. A wide range of statistical validation tests of the MarkSim simulated data has been presented in Jones and Thornton (1993, 1997, 1999, 2000).

Soils data

We used the Food and Agriculture Organization digital soil map of the world (FAO 1974, 1995) and cut out the appropriate window (see Fig. 1). For all of the soil types in the window, we made a qualitative assessment (based on the soil unit ratings in FAO [1978]) as to their agricultural suitability for maize production: class 1, unsuitable; class 2, moderately suitable; and class 3, highly suitable. We then assembled representative profiles from the International Soils Reference and Information Center's World Inventory of Soil Emission Potentials (WISE) database (Batjes and Bridges 1994, Batjes 1995) for each of the soils in the FAO soil map units that fell into classes 2 and 3. We used a combination of the pedotransfer functions in the decision support system for agricultural technology transfer, implemented in a VisualBasic program by Ravic Nijbroek at International Livestock Research Institute (ILRI), and a database at CIAT, assembled by Jamie Fairbairn (*unpublished data*) to estimate water-holding capacities.

Genetic coefficient data and management data

We used Katumani Composite B (KCB), a Kenyan, open-pollinated maize variety developed >25 years ago as a fairly short-season variety (about 120 days) for the dry mid-altitude conditions of Kenya (Hassan 1998). It was planted at a density of 3.7 plants/m^2, with 50 kg/ha of mineral N distributed through the soil profile. For all soils, 10 kg/ha of inorganic N was applied to the crop at planting. Planting was carried out automatically, when the first 30 cm of the soil profile first reaches 40% field moisture capacity each season. The genetic coefficients for KCB were determined in growth experiments carried out in the Republic of South Africa (A. S. du Toit, *personal communication* 1999).

Climate change models

To derive a set of climate surfaces for Africa for the middle of 2041–2070, we accessed the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Centre on the worldwide web (URL: http://ipcc-ddc.cru.uea.ac.uk/). We decided to use a recent experiment conducted at the Hadley Centre, East Anglia, using the new Unified Model (Cullen 1993). The model, HadCM2, has a spatial resolution of 2.5° x 3.75° (latitude by longitude). This produces a surface spatial resolution of about 417 km x 278 km at the equator. In order to undertake a "warm-start" experiment, the model must be perturbed with a forcing from an early historical era when the radiative forcing was relatively small compared with the present. The experiment performed with HadCM2 started with forcing from the middle industrial era, around 1860 (Mitchell et al. 1995, Johns et al. 1997). We used the monthly mean values of maximum and minimum temperature and precipitation for the period 2041–2070. In the following analyses, we refer to these as the 2055 data. We used the standard CIAT technique of inverse square distance weighted interpolation on the GCM model results to interpolate to the same grid as MarkSim (Jones and Thornton 2000).

Coherence clustering and modification of MarkSim

The spatial coherence and variability of weather are manifest at a wide range of scales. On a daily basis, it is not unusual to have rain on one farm while the neighbors' fields are dry. A county, watershed, or market hinterland may be subject to water restrictions, while another area of the country experiences good rains. Events such as ENSO (El Niño-Southern Oscillation) may produce widespread drought in large areas, whereas other areas are subject to flooding.

The pixel-by-pixel simulation of MarkSim produces realistic results in the first case. Local variation in weather is built into the basic stochastic process. We conjecture that the mid-scale regional coherence may be approached via the resampling of the Markov probability parameters, but this remains to be tested thoroughly. If these change in lock step across a region, the resultant weather patterns will show a marked regional coherence imposed on the basic Markov process. Global forcing events, such as ENSO, are not yet incorporated in MarkSim, but we will be looking at this possibility soon.

In this study, we have concentrated on the mid-range spatial coherence of climate. We used the MarkSim cluster algorithm to group the climates of the study window (23,760 pixels). This was a leader cluster algorithm with a second pass to reallocate pixels to the closest cluster seed using the normalized monthly rainfall, temperature, and diurnal temperature range as the 36 cluster variates. Rainfall was transformed to the square root before normalization. We made one run from cluster to a few large climate regions, and a second to produce more, but smaller, areas. After cleaning to eliminate areas with less than six pixels, we obtained 21 areas in the first case and 51 in the second.

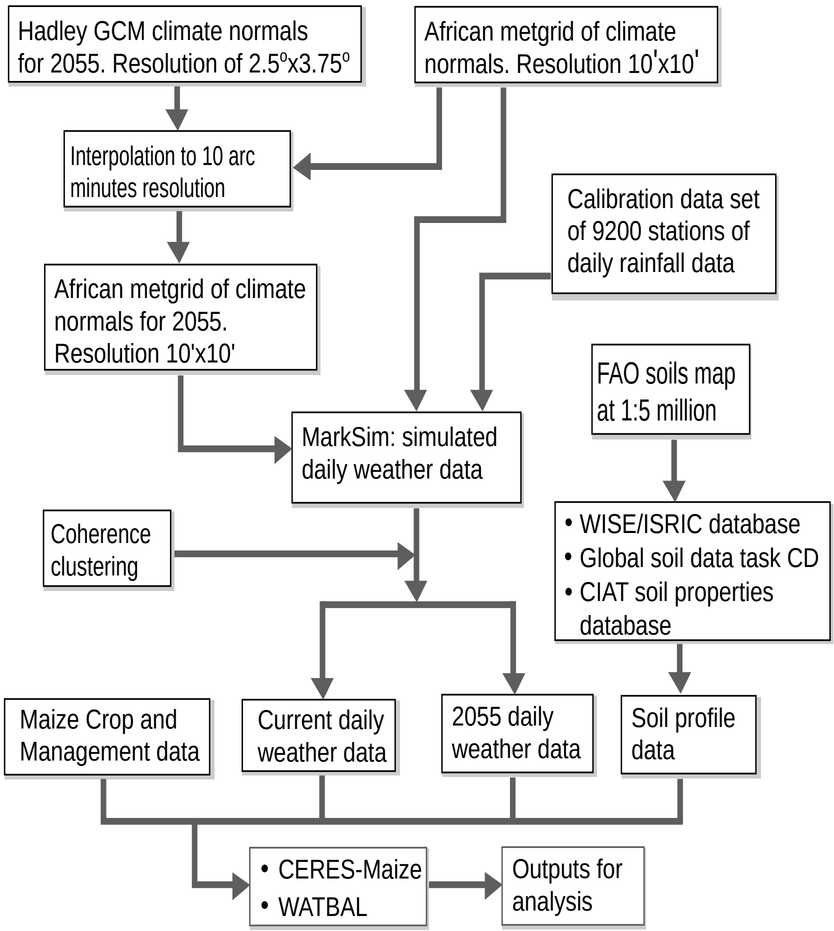
We modified MarkSim to separate the random number series for the parameter resampling from the basic Markov process and the gamma distribution sampling of rainfall event size. In each case, we constructed a common set of random normal deviates that were used to coordinate the random resampling throughout each climate zone.

Simulations

Figure 2 shows the links between the various databases and tools that were previously described. We ran six experiments or scenarios. These involved 3975 treatments (unique combinations of soil and weather inputs for the 1042 sample points; note that there may be 1–6 soil types per pixel) of CERES-Maize. Each treatment was replicated 29 times (making use of 30 years of simulated weather, because the maize growing season usually crossed years). The six experiments were:

1. Markov weather parameters using current long-term climate ("present weather") assuming complete independence between weather grid cells ("random weather").
2. Weather parameters using current long-term climate, but with weather dependence across 21 zones as described earlier.

Figure 2. Schema of steps and methods in the analysis.



3. Weather parameters using current long-term climate, but with weather dependence across 51 zones.
4. Weather parameters using estimated long-term climate for the period 2041–2070 ("2055 weather"), assuming complete independence between weather grid cells.
5. Weather parameters using 2055 long-term climate, but with weather dependence across 21 zones.
6. Weather parameters using 2055 long-term climate, but with weather dependence across 51 zones.

The 115,275 runs for each scenario took about 6 hours on a Pentium III processor. The model WATBAL was run for the same set of scenarios to give an indication of pasture

growth for the same sample points. As a proxy for this, we used the number of growing days, defined as the number of days when the ratio of actual to potential evapotranspiration exceeded 0.5. Because it is a much simpler model than CERES, it ran more quickly. Input and analysis programs were custom-written in FORTRAN, and maps were generated using IDRISI (Eastman 1993).

Our discussion of the results is limited to considering the impact of rainfall coherence and to comparing maize and pasture yields using current weather patterns and the 2055 scenario patterns.

RESULTS

To give an idea of the types of climate in the study window, Fig. 3 shows monthly rainfall and temperatures for four sites in four of the 21 zones, for current conditions and those simulated (using the Hadley GCM) to occur using in 2055. The four sites are:

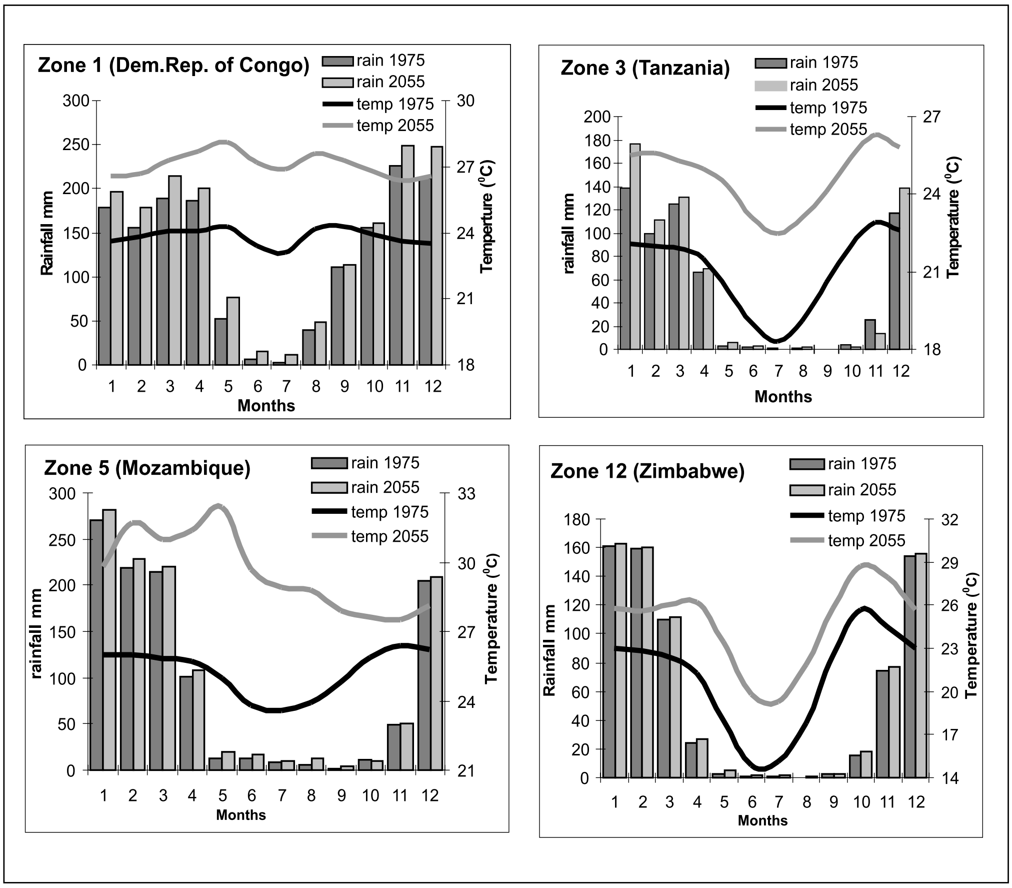
DRC: 6.58° S, 23.50° E, elevation 761 m
Tanzania: 6.25° S, 34.33° E, elevation 1356 m
Mozambique: 12.91° S, 39.50° E, elevation 426 m
Zambia: 16.91° S, 24.33° E, elevation 1066 m

Even for these four sites (see Fig. 3), although temperature increases in all months, the amounts and patterns of increase simulated to occur with the GCM show distinct differences. For most months in this sample, rainfall would appear to increase slightly, but this is offset by the increasing temperature.

Thus, the way in which changing rainfall patterns may interact with generally increased temperatures to affect agricultural production depends on location. Fig. 4 shows cumulative probability functions for simulated maize yield for these same four sites, using present and 2055 weather. The 2055 weather appears to reduce the probability of high maize yields at the Mozambique, Tanzania, and Zambia sites. Maize yields at the DRC site are predicted to be badly affected by the 2055 weather regime at the lower end of the yield spectrum, although the probabilities of obtaining yield above about 1.7 t/ha (conversion: 1 metric ton (t) = 1 Mg) are almost the same as at present. Conversely, the lower yield probabilities are strongly conserved at the Zambia site, but higher yields become far less probable. Yields at the Mozambique site are uniformly low and almost always in the 1–2 t/ha range, although the probability of achieving 2 t/ha is lower in the 2055 scenario.

Resource management must take these differences into account. At the Mozambique site, a low but constant source of domestic food supply may free resources for other enterprises, whereas, for the other three sites, domestic and regional food stocks might have to be stored to cover shortfalls arising from maize crop failure.

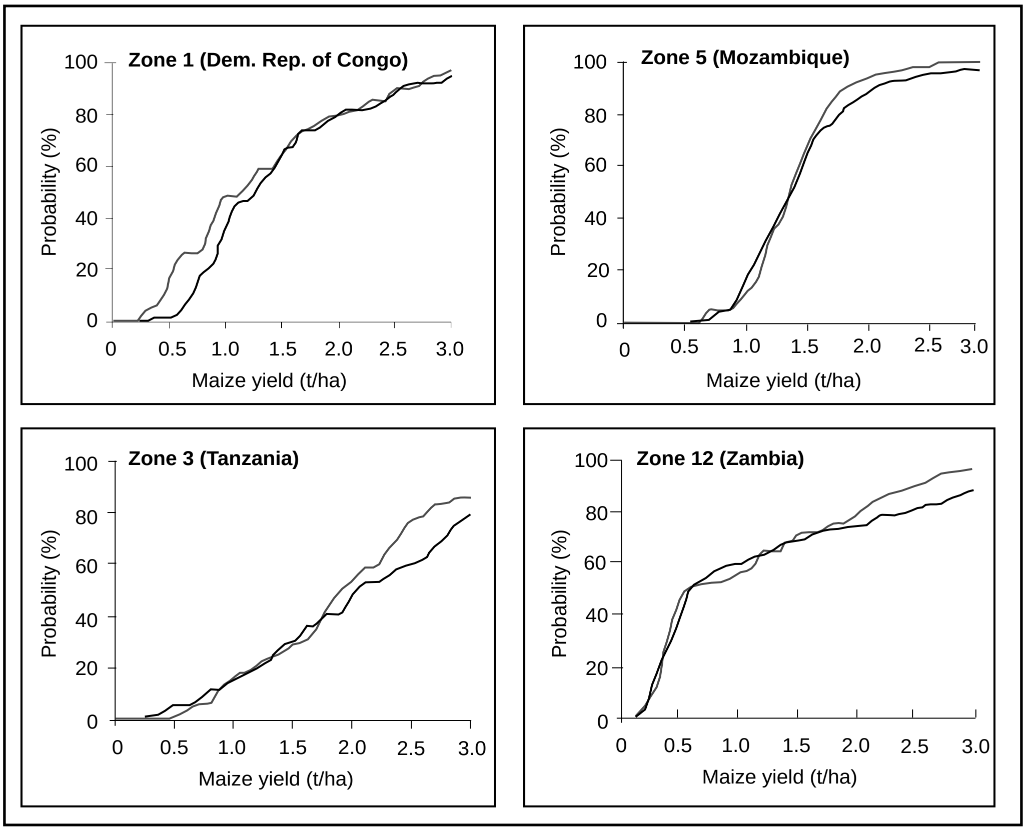
Figure 3. Monthly rainfall and temperatures representative of present and simulated 2055 climates for a random site in: zone 1 in the Democratic Republic of the Congo; zone 5 in Mozambique; zone 3 in Tanzania; and zone 12 in Zambia. See Fig. 1 for locations.



Weather coherence

Weather coherence, that is, the fact that weather conditions in a region or area are generally spatially correlated, might be expected to be of considerable importance. Fig. 5 (at left) shows an example, with the number of growing days (our proxy for pasture production) for five randomly selected sites in Zone 8 (one of the 51 weather zones located mostly in central Zimbabwe). The bottom graph shows the situation in which weather in Zone 8 is assumed to be independent, i.e., what occurs at any site in Zone 8 has no impact at all on the weather experienced at any other site. The heavy line shows the mean number of growing days. The pattern of growing days by season appears to be random; the correlation matrix for the random weather also bears this out. The top graph shows the number of growing days for the same five sites in Zone 8, this time with coherent weather. To simulate coherent rainfall at each site,

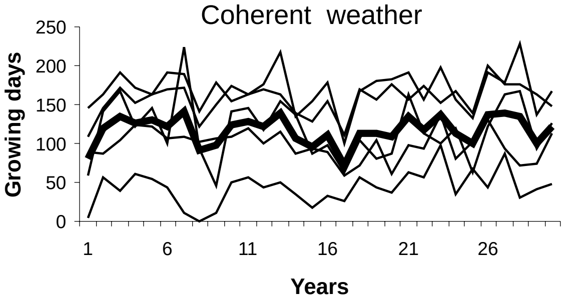
Figure 4. Cumulative maize yield probabilities [conversion: 1 t (metric ton) = 1 Mg] for present and simulated 2055 climates in the four sample zones.



the same set of normal deviates was used each year to resample the baseline rainfall probits, as outlined previously. A stronger pattern in the number of growing days is seen. Year 17 provides a good illustration of a “poor” year when, for at least four of the five sites, the number of growing days is close to the lowest number experienced in the 29 replicates. The correlation matrix in Fig. 5 (at right) indicates the “interdependence” of the weather experienced at these five sites.

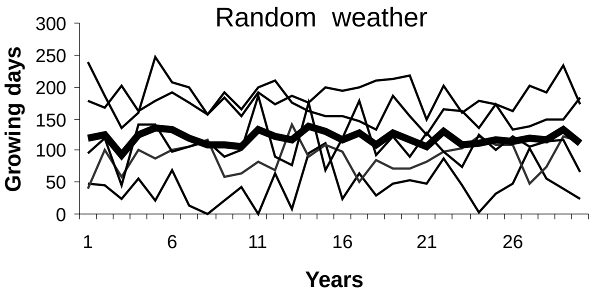
Figures 6 and 7 further illustrate the importance of coherence (and of being able to account for it). Figure 6 shows the coefficients of variation in time (CVs) of the average rainfall per zone during the maize-growing season, using random and coherent present-day weather over the 51 zones for the study window. (The higher the CV, the lighter the map shade.) For these maps, the average was calculated across the sample points in each zone and the standard error of the time series was computed for each zone. For the area to the south of Lake Kariba, for example, the CV of rain increases from 22% to 107%, simply by imposing coherence on the zonal rainfall. The same effect appears in Fig. 7, which shows the CV of

Figure 5. An example of the effect of weather coherence on five sites within a coherence zone. The zone average (heavy line) is much more stable in random climates. The correlation matrices show the degree of dependence in the coherent samples.



Correlations

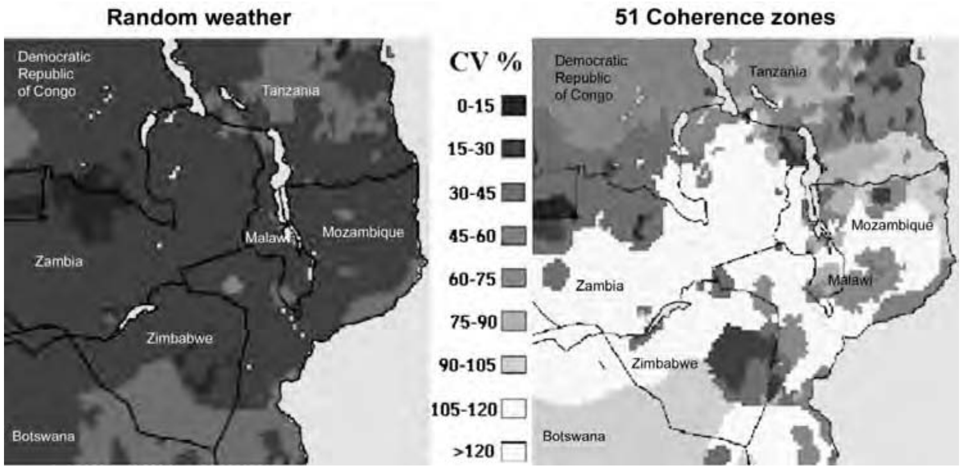
Site	1	2	3	4	5
1	1	0.25	0.31	0.57	0.47
2		1	0.32	0.33	0.23
3			1	0.23	0.23
4				1	0.52
5					1



Correlations

Site	1	2	3	4	5
1	1	0.13	-0.11	0.00	0.15
2		1	-0.29	-0.22	0.01
3			1	-0.15	-0.09
4				1	-0.20
5					1

Figure 6. The coefficient of variation of rainfall during the maize-growing season, with random climates (left) and 51 coherence zones (right).



maize yield on soils of class 2 (moderately suitable for maize production). A general lightening of the map indicates substantial increases in the CV of simulated yield in response to imposing weather coherence within the 51 zones.

Figure 7. The coefficient of variation of zonal maize yields on poor soils in random climates (left) and 51 coherence zones (right).

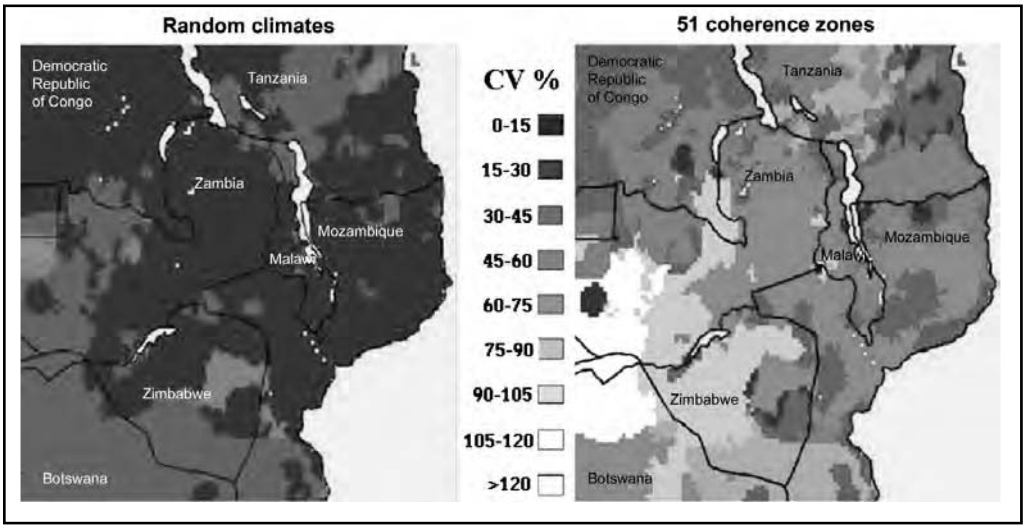
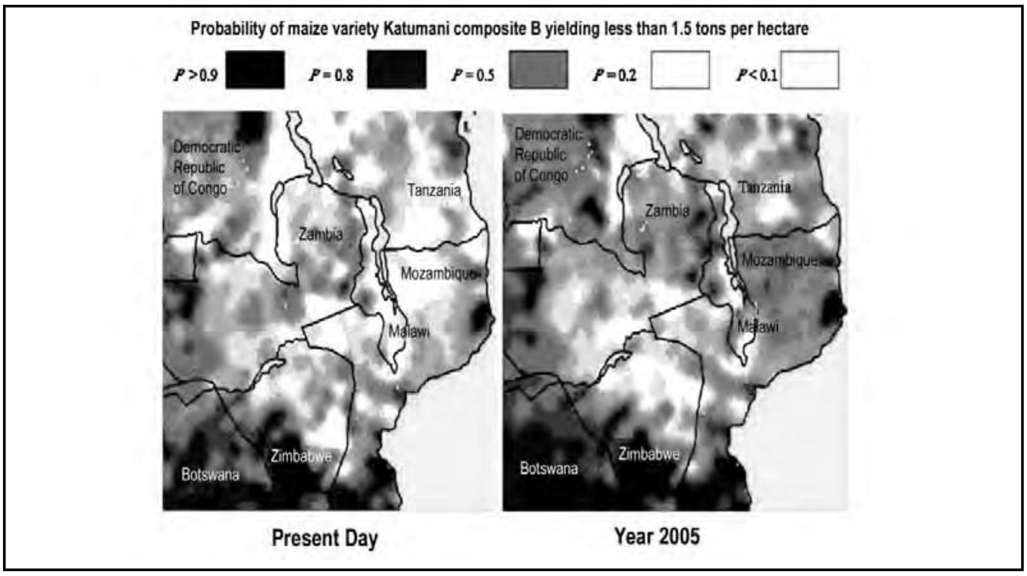


Figure 8. The probability that maize yields will fall below 1.5 t/ha (1 t = 1 Mg) in the present climate regime (left) and the simulated 2055 climate regime (right).



The implication is clear: in a region with a coherent weather system, if one site experiences bad conditions, then the chances are that other sites in the same region will also. Agricultural production will thus suffer both locally and regionally and, if coherence extends over a large area, continentally. In such cases, there may be profound implications for government policy (and marketing and transport) in attempting to ensure adequate food supply for many people over a potentially vast area.

Maize and pasture performance

Figure 8 maps the overall simulated performance of maize as the probability of not achieving a yield of 1.5 t/ha using present and 2055-based weather (this figure was chosen arbitrarily, but is similar to current average maize yields on smallholder farms in the region). These values were calculated by computing the cumulative probabilities for the sample points in each zone. As an example, consider sample point number 104; located at 15.67° S and 30.50° E; it has the following Class 2 and 3 soil units:

Fh (humic Ferralsol): 10% area
Fo (orthic Ferralsol): 20%
Fx (xanthic Ferralsol): 10%
Ge (eutric Gleysol): 20%
Je (eutric Fluvisol): 10%

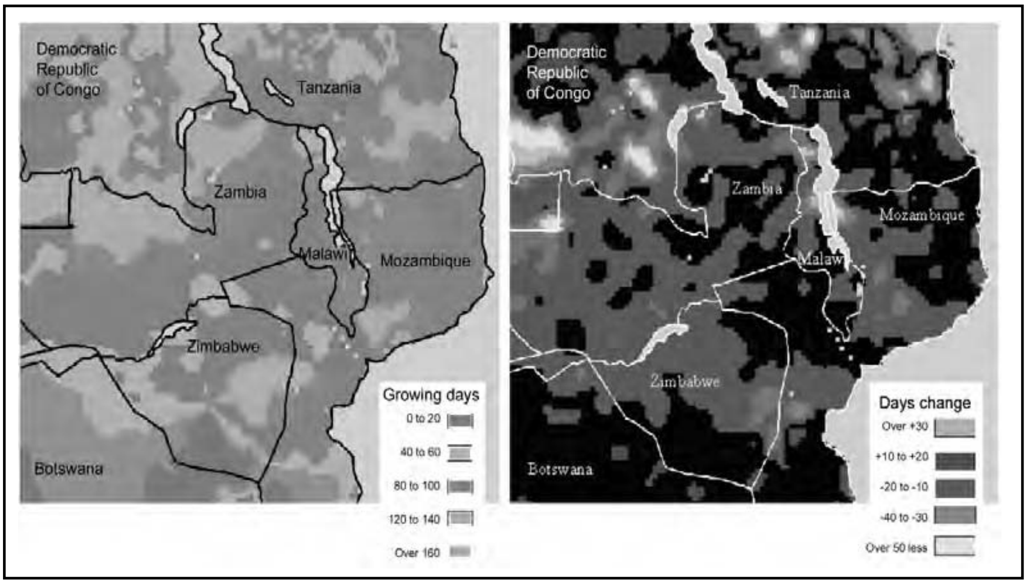
The rest of the pixel is taken up with a Class 1 soil. Five simulations were made using the characteristics of each soil unit. For display purposes, we assigned the eutric Gleysol and the eutric Fluvisol to Class 3, and the three Ferralsols to Class 2. Thus, for the map in Fig. 8, the simulated maize yields on the three Ferralsols were weighted by their relative occurrence to calculate the probabilities shown on the map.

Although an overall reduction in mean yields is apparent between the simulations carried out using the present-day and 2055 weather, in a few small zones, mean yields are actually simulated to increase between now and 2055. CERES-Maize accurately simulates the C_4 nature of the maize crop. Yields are predicted to increase in highland areas where the crop responds to rising temperatures. It should be borne in mind that these changes are also occurring along with a general increase in the standard deviation of maize yields, although these results are not shown here.

Figure 9 (at left) shows the average lower quartile of potential pasture-growing days in the 51 zones simulated using present and 2055-based weather. The actual number of growing season days is expected to fall below this in only one year out of four. As for the maize yields in Fig. 8, the change in this statistic (Fig. 9, at right) shows a general decline brought about by increased evaporation owing to increased temperatures being inadequately compensated by the small increase in monthly rainfall. In some areas, rainfall increases sufficiently to outweigh this effect.

The effects of global warming, in general, will lead to a reduction of maize yield and pasture, and to a greater risk. Small areas may actually benefit from the change, although they are not the same areas in each case. This may have serious implications for resource management, agricultural intensification, and population growth and movement.

Figure 9. Lower quartile of the number of pasture-growing days: the average of present and 2055-based climate regimes (left), and the change from the present to 2055 (right).



CONCLUSIONS

Natural resource modeling is a highly scale-specific process; methods change with scale as wider spatial linkages are incorporated. We have demonstrated a method by which plot-level models can be run over large land areas and the results can be aggregated to provide information at the regional level. We have shown how the output from much lower resolution global models (in this case, a GCM) can be broken down using a higher resolution weather grid and an interpolation technique (for other methods, see Schulze 2000). The study has achieved an integration from process-level, plant-growth models to global climate models, the full gamut of the scaling problem.

Results of our study indicate that there may be substantial spatial shifts in maize cultivation in the region. Despite numerous uncertainties in the analysis, climate will clearly change by about 2055, with concomitant impacts on crop and livestock production. The highlands may become more suitable for maize (higher night temperatures and more rain, in places), whereas the marginal areas in the lowlands may become even more marginal and risky. Spatial shifts in maize production may arise as a result of climate change. These could be expected to have significant implications for regional maize-related agricultural research in the future and for the way in which technologies (such as different varieties, modified management practices, and improved water conservation practices) might be targeted. We will return to this issue.

Results of the study have also illustrated the importance of taking into account weather coherence in regional analyses. Using random weather patterns over a wide range of soil types can result in highly misleading simulations, because aggregation tends to lead to a general smoothing of the inherent weather variability in a region. This can markedly underestimate the variance of regional food supply and fodder availability.

Africa has been identified as the continent most vulnerable to the impacts of projected climate change on (among other things) agriculture and human health, largely because widespread poverty is expected to limit adaptation capabilities (IPCC 2001*a*). At the same time, human populations in Africa continue to grow, driving the intensification of agricultural production so that food production and income levels can be maintained (Staal et al. 2001). Agricultural systems in the region are thus highly dynamic, and climate change effects will surely contribute greatly to this dynamism in the coming decades.

We believe that methods such as the one we have outlined are potentially valuable in studying the impacts of climate change. At best, however, these are tentative first steps only. How can such tools and methods be converted into something much more comprehensive that can genuinely inform natural resource management issues at both community and policy levels? We will highlight three areas in which considerably more work is required.

First, the agricultural impacts of climate change have to be assessed at the level of the agricultural system. Smallholder mixed systems involving many different mixes of livestock and crops are very important in the region and in Africa in general. Interactions between crops and livestock are critical in maintaining soil fertility and providing dry-season feed for animals (Staal et al. 2001). In any meaningful assessment of possible system evolution in response to climate change, and to identify possible adaptation and mitigation strategies, clearly we need to be able to represent the major biological processes operating at the household level, as well as the objectives and attitudes of smallholders. There is a wide variety of crop and livestock models, but substantial work remains in combining these into robust systems models that can account for the major interactions between crops and livestock at the systems level (Thornton and Herrero 2001). In addition, although maize-based mixed systems are of particular importance to the rural poor in many areas of southern and eastern Africa, climate change impacts need to be studied in other systems such as mixed systems not based on maize, commercial crop–livestock systems, and pastoral systems. Further, climate change will induce changes in habitat suitability for important disease vectors such as mosquitoes, tsetse flies, and ticks (Hulme 1996). Studies are being undertaken on some of these (e.g., Rogers and Randolph 2000, McDermott et al. 2001). However, a great deal of work remains to be done before we have integrated models that can be used in concert with global circulation models (GCMs) to study the system impacts of climate change in a comprehensive fashion.

Second, a wide variety of different GCMs and GCM scenarios are available. There are inherent uncertainties in the outputs from all of these different models, arising from the way they have been constructed and parameterized. Even for the relatively simple analysis presented here, which involves only one crop and one variety, other GCMs and climate change scenarios could be used to assess the variation in GCM projections in terms of possible future maize and pasture production in the region. If this variation were to be relatively small, this would help to build confidence in the results of such scenario assessments. Convergence of results from widely differing impact assessment analyses would also assist greatly in clarifying and unifying the messages that could be distilled from them.

Third, we believe that a much better understanding is required of the information needs of decision makers with respect to natural resource management and the possible impacts of climate change. Policy decisions concerning natural resource management are taken at many levels, from the local community to national government. Information needs will thus vary widely, in terms of format, content, timing, and delivery mechanism, and probably in ways that are as yet imperfectly understood. An improved understanding of community and governmental decision-making processes could ultimately bring about much better matching of the demand for information of particular types with information supply from assessments of climate change impact. This applies to setting priorities for helping national agricultural research and extensions systems to make resource allocation decisions (e.g., is it worth investing in a breeding program for shorter duration bean varieties?). It applies equally to assisting in the identification of longer term adaptation options for rural communities that may be particularly vulnerable to climate change (e.g., are there other varieties and crops that can be grown to help diversify agricultural income, given likely changes in temperature regimes and rainfall patterns?).

The initial investigation reported here shows that plot-level process models could be integrated into large-scale, land use models that attempt to simulate agricultural production and use of resources at a landscape level. Evaluation of natural resource management options is a highly complex problem, and a great deal of work is still needed to produce systems models that are truly adequate for the task. Recent evidence shows clearly that the implications of climate change for rural poor people in Africa, in particular, may be enormous (IPCC 2001*b*). Despite their limitations, existing crop and livestock models, coupled with improved methods of downscaling GCM outputs, offer potentially fruitful pathways to the provision of climate change impact assessments that can help highly vulnerable rural poor people to adapt and cope.

ACKNOWLEDGMENTS

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10.
Landcare on the Poverty–Protection Interface in an Asian Watershed

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ABSTRACT

Serious methodological and policy hurdles constrain effective natural resource management that alleviates poverty while protecting environmental services in tropical watersheds. We review the development of an approach to integrate biodiversity conservation and agroforestry development through the active involvement of communities and their local governments near the Kitanglad Range Natural Park in the Manupali watershed, central Mindanao, the Philippines. Agroforestry innovations were developed to suit the biophysical and socioeconomic conditions of the buffer zone. These included practices for tree farming, and conservation farming for annual cropping on slopes. Institutional innovations improved resource management, resulting in an effective social contract to protect the natural biodiversity of the park. Fruit and timber tree production dramatically increased, re-establishing tree cover in the buffer zone. Natural vegetative contour strips were installed on several hundred sloping farms. Soil erosion and runoff declined, while the buffer strips increased maize yields by an average of 0.5 t/ha on hill-slope farms. The scientific knowledge base guided the development and implementation of a natural resource management plan for the municipality of Lantapan. A dynamic grassroots movement of farmer-led Landcare groups evolved

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in the villages near the park boundary, which had significant impact on conservation in both the natural and managed ecosystems. Encroachment in the natural park was reduced 95% in three years. The local Landcare groups also restored stream corridor vegetation. This integrated approach has been recognized as a national model for local natural resource and watershed management in the Philippines. Currently, the collaborating institutions are evolving a negotiation support system to resolve the interactions between the three management domains: the park, the ancestral domain claim, and the municipalities. This integrated systems approach operated effectively with highly constrained funding, suggesting that commitment and impact may best be stimulated by a "drip-feed" approach rather than by large, externally funded efforts.

KEY WORDS: integrated conservation-development projects, sustainable agriculture, agroforestry, soil conservation, buffer zone, protected national park, biodiversity, Landcare, timber.

INTRODUCTION

The classical method of preserving a natural area has always been to declare it off-limits and enforce exclusion. In many developing countries, enforcement often was not successful because population pressure was intense, or the costs were too high. The approach of integrating conservation and development attempts to link enforcement with compensation to the communities that are directly affected by the presence of the natural area (Wells and Brandon 1992, Conroy et al. 2002, Kumar and Bakshi 2002). During the past decade there has been an increase in the use of participatory methods in integrated watershed management projects and integrated conservation-development projects (ICDPs). However, the participatory mode is novel and complex, and such projects have little theory or experience to draw upon (Rhoades 1998, Cook and Kothari 2001).

The Sustainable Agriculture and Natural Resources Management (SANREM) Program is a global research effort that aims to develop a new paradigm for research on sustainable agriculture and natural resources management (Hargrove et al. 2000). The program takes the whole landscape and lifescape of a watershed as the basis for formulating and resolving major management issues. It includes communities and local government bodies as reviewers, partners, and implementers of the research and development. The approach seems well suited to addressing some of the key methodological issues in protecting the natural habitats of unique tropical biodiversity encountering human pressure.

One of the three global sites where SANREM has been working is the Manupali watershed on the southern border of the Kitanglad Range Natural Park in central Mindanao, the Philippines. The Biodiversity Consortium at the Philippine site is composed of collaborating organizations including a university, NGOs, and government agencies, convened by the International Centre for Research in Agroforestry (ICRAF). The work was also linked with the global program on Alternatives to Slash-and-Burn. The objective was to conduct research to develop tools and approaches that combined improved biodiversity conservation with better livelihood opportunities through agroforestry for the communities that live near the Kitanglad Range Natural Park. This paper reviews that experience. It concludes by examining the implications of an integrated natural research management approach in this context.

The consortium began its work by drawing on the lessons learned from the global experience with ICDPs (Wells and Brandon 1992, McNeely 1995). One of the critical lessons that has emerged is that the active leadership of local people is the key. Communities near protected areas often bear substantial costs in forgone use or extraction from the protected area, yet may gain little in return. They are usually poor and quite remote from normal government services (Stoll-Kleemann and O'Riordan 2002). An integrated approach with balanced attention to both enforcement and development is necessary to ensure explicit linkages between project components. To achieve the goals of protecting biological diversity and helping to improve the welfare of the people living near the protected area, it is necessary to pay explicit attention to how the rural development activities directly support the objective of protection. Some types of development initiatives may increase the pressure on the reserve. Road construction, or growth in agricultural productivity, may have this outcome under some circumstances. Introducing technologies that raise agricultural productivity may elevate land values, and may make it more attractive to encroach onto reserve land. Compensation to communities to promote local development may take many forms. This has often included agroforestry practices, crop intensification and irrigation, conservation farming practices, and community forestry (Wells and Brandon 1992, Ecot 2002). The objectives are to involve local people in natural resource management activities that empower them, increase their incomes, and shift their production systems in ways that better protect natural biodiversity in the agricultural landscape, and reduce their need to extract resources from the protected area. For sustained protection, in-migration must also be managed, and greater off-farm employment generated.

INTEGRATING CONSERVATION AND DEVELOPMENT IN THE MANUPALI WATERSHED

Biodiversity value

The Kitanglad Range Natural Park is acknowledged as one of the most important biodiversity reserves in the Philippines. It supports the richest known vertebrate fauna (mammals and birds) in the country (Amoroso et al. 1996, Heaney and Peterson 1992, Heaney 1993). It is the habitat of many endangered, endemic, rare and economically important species of animals and plants. Heaney and Peterson (1992) observed 13 of the 14 species of birds endemic to Mindanao, including the critically endangered Philippine Eagle (*Pithecophaga jefferyi*). One genus of mammal is endemic to the park alone, the little known *Alionycteris paucedentata*.

The park is a relatively small ecosystem of approximately 50,000 hectares, but is also of exceptionally high conservation value in terms of high endemism of the vascular flora (Amoroso et al. 1996; Pipoly and Masdulid, personal communication, 1995). This includes the endangered rootless vascular plant (*Tmesipteris lanceolata* Dang.; Amoroso et al. 1996). The park was recently found to have the highest tree density ever reported in a tropical forest (Pipoly and Masdulid, personal communication, 1995). This combination of a small, manageable size, and a rich, singular biodiversity, conforms to the type of protected ecosystem that Sayer (1995) proposes ought to receive the most determined attention in tropical biodiversity protection.

The watershed

The people residing in the Manupali watershed, downslope from the park, exert pressures on both the natural and managed ecosystems, particularly on the remaining protected forest. Amoroso (1997) noted an alarming rate of habitat destruction due to human activities, including illegal cutting of trees, over-harvesting of minor products, shifting cultivation, and conversion of forest lands to agricultural production. The present landscape of the upper reaches of the Manupali watershed consists of essentially three belts of land:

1. The natural park, consisting mostly of pristine forested land at high altitudes (>1200 m asl) with few current household land claims and natural park status.
2. A zone of land surrounding the park that is managed by the Department of Environment and Natural Resources (DENR) as production forest: this is the external buffer zone of the park. This land is on the fringe of the forest and has now been mainly converted to agricultural fields interspersed with *Imperata*-dominated grassland. Encroachment here has been partly sanctioned through the expectation of social forestry stewardship contracts, with eviction no longer a tenable management option.
3. Privately owned agricultural land that is further downslope from the public DENR lands. These landholdings comprise a mosaic of agroforest, crop, and fallowed fields, with remnant forest existing in the steep ravines, which border the streams that drain the natural park.

A Participatory Learning Landscape Appraisal (PLLA), and our research during the initial years (1993–96), documented the land-use practices (COPARD 1996, Banaynal 1996). This work highlighted the urgent need to develop an integrated and sustainable buffer zone management program. The indigenous Tala-andig people regard the public lands as their ancestral domain. Initial research indicated there was a strong perception among communities on the boundary of the park that the protection of the natural biodiversity was in their own self-interest (Cairns 1996). This somewhat contrasted with the concerns of the dominant in-migrant population, which tended to emphasize resource exploitation and extraction for cash income. A major concern of the Tala-andig villagers was protection of the hydrological functions of the upper watershed for their water supplies. They were quite explicitly sensitive to spiritual and cultural values of the forest. They attributed the current failure to protect these resources to the lack of institutional mechanisms to manage the resources in a way that explicitly recognized local needs for more secure land tenure and alternative livelihoods.

Lack of state recognition of secure tenure by the households residing in the buffer zone outside the park boundaries was a critical constraint that would need to be addressed eventually.

The project framework

The project goal was to elucidate a more fundamental understanding of people–ecosystem interactions to guide development of practicable natural resource management plans and processes. The research aimed to develop the elements of a workable social contract between buffer zone communities and the non-local stakeholders concerned with resource protection. We hypothesized that there were two essential conditions for sustainable buffer zone management and biodiversity conservation in the Kitanglad Natural Park:

1. agricultural/agroforestry intensification in the buffer zone to enhance income growth, complemented by other forms of off-farm employment generation in the local and national economy; and
2. community-supported enforcement of the boundaries of the park.

Our work focused on both aspects. We investigated appropriate technical innovations suited to the biophysical and socioeconomic conditions of the buffer zone, and we studied how to induce institutional innovations to enable better natural resource management. The social contract underlying the model links the provision of assistance in intensifying agriculture to local responsibility for park boundary protection.

ENHANCING AGRODIVERSITY

Agriculture is the dominant livelihood in the villages near the park, as is the case with many other protected areas in the tropics. The boundary area of Kitanglad Range Natural Park is located at an elevation of 600 to 1700 m, where temperate vegetable crops (including potatoes, cabbages, and tomatoes) are quite productive. Vegetable production is expected to further expand in the future. Our analysis indicated that the most likely future trajectory for farming systems in the buffer zone is towards continuous vegetable production on a portion of the farm (0.1–1.0 ha), with perennials (timber and fruit trees) grown on the remaining farm area, particularly on the steeper parts. A farm planning exercise with 67 families in three buffer zone villages (COPARD 1996) found that the greatest interest was in establishing simple contour buffer strip systems on the annual crop areas of the farm, and increasing the area of fruit and timber tree crops on the remainder. The farmer-participatory research effort (described below) thus focused on enhancing the environment for smallholder tree production and contour buffer systems to sustain annual cropping. It involved numerous tests carried out by farmers independently, supplemented by experimental trials conducted by researchers on farmers' fields.

Smallholder tree production systems

Prior attempts to reforest the buffer zones of deforested areas in the Philippines focused on planting large blocks of trees with local wage labor by DENR. Such a project was implemented in the Manupali watershed during the late 1980s, prior to SANREM. Like many other such top-down attempts, it failed. The plantations were burned, often by local smallholders, on whose land the trees were planted. Only a few small remnant stands now remain in the "reforested" buffer zone area.

Research in northern Mindanao documented a major transformation towards smallholder timber tree production in this region in response to market development (Garrity and Mercado 1994). There is increasing evidence that smallholders are a key to future reforestation efforts in the tropics (Garrity 1994, Pasicolan 1996). Our approach was to ensure that improved germplasm was available for a variety of species to enhance income and reduce risk, and that best management practices suited to local farm circumstances were in place. The initial work focused on determining an appropriate mix of species of interest to farmers, and testing diffusion strategies to incorporate them into farming systems. A farming systems survey (COPARD 1996) was conducted through open-ended interviews with farmers and neighborhood groups. Several training exercises (Koffa and Garrity 2001) were also convened that fostered mutual learning between farm households and researchers. Farmers in the buffer zone and private lands showed strong interest in expanding the area of timber trees on their farms.

The constraints to accelerating the process were a lack of seedling supply, knowledge of which species were most profitable, appropriate tree management, and availability of a wider range of tree germplasm to diversify risk. Subsequently, a detailed survey was undertaken that developed a comprehensive knowledge base on multipurpose tree species performance at different elevations in the upper watershed (Glynn 1996). The most common timber species planted in the upper watershed were found to be *Paraserianthes falcataria*, *Gmelina arborea*, and *Eucalyptus camaldulensis*. Farmers observed that the eucalyptus species perform particularly well at the buffer zone elevation levels (Glynn 1996). Germplasm of a range of other fast-growing timber species was introduced, with emphasis on new accessions of *Eucalyptus deglupta* and others. This was accompanied by a series of replicated on-farm experiments that evaluated the available commercial species for performance at different elevations. The work was complemented by attempts to domesticate a number of local species identified and used by farmers for timber (Palis 1997). Experience was also obtained, through working with farmer groups, on the effectiveness of three types of smallholder nursery systems. These activities resulted in a major acceleration of tree production in the buffer zone (see section below on Landcare).

Enhancing conservation farming

Continuous crop production on steep slopes in Mindanao induces annual rates of soil loss often exceeding 100–200 t/ha (Garrity et al. 1993). The installation of contour buffer strips reduces these losses by 50–99% and creates natural terraces that stabilize the landscape and facilitate further management intensification. These advantages have led to wide promotion of contour hedgerow systems by the DENR and the Department of Agriculture (DA). These systems are based on double rows of leguminous trees that are pruned periodically to provide green manure for the associated annual crops. Although the system has been shown to increase yields and better sustain soil fertility, adoption has been poor. Installed hedgerows were usually abandoned because farmers found that it took too much labor to manage the tree hedgerows (ICRAF 1997).

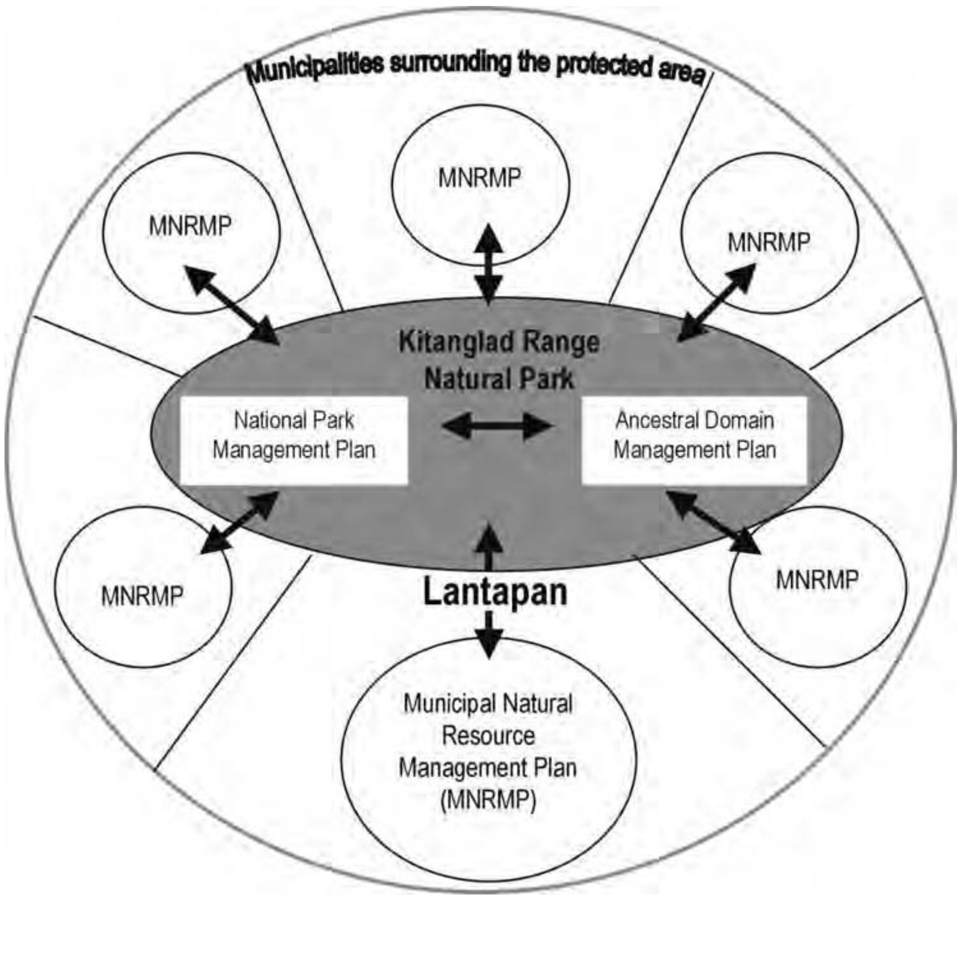
We had observed an indigenous buffer strip practice that had been evolved by a few farmers at another location in the Philippines. These natural vegetative strips (NVS) were introduced in the watershed as an alternative to the recommended tree hedgerow system. NVS are created by laying out the contour lines on sloping fields. These are then allowed to revegetate with the regrowth of natural grasses (Garrity et al. 1993). We found that NVS are exceptionally effective in soil conservation with minimal maintenance, and require no outside source of planting materials. Nelson et al. (1998) modeled the long-term trends in maize yields, and found that yields increased after NVS were established. On fields with NVS maize production increased by about 0.5 t/ha. This was further supported by the experience of many farmers who claimed that the buffer strips substantially increased their yields within a few years after installation. Widespread popularization of the practice occurred through farmer-to-farmer knowledge sharing in the Landcare movement. Since 1996 it has led to about 300 farmers adopting the NVS practice on their farms in the upper watershed. In addition to the demonstrated effects on sustaining and increasing crop yields, farmers in the buffer zone also perceived that the practice also strengthened their tenurial claim to the land they were tilled.

The tree farming and contour buffer strip activities had immediate potential to help farmers in the buffer zone intensify land use and increase profitability, while sustaining land resources. Their widespread adoption is now supporting the institutional innovations. It provides pragmatic alternatives to encroachment in the park. Current research is estimating the aggregate effects of these vegetative buffers and filters on the hydrological functions at the landscape level (van Noordwijk et al. this volume). We now turn to the process of evolving participatory institutional innovations for local natural resource management.

ASSEMBLING THE ELEMENTS OF A SOCIAL CONTRACT

The foremost policy issue impinging on local natural resource management systems is the reality of overlapping land rights and management priorities. There are three sets of overlapping management claims and systems operating in the vicinity of the park. These are: the park and production forest land administered by the state (DENR); the ancestral domain claim of the Tala-andig people; and the jurisdictions of the six municipalities that surround the park. These claims and systems interact geographically (Fig. 1). SANREM policy research focused on understanding the ways in which the three overlapping jurisdictions can be reconciled, and on developing a scientific basis for management plans by the three sets of entities. The work aimed to provide options leading to a consensus that would meet the various stakeholders' concerns. We envision the development of a natural resource management system for the buffer zone of the park that is based on a holistic park management plan, coordinated with an ancestral domain management plan. These need to be supported by the municipal-level natural resource management plans. We are using an integrated natural resource management framework to evolve a negotiation support system to resolve the interactions between these three management domains (van Noordwijk et al. this volume). The following sections review the current status of that work.

Figure 1. Linkages between the three types of natural resource management plans in and around the Kitanglad Range Natural Park.



Municipal natural resource management planning model

In late 1995, the mayor of the municipality of Lantapan committed human and financial resources to the development and implementation of such a plan, for which there was no precedent in the Philippines (Catacutan et al. 1999). The municipal government created a multisectoral Natural Resources Management Council made up of representatives of all the major sectors of the community, including smallholder farm households, church, civic, and business and educational leaders. The 25 members of the Council were appointed by the municipal mayor. He also established a local planning team that received support from the municipal environmental planning officer. The research team focused on assembling the knowledge for a scientifically based, local natural resource management plan. The draft plan was circulated, and a series of public hearings were held. Many changes were incorporated, and the municipal council enacted it in early 1998. The municipal government has currently allocated 5% of the municipal budget for implementation of the plan. In addition, 10 villages within the municipality have, through their locally elected bodies, allocated an average of 10% of their budgets for implementing activities to achieve objectives related to the plan. The initial impact of the plan has included a number of new policies and regulations related to resource conservation. They were proposed by the village representatives on the municipal council. Many on-the-ground activities have now been completed that enhanced the conservation of land, water, and biodiversity aspects of the plan.

The research consortium's technical contributions to the plan stemmed from its work on agroforestry, conservation farming, and biodiversity conservation. For example, numerous steep ravines emanate from the Kitanglad range out into the agricultural landscape. These valleys are the least disturbed parts of the agricultural area, and they harbor diverse natural communities. They may be valuable in radiating strands of natural biodiversity outward from the protected area into the agricultural parts of the landscape. A strategy to enhance the biological integrity of the ravines was developed (Glynn 1996). A methodology to survey and map the vegetative communities of major ravines of the Alanib River was evolved. The maps that were developed provided a basis for identifying the hot spots where change in land management practices was needed to protect stream water quality and riparian biodiversity. A local volunteer water-watch organization has been monitoring the water quality of the major streams. Its results pointed to serious biological contamination of several communities' water supplies. Based on this information, a ravine habitat management component was incorporated into the municipal natural resource management plan. The communities have now been actively revegetating the degraded stream-bank areas with trees, through voluntary initiative and efforts.

The Lantapan experience is a significant advancement in municipality-led and participatory local natural resource management planning. In 1998, the DENR recognized the Lantapan experience as a national model for natural resource management planning in the Philippines Strategy for Improved Watershed Resources Management (DENR 1998). The model is now being implemented in other municipalities in Bukidnon, and other provinces throughout the country. It is a significant step in the devolution of planning and management for natural resource protection to the local level, and a major shift from traditional top-down planning approaches towards participatory, multisectoral planning and research-based decision-making.

The Landcare movement mobilizes grassroots conservation

The villages that immediately surround the protected area are on the conservation interface. They are embedded physically in the competing jurisdictions of the local municipality, the state forest land claimed by DENR, and the ancestral domain claim of the original inhabitants. Ultimately, the success of natural resource conservation depends on the initiative, active involvement, and support of the local residents. This requires a stronger conservation ethic at the community level, adoption and adaptation of conservation-oriented and more productive farming practices, and collaboration between villagers and the park administration in boundary enforcement (Garrity 1995). Our hypothesis was that village-level, knowledge-sharing, community-action organizations are fundamental to addressing these natural resource management challenges.

A movement of farmer-led knowledge-sharing organizations had evolved in the nearby municipality of Claveria (in a watershed in northern Mindanao). This Landcare movement (Mercado et al. 2000) was initiated by small self-governing groups of farmers. Their initial objective was to diffuse agroforestry practices among upland farming neighborhoods. Their interest was in learning and sharing experiences with new technologies that increased income while conserving natural resources. The groups formed themselves at the neighborhood (sub-village) level. The agenda later expanded to many other aspects of community action for local natural resource management such as fire control, soil conservation policies, and riparian protection. Today, there are more than 3,000 households in Claveria who are members of the 145 chapters of the Landcare Association. They have initiated more than 300 fruit and timber tree nurseries, and are actively disseminating conservation technologies to fellow farmers via farmer-to-farmer contacts. More than 1500 farms in Claveria have adopted contour buffer strip systems on their sloping agricultural lands through these voluntary exchanges. As the movement grew, it began to attract strong support from the local government units at the village and municipal levels. It received technical support from NGOs and the Department of Agriculture extension agents (Mercado et al. 2000). Landcare is now active in 15 municipalities in five Philippines provinces.

The Landcare approach was introduced in Lantapan in 1998, through exchange visits by the numerous Lantapan farmers and civic leaders to Claveria. This was enhanced by networking with the local government, and with the municipal agricultural extension agents. The movement grew rapidly. Currently, there are more than 45 Landcare groups in Lantapan, with a total of over 800 members. Most of these groups live in the villages near the park boundary. The neighborhood groups coalesced into village chapters. Representatives of the chapters meet monthly as part of the municipal Landcare Federation. They share new information and ideas that have emerged in the various groups, and together they plan larger-scale community activities. The municipal and village governments actively support the Landcare groups through annual budgetary allocations.

The chapters have stimulated the development of over 40 nurseries for timber and fruit trees, and have fostered the adoption of contour buffer strips on several hundred farms. They have begun community-wide environmental protection by assisting with the planting of thousands of trees to protect the riparian buffer zone along the Kalasihan River. The Kalasihan was shown to be encountering the most severe pollution problems in the municipality by the local water-watch monitoring group. Municipality-wide environmental awareness has increased during the past three years as a result of the intensified activities of the Landcare movement and the support of the municipal and village government units. The effects of these developments on the protection of the natural park are now clearly evident. Previously, the frequency of encroachment for extraction or slash-and-burn farming in the park was completely out of control, with hundreds per year. The annual number of park encroachment incidents during the past three years has declined by about 95% (F. Mirasol, Park Director, personal communication). This was attributed to the enhanced collaboration between the villagers, the park administration, and the municipal governments through the institutional innovations described above.

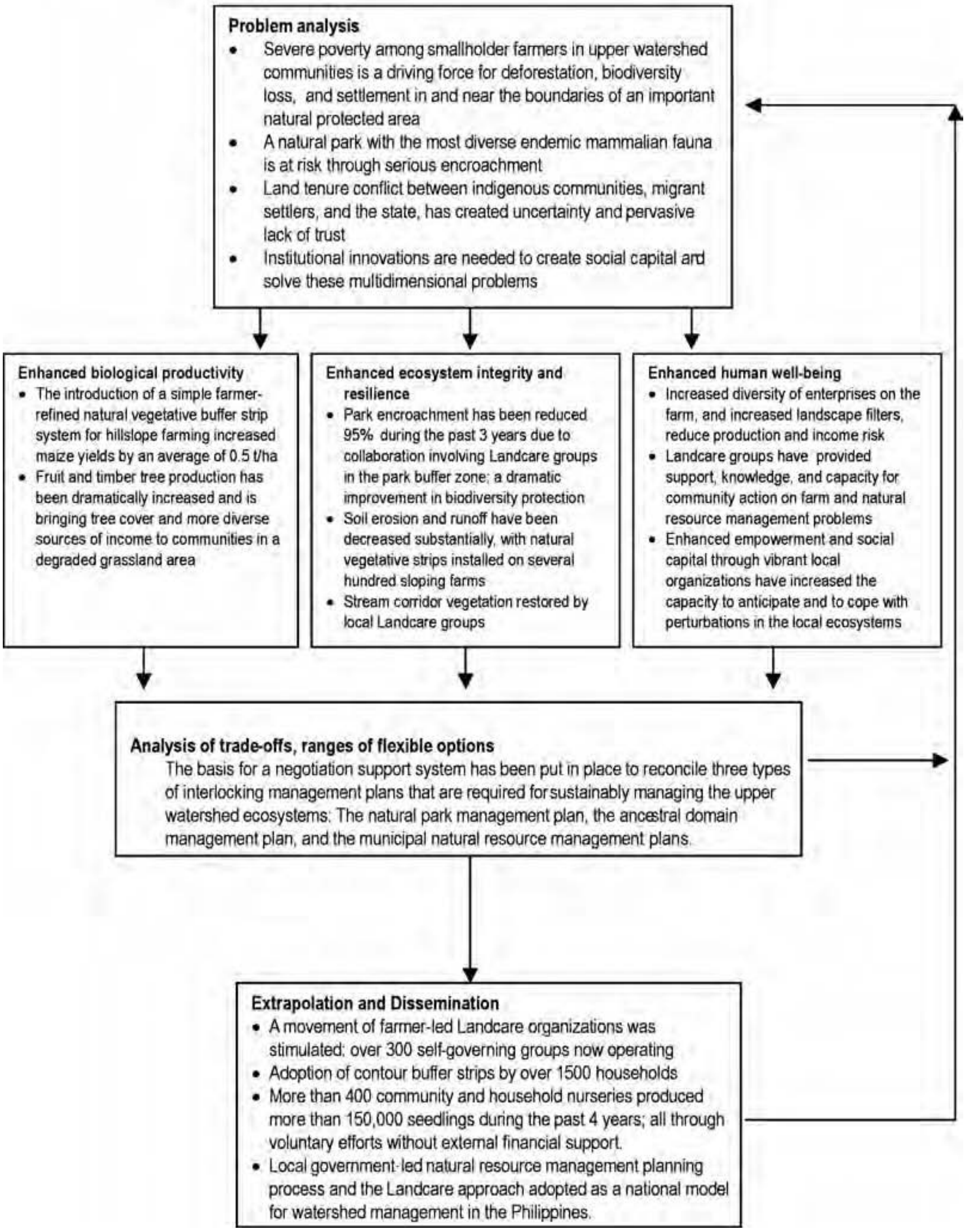
A legal system of secure land tenure for the farm populations inhabiting the buffer zone area has yet to be fully devised and implemented. In the meantime, however, the Landcare experience indicates that the residents perceive that regulations to more formally recognize their local tenurial rights will be forthcoming. Evidence of this is abundant in the types of long-term investments in soil conservation and tree production systems that are rapidly being adopted. The Landcare movement has significantly increased the social and political capital of the residents. It has been a contributing factor enabling positive developments in local natural resource management.

Douthwaite et al. (this volume) have pointed out that in complex environments, integrated natural resource management (INRM) interventions must be able to foster and motivate the innovative potential of local people. They note that a grassroots, community-development model can lever enormous amounts of creative talent. This has striking implications for INRM. Our ongoing evaluation of the Landcare experience in Mindanao, combined with locally led natural resource management planning and implementation at the municipal level, suggests that it embodies the creation of these types of human and social capital.

DISCUSSION

This paper has reviewed an approach to integrating conservation and development that links the protection of biodiversity with the development and adoption of improved agroforestry farming methods, and local institutional innovations by the communities that are directly affected by the presence of a natural park. The objectives were to develop tools and approaches that combined improved biodiversity conservation with better livelihood opportunities, to increase local capacity to manage natural resources, and to apply the tools to solve a set of

Figure 2. Elements of the approach in the Manupali watershed to alleviate poverty and protect environment services in an integrated natural resource management research framework.



complex natural resource management challenges. To achieve the goals of protecting biological diversity and helping to improve the welfare of the people living near the protected area, it was necessary to pay explicit attention to how the rural development activities directly supported the objective of protection.

Significant progress has now been achieved in assembling the elements for an effective social contract to protect the natural biodiversity of Kitanglad Range Natural Park, while also improving the livelihoods of the communities on the park boundary. The work can be seen in the context of an integrated natural resources management (INRM) framework (see Fig. 2; Izac and Sanchez 2001). This framework is an intellectual and methodological successor to the farming systems research framework. But it places more emphasis on the links and trade-offs between enhanced biological productivity, ecosystem integrity and resilience, and human well-being. There is significant evidence that the integrated approach creates an effective linkage between development and conservation. As a result of strong initiative and support for natural resource management planning and implementation at the local level, and the efforts of the grassroots Landcare farmer groups, a conservation ethic has been spreading through all segments of the community. Strong support for a wide range of environmental concerns is now common among migrant households, religious and educational leaders, local politicians, staff of the local government units, and the commercial agribusiness community, in addition to the original Tala-andig inhabitants.

Sensitivity of the wider community to the environmental and religious values of the Tala-andig has also broadened and deepened. Biodiversity protection is now accepted as a local responsibility by a broad segment of the local society beyond the ancestral communities. It is now pursued with a strong civic pride. Some of the key success factors identified have been a strong consortium of both research and development institutions, and local government entities committed to an integrated systems approach. This group evolved with a common vision, and the patience to nurture that vision under highly constrained funding conditions. Indeed, the funding constraints may have been a blessing. Increasingly, it is observed that higher levels of commitment and impact for integrated conservation-development may be stimulated by a "drip-feed" approach rather than by large, externally funded efforts.

The challenge yet to be resolved is the reconciliation of the ancestral domain claim with the park jurisdiction, and with the need for greater tenurial security among immigrant settlers in the buffer zone. Similar manifestations of these upland tenurial issues are observed in various forms throughout Southeast Asia. A negotiation support system is being developed to facilitate the resolution of such conflicts (see van Noordwijk et al. this volume). These tools are being developed through work at three key watersheds in the region. These include Sumberjaya, Indonesia, and Mae Chaem, Thailand, in addition to the work in the Manupali watershed, Philippines, that was reviewed in this article.

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11.

Integrated Natural Resource Management: Approaches and Lessons from the Himalaya

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ABSTRACT

Losses of forest cover, biodiversity, agricultural productivity, and ecosystem services in the Himalayan mountain region are interlinked problems and threats to the sustainable livelihoods of 115 x 10^6 mountain people as well as the inhabitants of the adjoining Indo-gangetic plains. Until the 1970s, environmental conservation, food security, and rural economic development were treated as independent sectors. The poor outcomes of sector-oriented approaches catalyzed efforts to address environmental and socioeconomic problems concurrently. The identification of "key" natural resource management interventions is an important dimension of integrated management. Projects to rehabilitate the degraded lands that cover 40% of the Indian Himalaya could be key interventions provided that they address both socioeconomic and environmental concerns across spatial and temporal scales. However, projects of this type, e.g., investments in conifer plantations on degraded forest lands, have failed because their designs did not take into account the needs of local residents. This study illustrates a case of land rehabilitation in a small isolated village close to the alpine zone. Vital elements of this project strategy included identifying local perceptions and knowledge and involving the local people in the selection and implementation of the interventions needed to

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restore the land. Communities were found to be more concerned with the immediate economic benefits from bamboo and medicinal species than the long-term benefits of tree planting. The villagers eventually reached a consensus to plant broadleaved multipurpose trees in association with bamboo and medicinal species. Despite assurances that all the economic benefits from rehabilitation would go to the community, the people would not agree to voluntary labor, although they did absorb significant costs by providing social fencing, farmyard manure, and propagules from community forests. Households shared costs and benefits according to traditional norms. The economic benefits to the local people exceeded the rehabilitation cost over the 7-yr life of the project. There were significant on-site environmental benefits in terms of improvements in soil fertility, biodiversity, protective cover, and carbon sequestration, and off-site benefits from more productive use of labor, reduced pressure on protected areas, and the introduction of rare and threatened medicinal species onto private farmland.

KEY WORDS: bamboo, community decision making, Himalaya, India, integrated natural resource management, land rehabilitation, medicinal plants, reforestation, village.

INTRODUCTION

The Himalaya is a vast mountain system extending into eight developing countries in South Asia: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan. The fact that India is recognized as a megadiversity country and as one of the 10 most extensively forested areas in the world is due mainly to the Himalaya. Although it covers only 18% of India's geographical area, the Himalaya accounts for more than 50% of the country's forest cover and 40% of the species endemic to the Indian subcontinent. Losses of forest cover, biodiversity, agricultural productivity, and ecosystem services are interlinked problems in the region that threaten the sustainable livelihoods of not only 115×10^6 mountain people but also the much larger population inhabiting the adjoining Indo-gangetic plains (Hamilton 1987, Ives and Messerli 1989, Myers 1990, Hurni 1999).

Until the 1970s, environmental conservation, food security, and rural economic advances were treated as largely independent sectors of research and development. The poor outcomes of sector-oriented approaches catalyzed efforts to address environmental and socioeconomic problems concurrently. Such approaches, commonly referred to as integrated natural resource research or management or development, essentially meant the integration of ecological and socioeconomic research, of traditional and conventional science, and of different actors and stakeholders (Conroy et al. 2002). Multiple scales of environmental and economic development imperatives, from long to short term and from local to global, need to be considered in this type of undertaking. Although knowledge about the principles and potential advantages of integrated approaches has increased in recent years (Holling and Meffe 1996, Jenssen and Goldsworthy 1996, Antunes and Santos 1999, Bellamy and Johnson 2000, Lunde and Iremonger 2000, Costanza and Jorgensen 2002, Ashley and Maxwell 2002), there are scientific, technological, and institutional limitations when it comes to putting the theory into practice (Thapa and Weber 1995, Maikhuri et al. 2000).

The identification of "key" natural resource management interventions, analogous to the concept of keystone species discussed by Paine (1969) and Walker (1991), that would make it possible to address environmental and socioeconomic problems simultaneously is an important dimension of integrated management. About 40% of the Indian Himalaya is degraded land. Rehabilitation will be a key intervention if it enables local communities to regenerate and/or conserve natural resources while at the same time aiding their social development (Ecot 2002). The benefits to vegetation recovery, the hydrological balance, and soil conservation that would be gained by rehabilitating such a vast area would also help the global community by reducing the frequency and intensity of flood damage in the downstream Indo-gangetic plains and improving biodiversity conservation and carbon sequestration.

Since the 1970s there have been huge investments in establishing tree plantations on degraded lands, but the outcomes have been poor, largely because the project designs did not address the needs of local residents (Blaikie 1989, Chambers et al. 1989, Doolette and Magrath 1990, Kumar and Bakshi 2002). Villagers deliberately damaged plantations for several reasons. First, the species chosen for planting were conifers, rather than the multipurpose broadleaved species that could meet the essential needs of the local people. Although conifer timber could be a source of income to local residents, India's national forest policy does not allow it to be harvested commercially because of the ecological damage that harvesting causes on steep slopes. As a result, the villagers perceived the establishment of conifer plantations as a commitment to enhancing global environmental benefits at the expense of their own socioeconomic development. Second, the only involvement that local people had in these plantation projects was as part of the labor force. They did receive some benefits from this in the form of wages, but it was made clear that they were hired only because that was cheaper than importing workers from outside. Finally, local residents frequently set fires in the plantations to improve the grass forage that is so important for traditional livestock husbandry. The mortality of planted saplings caused by these fires led to replanting, which meant more wages for the villagers. Another problem was the fact that the saplings, which were raised in centralized nurseries and transported long distances to the plantations, were often damaged by the time they were planted. The absence of treatments to ameliorate nutrient and water stresses also contributed to the failure of these plantations (Saxena et al. 1993, Rao and Saxena 1994).

A major challenge is to develop rehabilitation strategies that address both economic and environmental concerns across spatial (local/global) and temporal (short-term/long-term) scales. This paper describes a case study in a high-altitude Himalayan village where this challenge was met by identifying rehabilitation technologies based on indigenous knowledge and by involving the villagers directly in the design, implementation, and monitoring of the project.

SOCIO-ECOLOGICAL SETTING OF THE STUDY AREA

The study was carried out in Khaljhuni village (Table 1), which is on the margin of the Nanda Devi Biosphere Reserve in the Indian central Himalaya. It is typical of the 4175 villages located close to the alpine zone. All these villages are characterized by relatively high inaccessibility, small populations, a subsistence economy based on crop-livestock mixed farming and nontimber forest products, homogeneity of resource use by different sociocultural-economic groups, and strong traditions of social integration (Farooquee and Saxena 1996, Rao and Saxena 1996). The Khaljhuni village community comprises two indigenous ethnic groups: the Bhotiya tribe and nontribals. Forty-three percent of land holdings are > 2 ha, 42% are 0.2–2 ha, and 15% are < 0.2 ha. Smallholders provide labor for large landholders and receive food grains as payment. At the village level, food production is sufficient to meet local subsistence needs.

Table 1. Ecological and socioeconomic features of the Khaljhuni village, Almora district, India (values in parentheses are the percentage of the total in a given category).

Number or households	29
Population	
Bhotiya tribe	194
Non tribals	26
Total	220
Elevation (m asl)	2200–2500
Aspect	East facing
Slope (°)	35–45
Annual rainfall (cm)	110
Mean monthly maximum temperature (°C)	8.5–24.2
Mean monthly minimum temperature (°C)	1.8–16.1
Soil depth (cm)	20–100
Land use (ha)	
Agriculture	68.0 (13.5)
Community/Panchayat forests	301.9 (59.9)
Civil forests	134.3 (26.6)
Total geographical area	504.2 (100.00)
Livestock	
Bullocks and cows	241 (31.9)
Sheep and goats	515 (68.1)
Total	756 (100.00)

The village landscape is divided into three elements: rain-fed agriculture, village community forests, and civil forests. Forest leaf litter mixed with livestock excreta is applied as manure in crop fields. Three crops are harvested over a period of 2 yr near homesteads, and one crop every 4–6 yr in distant farm fields. *Amaranthus paniculatus*, *Hordeum vulgare*, *H. himalayense*, and *Fagopyrum esculentum* are the major crops. Government reserve forests and alpine meadows surround the village. Village community and reserve forests are dense

(> 80% crown cover and 80–140 m^2/ha basal area). Civil forests are highly degraded (crown cover < 10% and 0.4–5 m^2/ha basal area).

Except for the core zone of the biosphere reserve, the local people have been granted rights of utilization for nontimber forest products. The forest council, which consists of seven individuals elected by the people and one government official, is empowered to make decisions about how the resources of the community forests are used, and the government forest department has authority over the reserve and civil forests. Resource use rights in the core zone, an area far from the village, were terminated in 1988. Until that time, the villagers would camp there during the summer to graze livestock, collect medicinal and wild edible plants, and harvest temperate bamboo (*Thamnocalamus spathiflorus*), which is used to make traditional handicrafts, from the reserve forests between the village and the core zone. When customary rights in the core zone were terminated, the inhabitants used the areas near the village much more intensively, resulting in extreme degradation of the civil forest land (Rao and Saxena 1994).

THE PRESENT APPROACH

The rehabilitation strategy comprised the following steps: (1) conducting a survey of local perceptions and indigenous knowledge related to the rehabilitation of degraded forest land, (2) analyzing the villagers' perceptions from the perspectives of other stakeholders and their concerns, (3) discussing these perceptions with the villagers and identifying possible rehabilitation methods based on scientific knowledge, and (4) facilitating consensus with regard to the framework, implementation, and monitoring of the rehabilitation project.

People's perceptions

Seventy adults, including at least one male and one female from each household, were interviewed. We explained our intention to conduct a rehabilitation trial based on indigenous knowledge and designed to address local needs and preferences, and then sought responses to these questions:

- What were his/her preferences with regard to land rehabilitation, and what were the reasons for those preferences?
- What contributions could s/he make to rehabilitation?

Most people responded to the first question by saying that they would prefer to plant temperate bamboo (*Thamnocalamus spathiflorus*); the second choice was the cultivation of medicinal plants (Table 2). These species were chosen because of their significant contributions to the rural economy and the restrictions on their extraction from the wild imposed by conservation policies. Only 8% of the respondents suggested planting trees. It was clear that

Table 2. Results of a survey of villagers' preferences regarding the rehabilitation of degraded lands.

Land use option	% of all respondents
Treatments/inputs	
Planting trees	8
Planting bamboo (*Thamnocalamus spathiflorus*)	58
Cultivation of medicinal plants	
Aconitum heterophyllum	34
Allium stracheyi	34
Angelica glauca	34
Carum carvi	34
Nardostachys grandiflora	17
Orachis latifolia	9
Picrorhiza kurrooa	34
Podophyllum hexandrum	17
Rheum australe	34
Saussurea lappa	9
Swertia chirayta	9
Tanacetum tomentosum	34
Thalictrum foliosum	17
Introduction of both bamboo and medicinal species	27
Protection from grazing	100
Soil management/organic manuring	100
Decision making	
By formal village institutions	Nil
By entire village community informally	100
People's contribution	
Voluntary labor	Nil
Farmyard manure	95
Propagules/seedlings/saplings from community forest	98

the local residents were more interested in the immediate tangible benefits they could obtain from rehabilitation than in the long-term tangible and intangible benefits (e.g., soil conservation, hydrological balance, carbon sequestration, and biodiversity conservation) that were the primary national and global concerns. They were, however, aware of all these benefits except for carbon sequestration. All the respondents suggested the application of a basal dose of manure and protection from grazing as prerequisites to successful rehabilitation.

The fact that all the villagers considered it important to involve the whole community in decision making suggested that they had lost faith in the forest council. The council was unpopular because: (1) it made decisions without consulting the community, (2) council members tended to use their power and position to advance their own interests rather than for the benefit of the community, (3) it had used grants improperly, and (4) most council members had a poor understanding of appropriate rehabilitation technologies. Even though we assured the villagers that all the tangible benefits from rehabilitation would accrue to the community, they would not agree to provide voluntary labor. Instead, they insisted on securing grants for payment of wages as had occurred during previous projects. However, they did agree to contribute to the project by providing social fencing, which would enable traditional regulatory mechanisms to protect the treated area from grazing and fire, and by supplying farmyard manure and seeds, seedlings, and saplings from the community forests. All the respondents suggested following traditional norms for sharing costs and benefits, implying an equal distribution between all households and the transfer of costs/benefits between households by mutual understanding.

Enhancement of people's perceptions and project implementation

A review of the villagers' perceptions showed that they were unaware of or did not understand several important issues identified by the scientific literature and a rapid ecological survey of the area. In addition, they were not familiar with the biological peculiarities of *T. spathiflorus*, which is a gregarious, flowering plant that displays low productivity for 3–4 yr after flowering. Because bamboo flowering is unpredictable, planting this species alone would be a high-risk proposal.

T. spathiflorus and many medicinal species were already regenerating in shaded and moist microhabitats dominated by *Quercus leucotrichophora*, *Aesculus indica*, and *Juglans regia.* The bamboo and the medicinal species requested were thus likely to survive the continued canopy growth of these multipurpose broadleaved trees. Poor agronomic knowledge about these rare and threatened medicinal species (Jain and Sastry 1979) and uncertainties related to market demand and price mean that more species should be tested than just those that are the most profitable at present.

Because medicinal species are tender herbs, they require intensive weeding and soil management to succeed on degraded sites and could be cultivated more profitably in abandoned fields, which are more fertile. The production of propagules of these species should be the primary objective and income generation the secondary purpose of rehabilitation. At the time the project was implemented, bamboo could be planted only through vegetative means because its seeds were not available, whereas both seed and vegetative propagation options were possible for medicinal plants. Mortality in a stressed environment is less likely with vegetative propagation than with sexual reproduction.

Planting trees on degraded lands could result in micro-environmental changes that would facilitate the natural regeneration of medicinal plants and temperate bamboo. A shortfall in grass production for fodder as the tree canopy developed was expected, because most palatable grasses grow in open habitats. It would probably be possible to compensate for this shortfall using income from bamboo, medicinal plants, and tree products.

Continuous harvesting of bamboo, medicinal species, and grass fodder is likely to aggravate nutrient stress in a recovering site because all these species have surface root systems. Although trees with litter that decomposes quickly may not provide immediate tangible benefits, they would draw nutrients from deeper soils and enrich the surface soil. This in turn would enhance the productivity of the products preferred by the villagers. The nitrogen-fixing trees *Alnus nepalensis* and *Alnus nitida* were more suitable for promoting the rapid recovery of soil fertility.

With the consent of forest council members, the above issues related to local perceptions and possibilities for development were discussed with the villagers at a meeting held on the same day as community cultural ceremonies to ensure that all families participated. This process made it easier to reach a consensus about undertaking the following interventions to rehabilitate an 8-ha plot of civil forest land:

- social fencing of the site;
- planting cuttings of *T. spathiflorus* and saplings of *A. indica*, *Q. leucotrichophora*, and *J. regia* collected from community forests at regular intervals of 1 m in pits measuring 40 x 40 x 40 cm, and providing 500 g of farmyard manure for each pit;
- bench-terracing microsites with a soil depth > 30 cm and treating them with 18 t/ha of organic manure to facilitate the introduction of the medicinal species *Aconitum heterophyllum*, *Allium stracheyi*, *Angelica glauca*, *Carum carvi*, *Picrorhiza kurrooa*, *Rheum australe*, and *Tanacetum tomentosum* from the community forests;
- harvesting bamboo and grasses at the end of the growing season (October) according to traditional practices;
- lopping and thinning the trees only after they had reached a height of 5 m; and employing only local people to meet labor needs and paying wages out of the project fund.

MONITORING

A complete census of planted species was undertaken after 7 yr to assess survival rates. The heights of 50 random individuals of each species were measured. Ten individuals per species were harvested for biomass estimation. Three farmers started cultivating their own medicinal plants after working on the rehabilitation site; their fields were monitored to estimate harvestable yields, and the same yields were assumed for the rehabilitated site. All inputs and outputs were monitored, converted to their monetary equivalents based on buying and selling prices in the village, and adjusted to net present value (NPV) at a 12% discount rate. Three composite samples of surface soil (0–15 cm deep) taken before and after 7 yr of rehabilitation were analyzed for pH, organic carbon, total nitrogen, and water-holding capacity (Jackson 1962, Rao et al. 1999).

On-site impacts

Bamboo (*Thamnocalamus spathiflorus*) showed the highest survival rate and biomass, followed by *Aesculus indica* trees. *Quercus leucotrichophora* had a lower survival rate than *Juglans regia*, although there was no significant difference in their biomass accumulation (Table 3). Natural regeneration of woody species at the site was negligible.

Table 3. Survival and growth of tree and bamboo species at rehabilitated sites after 7 yr (mean ± standard error of mean). Height growth is expressed in centimeters and biomass in kilograms per plant.

Parameter	*Aesculus indica*	*Juglans regia*	*Quercus leucotrichophora*	*Thamnocalamus spathiflorus*
Survival (%)	60	23	9	72
Height growth (cm)	260 ± 17	140 ± 13	160 ± 11	260 ± 4
Above-ground biomass (kg/plant)				
Bole/main stems	8.1 ± 1.1	2.8 ± 0.7	3.2 ± 0.6	25.6 ± 0.8
Branches	2.6 ± 0.3	1.1 ± 0.3	0.8 ± 0.1	8.1 ± 0.5
Leaves	1.1 ± 0.2	1.2 ± 0.5	1.5 ± 0.3	10.6 ± 0.8
Total	11.8 ± 1.2	5.1 ± 1.0	5.5 ± 0.5	44.3 ± 1.8

Aconitum heterophyllum was the most profitable medicinal species, and *Angelica glauca* the least (Table 4). Natural regeneration of introduced medicinal species was observed, but not beyond the microsites at which they were introduced.

Table 4. Prices and yields of medicinal products from the cultivation of medicinal species in private fields for the third through the seventh year of the study. Values in parentheses are the monetary values in U.S. dollars of the product per hectare (mean ± standard error of mean). Yield is expressed in kilograms per hectare, and price variations during the course of the study are given in U.S. dollars per kilogram.

Species	Price variation during study period (U.S.$/kg)	Yield during 3rd year (kg/ha)	Yield during 4th year (kg/ha)	Yield during 5th year (kg/ha)	Yield during 6th year (kg/ha)	Yield during 7th year (kg/ha)
Allium stracheyi	0.4–0.6	553 ± 47 (247 ± 21)	530 ± 71 (251 ± 34)	557 ± 67 (264 ± 32)	570 ± 92 (368 ± 48)	561 ± 41 (325 ± 24)
Angelica glauca	0.4–0.6	–	875 ± 43 (391 ± 19)	–	–	828 ± 39 (436 ± 21)
Carum carvi	05–0.6	370 ± 40 (195 ± 21)	440 ± 41 (243 ± 23)	484 ± 37 (280 ± 21)	437 ± 57 (288 ± 38)	464 ± 37 (305 ± 24)
Aconitum heteropyllum	24–32	–	270 ± 34 (6400 ± 805)	–	–	289 ± 31 (9126 ± 979)
Picrorhiza kurrooa	2.2–2.7	–	213 ± 29 (476 ± 65)	–	–	240 ± 31 (663 ± 86)
Rheum australe	1–1.2	–	638 ± 29 (487 ± 29)	–	597 ± 63 (738 ± 78)	–
Tanacetum tomentosum	0.9–1.1	827 ± 69 (740 ± 62)	776 ± 85 (735 ± 81)	801 ± 74 (759 ± 90)	784 ± 81 (867 ± 90)	780 ± 80 (862 ± 88)

Labor was the only paid input. Direct benefits to the local people were available from grass fodder from the beginning of the project, from medicinal plants after the third year, and from bamboo after the fourth year. The NPV of total benefits over the 7-yr period exceeded that of total costs (Table 5).

Soil organic carbon, nitrogen, and water-holding capacity improved significantly over the 7-yr period (Table 6). Rehabilitation also led to a higher level of carbon sequestration as a result of the buildup of soil organic matter and woody biomass (Table 7). The continuation of social fencing for the full 7 yr was a good indicator that the villagers appreciated the benefits generated by the rehabilitation trial.

Table 5. Monetary costs and benefits of land rehabilitation expressed in U.S. dollars per hectare (net present value at a discount rate of 12%).

Costs/benefits	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Total
Costs								
Land preparation	35	-	-	-	-	-	-	35
Plantation	141	-	-	-	-	-	-	141
Maintenance	73	13	12	9	8	7	7	129
Total cost	249	13	12	9	8	7	7	305
Benefits								
Fodder	42	44	39	35	31	28	22	241
Bamboo	-	-	-	7	20	22	25	74
Medicinal products	-	-	6	8	2	3	10	29
Total benefits	42	44	45	50	53	53	57	344

Table 6. Physical and chemical characteristics of the soil before and after 7 yr of rehabilitation (mean ± standard error of mean).

Characteristic	Before rehabilitation	After rehabilitation
pH	5.8 ± 0.02	6.1 ± 0.02
Water-holding capacity	27.5 ± 1.9	35.6 ± 1.6
Carbon (%)	1.7 ± 0.3	2.9 ± 0.3
Nitrogen (%)	0.15 ± 0.01	0.21 ± 0.04

Table 7. Carbon sequestration rate in soil and vegetation after 7 yr of planting on rehabilitation sites expressed as tons per hectare per year.

Characteristics	Carbon sequestration
Soil (0–15 cm)	3.4
Tree bole/bamboo culm	4.3
Total	7.7

Off-site benefits

The availability of fodder, medicinal plants, and bamboo from the rehabilitated site close to their dwellings could save the villagers an average of 28 man- and 20 woman-days of labor per year, time they would otherwise have spent collecting plants from distant forests and alpine meadows. During discussions of the overall impact of the project, people commented that this saving of labor gave them more time for farming, handicrafts, and health care. It was also suggested that the availability of products from degraded lands reduced the pressure on government forests and pastures. The fact that local farmers (even if there were only three of them) took the initiative to cultivate medicinal plants on private farmland after the rehabilitation treatment could also be considered an off-site benefit.

DISCUSSION

For the successful rehabilitation of degraded lands in developing countries, local concerns about immediate tangible benefits must be integrated into global concerns about the environment. This can be accomplished by building on indigenous knowledge and traditions (Altieri and Masera 1993, Dewalt 1994) and by involving the whole village community in decision making (Conroy et al. 2002). Communicating with villagers through the forest council is often unpopular, because this institution, which was imposed on the villages in the 1930s, has not been able to address their common needs and aspirations (Rao and Saxena 1996). The relatively small size of Himalayan villages and the high degree of similarity in resource use practices by the different socioeconomic and cultural groups within each village make it easier to reach a consensus on a rehabilitation approach. In the present study, the availability of medicinal plants, grass fodder, and bamboo from degraded lands provided direct economic benefits to the local people and also reduced the pressure on government forests and pastures. This made a significant contribution to Himalayan biodiversity and ecosystem services, which are a global concern.

Substantial environmental benefits accrue from planting trees on sloping lands, although the villagers initially showed little enthusiasm for this practice. However, after discussions designed to expand local perceptions, they accepted the planting of trees traditionally valued for nontimber products and also welcomed the income from shade-tolerant bamboo and medicinal species. People were reconciled to the shortfall in grass fodder production caused by the spreading shade of developing tree canopies by the income they obtained from medicinal plants and bamboo from the third year and the potential availability of tree fodder in the long term. Tree planting alone can succeed in situations where the scarcity of tree-based products threatens the livelihood of local communities and/or where policy provides for monetary benefits from commercial timber harvesting (Bartlett 1992, Fox 1993).

Although the present rehabilitation strategy appears costly (U.S.$305/ha) when compared with conventional conifer plantation projects (U.S.$160–190/ha), its ecological and socioeconomic benefits are significantly higher (Saxena et al. 1993, Maikhuri et al. 1997*a*, *b*, Rao et al. 1999). It should be noted, however, that the cost of conventional reforestation projects assumes a single expenditure for planting. The real cost may be much higher, because replanting is often necessary due to low survival rates. Furthermore, in those projects, saplings are raised in centralized nurseries, and the costs of nursery establishment and transportation to plantation sites are not included in the reforestation budget. Although transplantation of saplings from microsites in forests where natural regeneration is profuse can save time and expenditures for nursery maintenance, this method may not be appropriate for all species, as can be seen in the high mortality of *Quercus leucotrichophora* in this trial.

The introduction of "nurse species" or "keystone species" may speed up recovery while lowering labor and manure inputs (Ramakrishnan et al. 1996, Andreas and Michaela 1999). However, such species are likely to be acceptable to local people only if they serve their needs. In the present case, nitrogen-fixing *Alnus* spp. could have helped the soil recover its fertility more quickly, but was rejected by the villagers because it yielded poor-quality fodder and fuelwood. The *Q. leucotrichophora*, *Aesculus indica*, and *Juglans regia* selected by the local residents did not prove to be "nurse species" in that they failed to facilitate natural vegetation regeneration over a period of 7 yr. Although these tree species were not capable of fixing nitrogen, they could significantly improve soil fertility as a result of their rapid nutrient cycling and soil and water conservation functions. Improving our knowledge about the ecological attributes of the species valued by local people could offer better options for species selection.

CONCLUSION

Rehabilitation in developing countries that serves both local and global interests will have to be promoted as a fully funded government or donor initiative because of the limited capacity of ordinary hill people. The strategies that address local needs are the ones most likely to secure local participation and provide opportunities for achieving higher returns at lower rehabilitation costs. In the absence of such approaches, it is quite likely that local residents will adopt land use practices that provide quick monetary returns at huge environmental and social costs (Sen et al. 1997, Nautiyal et al. 1998).

Supplementing indigenous knowledge and the involvement of the whole village community in decision making seem to be the key requirements all across the Himalaya for integrating and reconciling diverse concerns related to land rehabilitation. The wide range in biophysical and socioeconomic conditions in the Himalaya demands flexible and adaptable approaches to the identification of appropriate rehabilitation technologies. The introduction of medicinal plants and temperate bamboo as well as multipurpose broadleaved trees offers comparative advantages only in high-altitude villages close to the alpine zone. In mid- and low-altitude villages, we found that the best options for rehabilitation were the development of multipurpose tree-crop mixed farming, the recycling of run-off, and soil management (Maikhuri et al. 1997*a, b*). More research is necessary to expand our knowledge about participatory land rehabilitation as a key intervention for addressing multiple problems and diverse concerns related to natural resources.

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12.

Assessing the Impact of Integrated Natural Resource Management: Challenges and Experiences

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ABSTRACT

Assessing the impact of integrated natural resource management (INRM) research poses a challenge to scientists. The complexity of INRM interventions requires a more holistic approach to impact assessment, beyond the plot and farm levels and beyond traditional analysis of economic returns. Impact assessment for INRM combines the traditional "what" and "where" factors of economic and environmental priorities with newer "who" and "how" aspects of social actors and institutions. This paper presents an analytical framework and methodology for assessing the impact of INRM. A key feature of the proposed methodology is that it starts with a detailed planning process that develops a well-defined, shared, and holistic strategy to achieve development impact. This methodology, which is known as the "paths of development impact" methodology, includes the mapping of research outputs, intermediate outcomes, and development impacts. A central challenge is to find a balance between the use of generalizable measures that facilitate cross-site comparison and slower participatory process methods that empower local stakeholders. Sufficient funding for impact assessment and distinct stakeholder interests are also challenges. Two hillside sites in Central America and one forest margin site in Peru serve as case studies.

KEY WORDS: agriculture, impact assessment, integrated natural resource management, monitoring and evaluation, natural resources, sustainable rural livelihoods.

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INTRODUCTION

Research conducted during the past 30 years by international agricultural research organizations has been successful in boosting productivity and providing enough food to feed the world. However, problems of food security, poverty, and natural resource degradation have persisted (Consultative Group on International Agricultural Research 2000). As a result, a new management and research approach called integrated natural resource management (INRM) is emerging. This is an evolving research and development (R&D) approach that combines the interconnected goals of poverty reduction, food security, and environmental sustainability (Costanza and Jorgensen 2002, Ashley and Maxwell 2002). It is defined as " ... the conscious process of incorporating multiple aspects of natural resource use into a system of sustainable management to meet explicit production goals of farmers and other uses (e.g., profitability, risk reduction) as well as goals of the wider community (sustainability) ... " (Consultative Group on International Agricultural Research 2000). To increase its potential impact, research on INRM is normally developed and planned by multiple organizational partners. As a result, INRM is not only conventionally defined research, but also "action research" that supports development initiatives led by or collaboratively managed with partners (Oglethorpe 2002, Gunderson and Holling 2002).

International R&D has also entered a new phase in which these multifaceted efforts must be accomplished with the efficient use of financial resources. During the last decade, slower growth in international research funding has resulted in calls to demonstrate research impact. For example, the real growth rate of funding to the Consultative Group on International Agricultural Research (CGIAR) declined from 4.0% per year in the 1980s to 0.5% per year since 1990 (Alston et al. 2000). To meet the triple challenge of (1) demonstrating more diverse impact with (2) fewer financial resources and (3) showing how this can be achieved, INRM requires a more holistic impact assessment (IA) approach that evaluates not only economic changes but also changes in the environment, people, and their organizations.

Impact assessment can also be a powerful tool when it come to quantifying benefits and obtaining a better understanding of the processes by which research translates into impacts. The quantification of the benefits that accrue from research interventions and outputs responds to the need for both more transparent accountability and good public relations. Impact assessment also facilitates learning by providing feedback to improve the efficiency and effectiveness of research. It should be noted that IA is not a retrospective exercise to be conducted at the end of a research project, but rather requires systematic and continuous monitoring (D. Pachico et al., 1998, *unpublished manuscript*). By identifying potential positive and negative research outcomes, it is possible to provide feedback to processes for planning and assigning priorities. Thus, information produced by IA permits scientists and other stakeholders to make more informed decisions.

Because of the larger-scope issues of INRM, there is still a lot to do before IA can be used to evaluate the final effects of more complex R&D projects. Moreover, a balance must be found between the use of generalizable measures that facilitate cross-site comparison and slower participatory methods that empower local stakeholders.

In this paper we present the advances and accomplishments of scientists from the Centro Internacional de Agricultura Tropical (CIAT) who developed and implemented an IA framework for three INRM sites in Latin America that represent two distinct agroecosystems: hillsides and forest margins. The objectives of this paper are to propose an analytical framework and methodology for impact assessment and to discuss the challenges encountered during its initial application at the reference sites.

IMPACT ASSESSMENT CHALLENGES OF INTEGRATED NATURAL RESOURCE MANAGEMENT

International agricultural research and the methodologies used to assess its impact have long reflected contemporary rural development thought. For decades, scientists have measured the impact of research, producing a vast number of studies (see Anderson et al. 1998). Themes related to the adoption of agricultural technologies and the economic returns on related investments dominate this literature. Reviews can be found in Lee et al. (1991), Horton et al. (1993), and Collinson and Tollens (1994). These studies continue to be synthesized and extended via new, robust quantitative methodologies that use economic surplus methods and estimate the net present value of benefits, internal rates of return, and cost–benefit ratios (Alston et al. 1995). Other impact assessment approaches include quantitative, qualitative, and often noneconomic measures that capture a variety of R&D effects (see Horton et al. 1993). Even though these measures do not use a common metric such as economic returns, they provide important information for giving priority to certain types of research. The potentially broad impacts of research on integrated natural resource management (INRM) require more comprehensive assessment measures than those of economic returns and the adoption of agricultural technologies.

Impact assessment is related to other concepts that require definition. For example, "monitoring" refers to the systematic and continuous process of assessing the progress and changes caused by the implementation of an activity, usually by means of predetermined indicators or recurrent questions. "Evaluation" identifies the broader positive and negative outcomes of an activity or process, draws conclusions about its overall value, and decides whether its objectives have been met (Guijt 1998). Monitoring and evaluation (M&E) are often considered to be a linked process.

No commonly accepted protocol exists for assessing the impact of INRM. The following four major themes represent different dimensions of the challenges involved in assessing its impact.

Finding feasible spatial and temporal boundaries

The impacts of INRM can be hard to evaluate because of its multifaceted nature. At different spatial and temporal scales, INRM themes change and can be assessed in terms of multiple objectives, e.g., poverty alleviation, ecological resilience, natural resource conservation, economic growth, and human and social development, that reflect the needs and expectations of different stakeholders (Izac and Sanchez 1998). Plot- and farm-level analyses that are relatively manageable expand to the more unwieldy scales of the community, the watershed, and even larger areas. Hierarchies and a wider scope introduce numerous complicating ecological, social, cultural, institutional, economic, and political factors.

The measurement of impact across spatial scales is a key issue in the impact assessment of INRM research (D. Pachico et al., 1998, *unpublished manuscript*, Lovell et al. 2002, Hagmann et al. 2002). For example, measures to assess the impact of erosion on the natural resource base differ from plot to slope face to watershed to river basin. Unlike agricultural research, impact assessment (IA) for INRM research concerns a number of ecosystem services that are distinct at each spatial scale, e.g., farming system, village, watershed, landscape, regional, and global (Izac 1998), and therefore depend on the spatial pattern of adoption.

With respect to temporal scales, Scherr (2000) argues that longer time periods are required to assess sustainability, despite the fact that these longer periods increase the likelihood of major socioeconomic or biophysical shifts taking place. Impact assessment faces the so-called "attribution problem" that confounds the impact measurement of R&D innovations with changes in other structural variables over time, such as changes in macroeconomic policies or environmental disasters. Therefore, IA for INRM must be designed to consider long-term change and, at the same time, analyze shorter-term successes and/or failures with regard to the achievement of the desired impact with M&E. To assess long-term changes, different instruments can be used, such as time series of remotely sensed variables, panel data sets, historical reconstruction of plot- or community-level trends with local people, and participatory historical mapping (Scherr 2000). At the same time, the issue of realizing results after a protracted time is not a new challenge to INRM alone. Research programs for agricultural crop improvement took at least a decade from their outset to deliver the first outputs, and in many cases even longer. INRM research may not require much longer than that to produce results (D. Pachico et al., 1998, *unpublished manuscript*).

Stakeholder participation in the impact assessment process

As a result of scale hierarchies, many perspectives, e.g., those of farmers, rural inhabitants, community organizations, support organizations, private entrepreneurs, scientists, donors, and policy makers, can lead to conflicting objectives, interests, and opinions. Therefore, a central concern of INRM is to both identify and assess the trade-offs among the various stakeholders (Izac 1998). Communication breaches and distinct stakeholder perspectives pose special challenges to measuring the impact of INRM. Differences in the ways stakeholder groups communicate with each other can sabotage dialogue, learning, and cooperation. These communication difficulties may, in fact, be symptoms of deeper, more fundamental differences in the ways that these groups learn and view the world (van Dusseldorp and Box 1993, Probst 2002).

Understanding and properly addressing both private and public incentives are the key difference between previous R&D efforts and those of INRM. To make optimal decisions, it is necessary not only to analyze trade-offs to determine who will benefit and who will not, but also to establish a forum for careful negotiation and collective action.

Participatory monitoring and evaluation (PM&E) approaches have been proposed for efficient, effective, and socially inclusive assessment (Abbot and Guijt 1998, Guijt 1998, Probst 2002). The PM&E approach has four identified benefits. First, because the application of INRM research produces a broad range of impacts in communities, including many of a social nature, these changes can be difficult for outsiders to observe (e.g., forest or water access). Participatory M&E improves the accuracy and relevance of the collected data, thereby reducing some of the problems inherent in externally defined IA studies, which risk misinterpreting the findings that result when variables are omitted (Scherr 2000, Probst 2002). Second, participation in self-evaluation can be a powerful contribution to local institution building (Scherr 2000). Guijt (1998) emphasizes that PM&E enhances local capacity to record and analyze change and improve community-based initiatives. Third, PM&E is cost-effective because it employs local capabilities rather than expensive external experts (Guijt 1998). Fourth, including stakeholders in the entire process increases the probability that the analyzed data and results will be used.

Although PM&E has its advantages, it also has drawbacks. Data collection on a voluntary, unremunerated basis, as often happens in participatory processes, is unlikely to be sustained unless the information has some direct relevance or value for community members, community organizations, and local and national organizations. In addition, PM&E can be expensive for local people because it involves a significant amount of time that could otherwise be spent on income-earning activities. Before embarking on a PM&E process, a basic understanding is needed of the limitations of what is possible to avoid poor-quality work and disillusionment.

Different assessment needs and interests may require parallel IA processes conducted by external and local groups; results and analysis can then be integrated. Therefore, a central challenge is to find a balance between faster generalizable measures that facilitate comparison across sites, and slower participatory processes that empower local stakeholders and validate results and analyses.

Linking research products to development impact

Demonstrating a clear link between research products and changed livelihood strategies that lead to development is a major difficulty in assessing the impact of INRM. Even though connections are plausible, they are often treated as a "black box" that cannot be analyzed or explained in detail (Goldsmith 1993). An impact cannot be attributed to an intervention unless it can be logically explained and justified. The final impact may be great, but the causality is usually too subtle to measure exactly. Complications are particularly acute with the diffusion of agricultural research and technology, because a long chain of events separates innovations made in the scientist's laboratory from their deployment in the farmer's field. Furthermore, it remains unclear how far scientists should work across the research-development continuum to increase the probability of making an impact.

Therefore, understanding the linkage between research products and development impact is a critical issue for both IA and M&E. To assess the impact of research, we must determine if and how people and organizations react, and whether they change their actions as a result (Sander, 1998, *unpublished manuscript*). These measures, called project "reach," refer to both the number and type, e.g., local or regional, of organizations affected. The methodology described below traces the multiple, and often nonlinear, chains of events that link researchers and their findings with other actors essential to the change process.

Selecting the criteria of success

Indicators are central to IA and M&E approaches because they help to communicate information about complex processes, events, or trends to a wider audience (Guijt 1998). However, selecting indicators is a difficult step in establishing these processes. These problems include the fact that:

- a range of different indicators is required for each “output,” “outcome,” and “impact”;
- chosen indicators are likely to change over time as the external environment changes and as the project objectives are adjusted;
- stakeholders select indicators based on different cultural values, priorities, information needs, and expectations;
- indicators are only proxy measures of a more complex reality that are required for empirical analysis; and
- indicators, even when they are relevant and accurate, are influenced by practicality and cost concerns related to data collection and analysis.

In summary, the challenges of impact assessment reflect the complexity of the interrelated goals and actors of INRM.

AN ANAYTICAL FRAMEWORK FOR INRM IMPACT ASSESSMENT

An impact assessment (IA) methodology for integrated natural resource management (INRM) should help clarify how an intervention affects a society’s economic, financial, natural, social, human, physical, and other resources. The “sustainable rural livelihoods” framework described by Scoones (1998) has scope for broad application to IA methods including INRM. Drawing on Chambers and Conway (1992), Scoones (1998) defines “sustainable rural livelihoods” as:

> *... the capabilities, assets (including both material and social resources), and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, and maintain or enhance its capabilities and assets, while not undermining the natural resource base.*

This definition can be divided into two subcomponents that reflect the themes of INRM. The first focuses on well-being or livelihoods and includes aspects of employment, income, and poverty reduction. The second is the sustainability dimension, which includes the resilience of livelihoods and the natural resource base on which they depend.

The IA analytical framework is based on the framework of sustainable rural livelihoods (see Fig. 1). This IA framework contains four key components that reflect the state of development (including the context), the process of development (livelihood strategies), institutions and organizations, and R&D interventions. An initial assessment or baseline study describes the current state of livelihood resources or the "capital" base from which different production processes are derived for each reference site. This capital base has five dimensions:

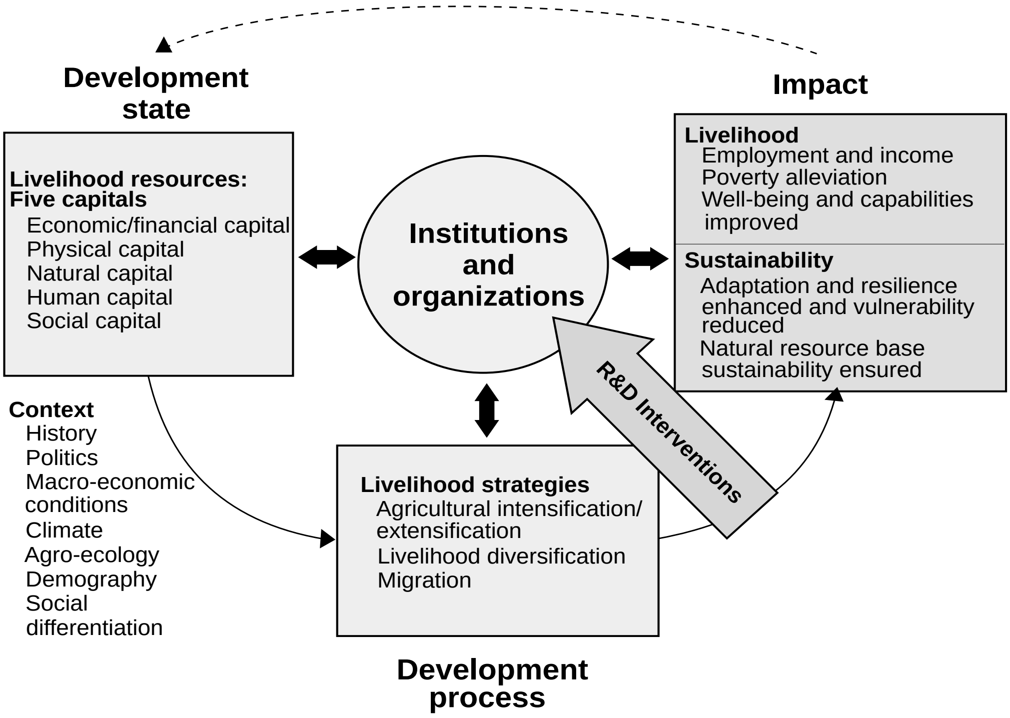
1. Economic/financial capital: the capital assets (cash, credit/debt, and savings) that are essential for the pursuit of any livelihood strategy.
2. Physical capital: the household assets and farm infrastructure, including production equipment, technologies, and plantations.
3. Natural capital: the stock of natural resources (soil, forests, water, air, genetic resources, etc.) and environmental services (hydrological cycle, carbon sequestration, etc.) from which both resource flows and useful services for livelihoods are derived.
4. Human capital: the capacities, skills, knowledge, ability to work, good health, and physical capability important for the successful pursuit of different livelihood strategies. Human capital can be developed consciously through formal education and training and unconsciously through experience.
5. Social capital: the social resources (networks, social relations, affiliations, associations, norms, trust, and disposition to work for the common good) upon which people draw when pursuing different livelihood strategies requiring coordinated and collective action.

The baseline also provides a description and a contextual analysis of conditions, trends, and policy setting in the community. These components include the exogenous characteristics (structural variables) of a site such as its history, politics, macroeconomic conditions, terms of trade, climate, agroecological conditions, demography, and social differentiation.

Households and communities use three broad clusters of livelihood strategies: (1) agricultural intensification/extensification, (2) livelihood diversification within agricultural activities or nonfarm activities, and (3) migration. Livelihood strategies are part of the development processes that enable individuals, households, and communities to reach a modified development state and move from an initial development state toward a subsequent one. If people change their livelihood strategies, then their livelihood outcomes will also change. Because this is a dynamic process, livelihood outcomes are not static.

Institutions and organizations are at the center, as befits their role in binding together the elements of the framework. According to Scoones (1998), understanding institutional processes is a prerequisite to identifying restrictions/barriers and opportunities with regard to sustainable rural livelihoods. Because formal and informal institutions mediate access to livelihood resources, an understanding of institutions and organizations is critical for designing R&D interventions.

Figure 1. Analytical framework for integrated natural resource management impact assessment on sustainable rural livelihoods (adapted from Scoones 1998).



For INRM research interventions to have an impact on rural livelihoods, it is not enough to merely produce research outputs (the “what”) that permit a better understanding of system dynamics and processes in a variety of sites (the “where”). It is essential to identify “who” is going to implement and adopt changes, and “how” to best improve livelihoods. Organizations, which are the vehicles of change, are thus the target for R&D interventions and the collective-action platform for planning, implementing, and evaluating them. Institutions provide the rules and norms by which individuals and their organizations operate, and therefore provide structures that can either hinder or foster the development processes. Adopting a sustainable livelihoods approach forces the R&D process to recognize the potentially “ ... enormous level of organizational and/or institutional failures that exists and (therefore affects) the impact of agricultural research ... ” (Shaxson, 1999, *unpublished manuscript*).

ASSESSING THE IMPACT OF INRM: A PROPOSED METHODOLOGY

The natural resource management (NRM) projects of the Centro Internacional de Agricultura Tropical (CIAT) work in three different agroecosystems throughout Latin America, including hillsides (Yorito, Honduras, and San Dionisio, Nicaragua), savannas (Puerto Lopez, Colombia), and forest margins (Pucallpa, Peru). At these sites, CIAT integrates germ plasm, technology, NRM, and institutional innovations into pilot activities that, together with development partners, are introduced to achieve CIAT's mission of reducing poverty while preserving the natural resource base. The partners lead or play a major role in development planning and implementation. The main objective of the reference site approach is not the development of the reference site per se, but rather the refinement of social, economic, biophysical, and institutional innovations that can be extrapolated beyond the reference site.

The "paths to development impact" methodology

To assess the impact of INRM R&D efforts, the "paths to development impact" methodology is a helpful tool in establishing a monitoring and evaluation (M&E) system. These paths make it easier for all stakeholders to understand the ways in which research-based interventions are interrelated within complex systems; they also make it possible to gather credible evidence and analyze it in a convincing way. At the planning stage, three different points along the path can be distinguished: (1) outputs, or the immediate products of a project after using the given inputs, (2) outcomes or consequences of the outputs, and (3) impacts, i.e., the broader and longer-term goals.

As one moves along the pathway from a research intervention to a development impact, control over specific activities declines. Although performance or output indicators rely exclusively on the project, outcomes depend on other factors besides the intervention itself. Final development impacts go beyond the sphere of influence of an intervention and depend on a range of structural factors. These include the context conditions and trends, the given livelihood resources, and the institutional processes and organizational structures (Smutylo 1998).

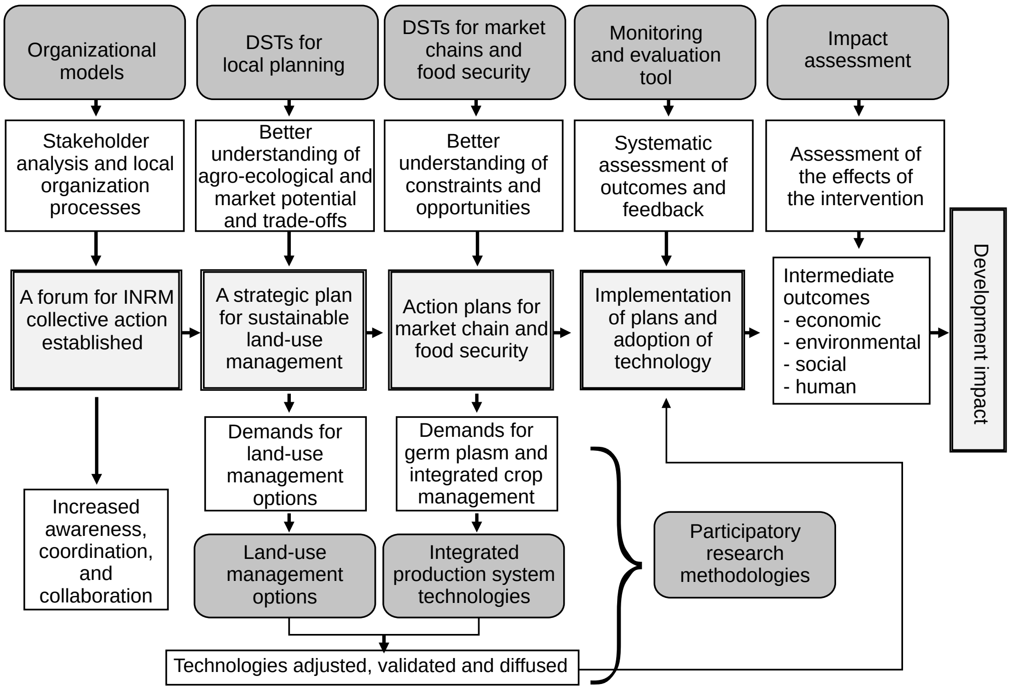
Paths to development impact identify the direct users and indirect beneficiaries of research and also represent a set of possible routes by which research may produce an impact. They serve not only to set up an appropriate M&E process and effective IA, but also to provide a basis for designing delivery strategies for research outputs. This is because some paths will be more likely than others to achieve the desired impacts.

A path to development impact methodology for CIAT INRM research

A generic path to development impact was constructed for CIAT's INRM strategy (Fig. 2). Because INRM interventions move beyond the farm to the landscape, they require collective action that involves local institutional planning, implementation, and evaluation activities. The rounded boxes (five at the top and three at the bottom of Fig. 2) are the CIAT R&D interventions and correspond to those targeted at the institutions and organizations presented in the above analytical framework. The center row of four double-bordered boxes represents the process steps. The unshaded boxes are the expected outcomes of the interventions.

The first intervention, organizational models, promotes collective action among community associations and support organizations for INRM. A second intervention includes two types of decision support tools (DSTs). The DSTs for local planning provide essential information for the design of a strategic plan for INRM, including a diversified portfolio of

Figure 2. Paths to development impact of CIAT's integrated natural resource management strategy. DST stands for "decision support tools."



market chains to be promoted, current and potential land uses, and different alternatives for promoting sustainable land-use management. The strategic plan also identifies the demands for technological land-use management options and provides feedback to NRM scientists.

Once a given portfolio of products is selected, DSTs for market chains and food security provide a better understanding of agricultural and land-use constraints and opportunities for the development of market chains and food security. These action plans identify demands for germ plasm and integrated crop management technologies and serve as a feedback channel to scientists.

The third intervention, technological options and information, includes two groups of technologies (bottom of Fig. 2): land-use management options and integrated production system technologies. The first group permits a scaling-out of technological options from the farm to the landscape. The second combines germ plasm with integrated soil and pest management technologies at the farm scale for a given commodity.

The fourth area of intervention, participatory research methodologies, improves the effectiveness of the technology development, adaptation, validation, and diffusion process of both integrated production system technologies and land-use management options.

The strategic and action plans, along with the adoption of technologies, improve land-use management, strengthen competitiveness, promote integrated production systems, and foster community empowerment. These changes in turn affect broader sustainable development goals by producing changes in the economy, the environment, the people, and their organizations.

Once the paths to development impact have been mapped, indicators for each critical outcome along the pathway need to be selected. Therefore, when objectives and users are clear and when outputs, outcomes, and impacts are mapped, the process of selecting and developing indicators becomes easier, and it is possible to avoid the trap of collecting a great deal of irrelevant information. Only indicators that are critical and feasible to monitor, analyze, and disseminate with the resources available should be chosen. In the case of CIAT, once the generic path to development was constructed, a list of proposed intermediate and development indicators that reflected the different capitals was prepared with the scientists involved (Appendix 1).

Implementing the path to development impact with local stakeholders

Initial efforts to develop a methodology to assess the impact of CIAT's NRM projects at three reference sites focused on creating the paths to development impact and developing and/or selecting indicators for the collection of baseline data. To implement the methodology with CIAT stakeholders, paths to development impact and their indicators were constructed in workshops conducted at the reference sites.

In April 1999, a workshop was organized with the dual objectives of establishing a structure to measure the impact of R&D efforts and to improve institutional coordination in Pucallpa, Peru. The effort followed a training seminar on participatory planning by objectives and logical frameworks held 2 years before. Representatives from more than 20 organizations attended a two-day Indicator Framework and Impact Assessment Workshop. Nongovernmental organizations, universities, and national and international institutions from diverse sectors of agricultural research and extension, health, and NRM attended the workshop.

Small groups of participants constructed paths to development impact by first identifying the goals of sustainable development. Goals developed from the previous workshop were used to avoid repeating the exercise. A series of intermediate steps representing the activities required to achieve these goals connected the research outputs with development impacts. Although some of the paths were relatively easy to construct, those related to institutional cooperation and policy formulation were the most challenging. The themes of technology development, management and conservation of natural resources, human and environmental health, and agribusiness development required less effort. However, some groups were dominated by the input of a few participants.

The participants agreed that an IA framework would facilitate the transparent reporting of results within their organizations and to donors. After the meeting, they set up working groups whose tasks were to refine indicators and collect data, but the participants met only a few times. Factors that contributed to the disintegration of these groups included the problems of overworked contributors, difficulties in finding convenient times to meet, and different institutional objectives. Had financial resources been specifically dedicated to this effort, the outcomes might have been more positive. Although these discussions could have led to an agreement on the paths to development impact and the indicators to be used, it was not possible to establish a participatory monitoring and evaluation (PM&E) process in this case. With decision-making power concentrated in the capital, there were irresistible incentives to obfuscate and even embellish reports in the highly politicized environment.

In July 2000, workshops and interviews were conducted at the Nicaragua and Honduras hillside reference sites to identify different development perspectives and goals of stakeholders ranging from community members and organization leaders to personnel from local organizations. Development objectives were discussed using a participatory tool developed by the CIAT team. First, a visioning exercise of the desired "development state" was conducted. The participants reflected on how they would like the watershed and its communities to be after 10 years. Based on this desired development state, current conditions were described. Finally, intermediate outcomes to be reached in the next 3 to 5 years were also proposed and discussed.

An analysis of the results shows that all of the groups were interested in human, social, economic, and environmental objectives. Scientists identified a broad range of indicators, whereas the inhabitants of poor rural communities had simpler, but specific and short-term, expectations. Rural people wanted to have a community where people have enough to eat, as well as a more diversified diet, and where they can buy clothes and shoes for their families. They also wanted access to the basic infrastructure and to appropriate education and health services. In contrast, the expectations of community organizations were focused on economic goals and tended to relate improved income and production as a means of meeting basic needs. Whereas scientists tended to see indicators and capitals as separate objectives, community organizations had a more complex and integrated perception of the different capitals.

It is clear that development agencies, donors and scientists consider central values such as gender, equity, and the environment to be significant. However, although community organizations are beginning to talk about gender as an important issue, they seem merely to be repeating the development discourse promoted by external organizations. Economic equity is rarely mentioned by community organizations. This could be related to the perception that "we are all poor," or the fact that the poorer community members often do not participate or express their opinions in community meetings.

With respect to the environment, whereas scientists talked about preserving or improving the natural resource base, community members placed more emphasis on the appropriate use and management of their natural resources. As a result of land degradation, recent natural disasters, water scarcity, and promotional campaigns by external organizations, an awareness of NRM appears to be growing. Rural dwellers give priority to the themes of improving land productivity and water availability, with an emphasis on having a community with more trees, especially around the watershed, and using farming practices that maintain soil fertility.

Often caught in the middle between donors and recipients, local governmental and nongovernmental support organizations have another perspective. Their central objective is building the capacity of local communities to analyze, reflect, and find collective solutions or alternatives to their problems. Communities, on the other hand, prefer fewer organizations, but with solid and clear goals that respond to community needs, and more external support. The emphasis placed by communities on the satisfaction of their basic needs provides a potentially effective entry point for intervention.

EMERGING LESSONS AND FURTHER RESEARCH QUESTIONS

The preliminary results of impact assessment research for integrated natural resource management (INRM) carried out by the Centro Internacional de Agricultura Tropical (CIAT) are mixed, reflecting the multifaceted demands of INRM research. A major constraint to advancing the impact assessment (IA) effort was a lack of well-described pathways tracing research outputs to development impact. The principal reason for this situation was that, although it is useful for monitoring project performance and reporting, the logical framework does not provide a means of carefully tracking how research outputs translate into development impacts. Furthermore, the logical framework does not consider who would adopt project outputs and why, or how the adoption of these outputs will then contribute to the project purpose and goals (Sartorius 1996, Technical Advisory Committee of the Consultative Group for International Agricultural Research 1999). The development and integration of the paths took longer than expected, and a scientist was assigned to facilitate the task. By developing the paths with organizational partners, gaps and overlaps appeared, thus clearly illustrating both unmet needs and opportunities for collaboration.

These advances will enable cross-site comparison of the reference sites and could raise interesting new research hypotheses. From the CIAT research perspective, this effort to standardize IA has improved coordination across sites and among scientists. A synthesis of the development indicators (Appendix 1) reveals that economic and agricultural production indicators are similar across sites, whereas environmental indicators reflect local issues. Baseline indicators for the reference sites range in scale from plot level to farm, landscape, watershed, region, and continent. Interestingly, scientists found it difficult to agree on definitions of scale beyond the farm level. Although physical boundaries such as watersheds are helpful when associating biophysical measures, policy decision making generally follows political boundaries such as municipalities. In the end, there was a consensus that the data should be analyzed using human-defined scales.

At the heart of INRM impact assessment lie important questions about how practical it is when financial resources are scarce. The CIAT impact assessment advances show a dependence on both the organization's research priorities and the willingness of or buy-in from national partners. As part of an action research approach, the challenge will be to define where research stops and development begins. In other words, how far along the path to development must/should research organizations dedicate financial and scientific resources? The answer will depend on the strength of local organizations and on donor requirements. In Peru, stakeholder interest was so ephemeral that the project was placed on hold. In Central America, with its diverse stakeholder objectives, CIAT research efforts have a higher priority. These outcomes reflect a scarcity of scientific and financial resources within CIAT.

Preliminary results of the application of this analytical framework and methodology in Central America show a promising opportunity and have made it possible for the processes of monitoring, evaluation, and impact assessment to move forward at the reference sites. However, fieldwork has only just begun and must be completed as planned for 2001 and 2002. Two parallel processes are being started at the reference sites in Central America. The first is a participatory monitoring and evaluation (PM&E) process for three specific projects that were selected because they were already working with partners and had been fostering local collective action. The second process is a longer-term IA process based on the analytical framework and the methodology described in this paper. When these processes are completed, their results will need to be compared and integrated.

This research is just the start of a broader effort to develop an appropriate methodology for the assessment of the impact of more complex R&D interventions such as INRM. Further research is required to develop a model (or a methodology) to assess and validate the pathways that link INRM research outputs with intermediate outcomes and final development impact. This will permit an analysis of the influence relationships among them, and the contributions of research outputs to development outcomes. Research should also be conducted to provide an ex ante analysis of alternative INRM R&D interventions and pathways that affect poverty and sustainable development. Given that the INRM process often takes years, ex ante modeling efforts are needed to allow researchers and stakeholders to analyze likely development scenarios. Coordination between both modeling and impact assessment efforts, which require measures of many variables, can permit validation of these models and prevent a duplication of data gathering.

Despite the arguments in favor of such approaches, INRM will be hard to justify if its impact is subject to the sort of assessment used for crop improvement research. Impact assessment estimates of agricultural research using annual economic returns are often sophisticated and elegant. Moreover, they simplify decision making to relatively simple numbers and, even if these analyses are becoming suspect (see Alston et al. 2000), these estimates remain an easy point of comparison and represent nearly 40 years of cutting-edge research efforts. The wider and less measurable goals of INRM will continue to challenge attempts to estimate impact.

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APPENDIX 1

List of proposed development indicators.

ECONOMIC AND POVERTY INDICATORS

Food security

Total and gender-differentiated available food in the household
Seasonal available food in the household

Income

Farm income (U.S.$/ha)
Household income (U.S.$/household, U.S.$/capita)
Household income stability (standard deviation)
Income sources (on/off farm, agricultural/nonagricultural)
New products or processes introduced in the agricultural sector
Participation on final consumer price (community gate price/final consumer price of most important selected commodities)
Value added to primary production (selling price/primary product farm-gate price)
Distribution of income sources

Equity

Farm and household income comparisons by well-being group and by gender
Distribution of economic surplus or value added
Land tenure situation (percentage of farmers who own land, mean farm size)

Employment generation

Number of jobs (total, gender-differentiated, and seasonal)
Percentage of active population employed (total, employees, self-employment, and gender-differentiated)

ENVIRONMENTAL INDICATORS

Production system

Land-use intensification

Number of cropping cycles per year

Fallow area as percentage of total area
Fallow time as percentage of cropping cycle
Fallow species diversity (native and enriched with introduced species)
Legume diversity
Land with improved pasture

Land-use diversification

Number of species/crops per farm and per landscape
Number/type of cropping systems within the farm
Number of weeks per year that the soil is exposed to erosive effects (wind and water)
Number of perennial crops in the cropping systems
Spatial distribution of crops
Temporal distribution of crops
New resource management practices introduced in the agricultural sector

Land productivity

Kilograms per hectare per year for selected crops, livestock, and forest products
Total factor productivity
Product/energy ratio (biophysical measure)

Forest

Area of forest cover (ha/farm, ha/community, ha/municipality)
Map of forest cover (spatial and temporal distribution)
Secondary forest regeneration
Species diversity in secondary forest (native successions and enrichment with introduced species)

Soils

Land productivity

Kilograms per hectare per year for selected crops (already an indicator of production systems)

Water balance

Area and spatial and temporal distribution of degraded land and pasture

Water

Water pollution

Contamination points

Water quality

Sedimentation
Turbidity
Levels of nitrates and phosphates
Conductivity

Water availability

Volume of water by season
Volume of water by levels of rain

Other indicators

Agro-chemical use (kg/farm, number of applications)
Burning of agricultural residues (Yes/No)
Air pollution (Yes/No, CO, CO_2)

HUMAN/SOCIAL INDICATORS

Community empowerment and equity in decision making

Projects designed and mobilized by the community and/or local and/or external organizations (number and description)

Participation in local policy decision making

Existing channels and mechanism for participation in democratic governance
Community access to political decision making
Community capacity to influence political decisions that affect the community

Human capital

Education and experience

Individual capacity (number of years formal/nonformal education, number of years experience)

Individual capacities

Capacity to participate in key decisions that affect NRM and primary production and agro-enterprises

Capacity to innovate in agriculture, agro-enterprises, and NRM
Knowledge of key causes and effects of NRM problems
Knowledge of key causes and effects of agricultural production, processing, and marketing relationships
Capacity to manage agro-enterprises, local agricultural research committees, community organizations, consortia, and farms

Access to opportunities

Percentage of children with access to primary education
Percentage of youths with access to secondary, technical, and university education
Technology
Market
Infrastructure
Health
Information

Social capital

Structural social capital

Organizational density
Networks
Support organizations
Procedures and norms
Precedents

Cognitive social capital

Conflict resolution
Collective action
Solidarity
Trust
Reciprocity
Cooperation

QUALITY OF LIFE INDICATORS

Nutritional levels
Access to health services and medicines
Access to consumer goods (clothes, shoes, etc.)
Migration
Local well-being indicators

13.

Assessing Viability and Sustainability: a Systems-based Approach for Deriving Comprehensive Indicator Sets

Hartmut Bossel

ABSTRACT

Performance assessment in holistic approaches such as integrated natural resource management has to deal with a complex set of interacting and self-organizing natural and human systems and agents, all pursuing their own "interests" while also contributing to the development of the total system. Performance indicators must therefore reflect the viability of essential component systems as well as their contributions to the viability and performance of other component systems and the total system under study. A systems-based derivation of a comprehensive set of performance indicators first requires the identification of essential component systems, their mutual (often hierarchical or reciprocal) relationships, and their contributions to the performance of other component systems and the total system. The second step consists of identifying the indicators that represent the viability states of the component systems and the contributions of these component systems to the performance of the total system. The search for performance indicators is guided by the realization that essential interests (orientations or orientors) of systems and actors are shaped by both their characteristic functions and the fundamental and general properties of their system environments (e.g., normal environmental state, scarcity of resources, variety, variability, change, other coexisting systems). To be viable, a system must devote an essential minimum amount of attention to satisfying the "basic orientors" that respond to the properties of its environment. This fact can be used to define comprehensive and system-specific sets of performance indicators that reflect all important concerns. Often, qualitative indicators and the study of qualitative systems are sufficient for reliable performance assessments. However,

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this approach can also be formalized for quantitative computer-assisted assessment. Examples are presented of indicator sets for the sustainable development of regions, including the computer-based, time-dependent assessment of system performance using time-series data. Because of its systems-theoretical foundation, this approach avoids the problems of incompleteness and double-counting common in ad hoc methods of indicator selection.

KEY WORDS: indicators of sustainability, integrated natural resources management, orientors, performance indicators, sustainability assessment, systems approach, viability.

INTRODUCTION

Competent management of real-world problems must recognize and account for real-world system complexity. Holistic approaches such as integrated natural resource management (INRM) and system dynamics are therefore spreading in a wide range of disciplines (Holling 1978, Sterman 2000, Gunderson and Holling 2002). A crucial aspect of this development is the search for appropriate indicators of system performance to condense vital information into a compact set of reliable signals for management. The need for comprehensive indicator sets that assess system viability, performance, and sustainability is especially urgent in management for sustainable development at all levels, from the global to the village (Luzadis et al. 2002).

The search for appropriate indicators of sustainable development has been going on for many years at many different levels of society: small communities, cities, regions, countries, and the world as a whole. There seems to be general agreement that it is impossible to define only a single indicator of sustainable development, and that a substantial number of indicators are necessary to capture all the important aspects of sustainable development in a particular application (Becker 1997, Hardi and Zdan 1997, Moldan and Billharz 1997, Meadows 1998, Bossel 1999, Michaelidou et al. 2002). However, defining an appropriate set of indicators for sustainable development is a difficult task. If too few indicators are monitored, crucially important developments may escape attention. If a large number of indicators have to be examined, data acquisition and data analysis may become prohibitively expensive and time-consuming. Obviously, practical schemes cannot include indicators for everything. It is therefore essential to define a set of representative indicators that provide a comprehensive description, or as many as are essential, but no more. But what are the “essential” indicators?

In the past, this problem has been solved mostly by the intuitive assessment of experts familiar with a particular discipline such as economics, ecology, sociology, or engineering. Corresponding indicator sets are usually characterized by specific disciplinary biases, with gaping oversights in some critical areas and overly dense indicator specifications in others.

This paper describes a different system-based approach based on new developments in ecological and general systems theory (Müller and Leupelt 1998). Development is seen as a coevolutionary process involving interacting systems in a common environment in which each system follows its own path of self-organization in response to the challenges of its particular environmental circumstances. The complex web of interacting systems can then be broken down recursively into a network of individual systems, each of them determining its own fate and affecting that of one or more other systems. Indicators then have to be found to describe the performance of the individual system and its contribution to the performance of the other system(s). A first task in the search for a proper indicator set therefore consists of identifying the essential component systems and analyzing and defining the relevant system structure. Obviously, a considerable amount of aggregation and condensation is required at this point to keep the project within manageable dimensions.

The next step requires that essential indicators be found for the performance of each "affecting" system and its contribution to each "affected" system. Based on orientation theory (Bossel 1977, 1999), it is argued that the essential indicators are those that provide a complete description of the state of satisfaction of the fundamental interests of each system, i.e., its basic orientors: existence, effectiveness, freedom of action, security, adaptability, coexistence, and psychological needs (for humans and for systems with humans as components). This leads to the selection of a comprehensive, but minimum, set of indicators that provide information about all essential aspects of viability, sustainability, and performance. In this context, "viability" means the ability to survive and develop, and "performance" refers to functions extending beyond mere viability requirements.

METHOD

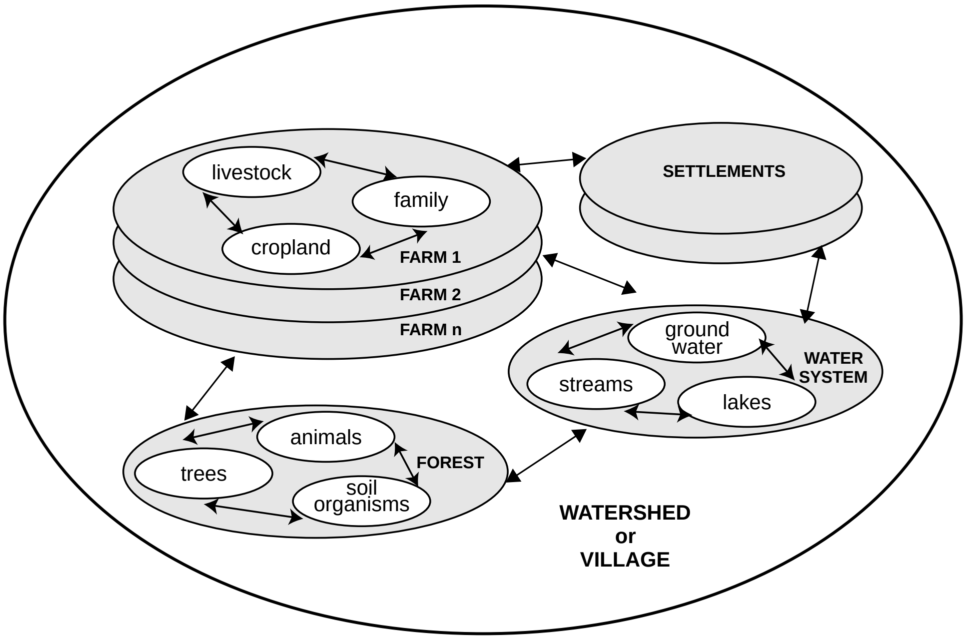
Reality as a nested system of nested systems

Integrated (holistic) management typically has to deal with complex systems (Fig. 1). The viability and performance of the total system of concern (e.g., a watershed region) depends on the viability and performance of each of several component systems (e.g., settlements, farming, the forest, the water system). Each of these is again dependent on the viability and performance of several subsystems (e.g., the farming system depends on the livestock, cropland, and family subsystems).

For the following discussion, it is essential to remember that a system is more than its parts, i.e., its function is not merely the sum of the functions of its component systems. Rather, its function and viability emerge from the interactions of the component systems within the specific system structure. Component systems contribute to the whole by being individually viable and by contributing to the viability of other component systems and/or the total system. Individual component systems may be affected by other component systems as well as by system variables outside the boundaries of component systems.

Depending on the purpose and depth of a particular study, component systems may have to be further broken down into their component subsystems in a recursive manner to track the "viability chain" to some possible cause of performance deficiency in the total system. A system study is therefore essential. A key element of such a study is the recursively repeated relationship of affecting system vs. affected system. A system study will usually reveal many relationships and component systems that are important to the operation and viability of the total system even though they may not be immediately obvious. It may also

Figure 1. An example of interacting nested systems. Integrated management has to deal with systems of this type. Subsystems contribute to the viability and performance of the component systems, which in turn contribute to the viability and performance of the total system.



reveal deficiencies on different levels of the system hierarchy, i.e., on different scales. It is therefore often necessary and entirely appropriate to develop indicator systems that consist of crucial indicators on very different scales, as in the Seattle example discussed below. Moreover, indicator sets should allow for dynamic change, because other indicators on different scales may become more appropriate during the course of dynamic changes in the system, in particular, during Schumpeter-Holling cycles.

Different kinds of relationships have to be considered when examining systems. All systems depend to some degree on the resource-providing and waste-absorbing capacities of their environments. Most systems interact with other systems that are essential to their viability. Many interactions are hierarchical, with systems controlling subsystems and subsystems contributing to the functioning of the systems that contribute to the functioning of a suprasystem, etc. The viability and performance of the total system depend on the viability and performance of many, but not necessarily all, of its subsystems.

At the level of the total system, the task is to find indicators that provide reliable information about its viability and performance, much as a thermometer is used to determine the health of a person (Fig. 2). In the case of the nested systems we usually encounter in the real world (Fig. 1), two sets of indicators are required for every system–subsystem relationship (Fig. 3). One set is required for determining subsystem viability and performance, whereas a second set is needed to assess the contribution of the subsystem to the viability and performance of the system as a whole. This duality of indicators is repeated at every level of the system hierarchy.

Figure 2. Influence of the environment on system viability. The performance indicators for a given system must reflect its viability and performance under the effects of its particular environment.

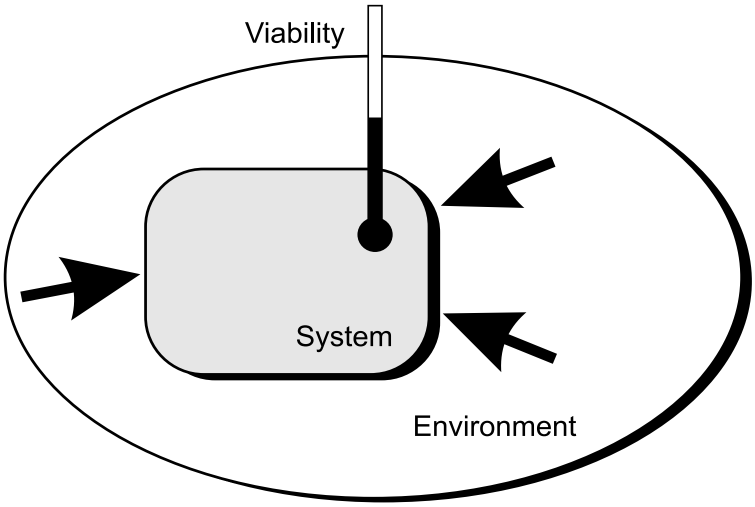
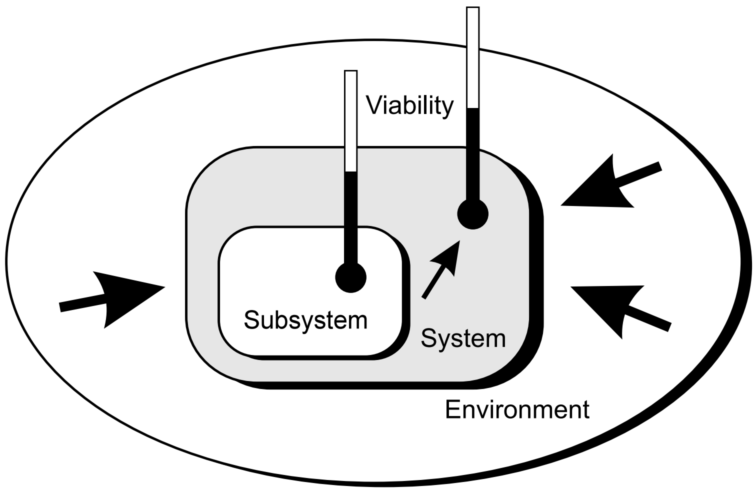


Figure 3. Illustration of the contribution of subsystem viability to the viability of the overall system. Generally, the viability and performance of a system depend on the viability and performance of its subsystems. Subsystem indicators must reflect, first, the viability and performance of the subsystem and, second, its contribution to the viability and performance of the overall system.



This paper deals with a practical procedure for finding appropriate indicators. It has several distinct steps:

- *Obtaining a conceptual understanding of the total system.* We cannot hope to find indicators that represent the viability of systems and their component systems unless we have at least a crude, but essentially realistic, understanding of the total system and its essential component systems. This requires a conceptual understanding in the form of at least a good mental model.
- *Identifying representative indicators.* We have to select a small number of representative indicators from a vast number of potential candidates in the system and its component systems. This means concentrating on the variables of those component systems that are essential to the viability and performance of the total system.
- *Assessing performance based on indicator states.* We must find measures that express the viability and performance of component systems and the total system. This requires translating indicator information into appropriate viability and performance measures.
- *Developing a participative process.* The previous three steps require a large number of choices that necessarily reflect the knowledge and values of those who make them. In holistic management, it is therefore essential to bring in a wide spectrum of knowledge, experience, mental models, and social and environmental concerns to ensure that a comprehensive indicator set and proper performance measures are found.

Matching a system to its environment: viability and basic orientors

At all levels of analysis, systems operate and must be viable in a particular, and variable, system environment. This system environment usually contains other systems that affect the particular system and/or are affected by it. For example, a human society depends on the natural environment and the systems in it for vital resources, which society in turn affects through its actions and waste streams.

The viability and performance of a particular system are therefore determined by (1) its characteristic system functions and (2) the characteristic properties of its particular system environment and of the systems in this environment. Viability implies that the two sets of characteristics must match in some way, because a system can survive and develop only in an environment to which it is adapted, or which has adapted to it. Fish have adapted their form and function for viability in their aquatic environment, but this particular adaptation is deadly in a terrestrial environment. The key to understanding viability and performance therefore lies in understanding the challenges of a particular environment.

There is obviously an immense variety of particular system environments, just as there is an immense variety of systems. However, the analysis is greatly simplified by the observation that all system environments have certain fundamental properties. System environments are characterized by these six fundamental environmental properties (Bossel 1998, 1999):

- *A normal environmental state.* The actual environmental state can vary within a certain range and still remain normal.
- *Resource scarcity.* The resources (energy, matter, information, etc.) required for a system's survival and development are not immediately available when and where needed.
- *Variety.* The system environment is seldom uniform; many qualitatively different processes and patterns of environmental variables occur and appear in the environment both constantly and intermittently.
- *Variability.* The state of the environment fluctuates within the normal environmental range in random ways, and these fluctuations occasionally take the environment outside this range.
- *Change.* Over time, the normal environmental state may gradually or abruptly change to a permanently different normal environmental state.
- *Other systems.* The environment contains other systems or agents whose behavior may have system-specific significance for the given system.

Applied in the context of human society, these fundamental environmental properties constrain development possibilities and limit management opportunities on all spatial scales. The normal environmental state in which humankind must develop is characterized by laws of nature and logic that cannot be broken and that limit the spectrum of possible physical, technical, and biological processes. The possibilities are further limited by the resource constraints of the global environment: available space; the waste-absorption capacity of soils, rivers, oceans, and atmosphere; the availability of renewable and nonrenewable resources; soil fertility; and climate. Some of these are state limitations (e.g., the amount of nonrenewable resources); others are rate limitations (e.g., the maximum rate of waste absorption). Variety is introduced by a wide spectrum of geological and climatic conditions, ecosystems, animal and plant species, cultures, languages, organizations, political systems, and technical solutions. Variability is introduced by unpredictable weather and other natural phenomena, random events, the spontaneous behavior of humans, or the population dynamics of organisms. Permanent changes in the normal environmental state result from the irreversibility of many developments; the coevolution of systems, organisms, and the environment; the modification of climate and the natural environment by humans, their technology, and their wastes; the depletion of resources; and changing human organizations, values, and aspirations. The many processes of the real world, which operate at different time scales ranging from seconds to centuries, often dictate the pace of development and determine the dynamics of change. Finally, human society is a composite of interacting systems that depend on the dynamic functions of more or less autonomous natural systems. Each of these systems is in some way dependent on, interacts with, or affects other systems. As the behavior of one system affects the "interests" of another, it often provokes an active response that negatively influences its own interests. This type of reaction is qualitatively different from the passive compliance of the environment.

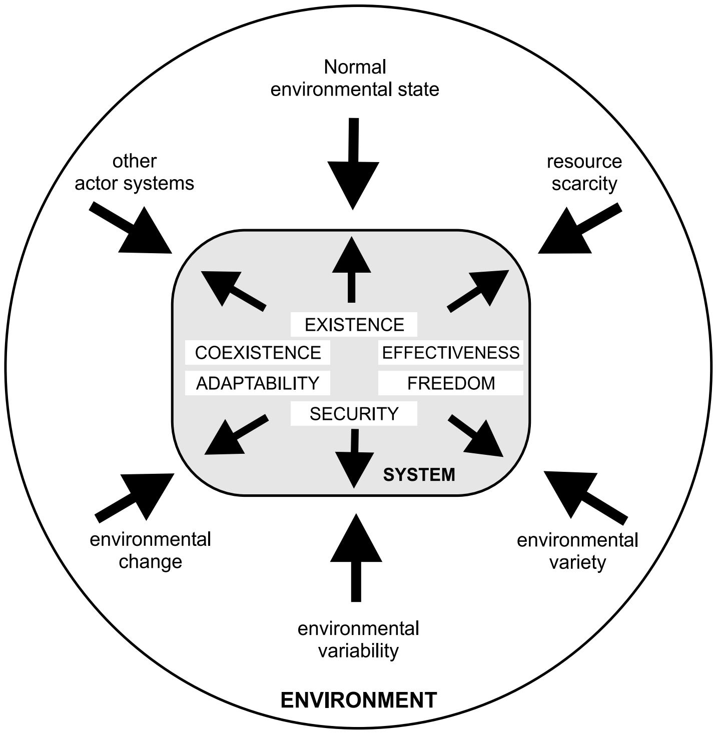
These fundamental properties of the environment are each unique, i.e., no fundamental property can be expressed by any combination of other fundamental properties. If we want to describe a system's environment fully, we have to say something about each of these properties. What is the normal environment? What resources are available in the environment? How rare are they? How are they distributed? How much diversity and variety exist in the environment? How variable is it? What are the trends toward change in the environment? What other actor systems and interests have to be respected in one way or another?

A system can be viable and sustainable only if the constraints imposed by the fundamental environmental properties are respected. This requirement imposes certain orientations or interests on systems in the course of their self-organizing or coevolutionary development. Systems fail when they do not respect the constraints of their environments. This is true for species shaped by thousands of generations of evolution as well as for the technologies or organizations developed by humans. The terms "orientation" and "interest" as used here do not imply any consciousness on the part of the system. A system is said to have an interest or orientation if it can be observed to express a preference (e.g., a plant growing toward light).

The six fundamental environmental properties cause six respective interests or orientations in self-organizing systems such as the organisms and organizations that constitute and support human society (Fig. 4). For such systems to be viable and sustainable, they must pay sufficient attention to and satisfy each of their basic orientors (Bossel 1977, 1999):

- *Existence.* The system must be compatible with and able to exist in the normal environmental state. The information, energy, and material inputs needed to sustain the system must be available.
- *Effectiveness.* The system should, on balance over the long term, be effective (not necessarily efficient) in its efforts to secure required scarce resources (information, matter, energy) and to exert influence on its environment when necessary.
- *Freedom of action.* The system must have the ability to cope in various ways with the challenges posed by environmental variety.
- *Security.* The system must be able to protect itself from the detrimental effects of environmental variability, i.e., variable, fluctuating, and unpredictable conditions outside the normal environmental state.
- *Adaptability.* The system should be able to learn, adapt, and self-organize to generate more appropriate responses to the challenges posed by environmental change.
- *Coexistence.* The system must be able to modify its behavior to respond appropriately to the behavior of the other systems in its environment.
- *Psychological needs.* These constitute an additional orientor for sentient beings.

Figure 4. Basic system orientors. These orientors emerge in response to the fundamental properties of the system environment.



System orientation for viability and performance is a two-phase assessment process. Each of the basic orientors stands for a unique requirement. First, a certain minimum satisfaction must be obtained separately for each of the orientors to ensure viability. A deficit in even one of the orientors threatens the viability of the whole system. The system will have to focus its attention on this deficit. Compensation for deficits by the overfulfillment of other basic orientors is not possible. For example, a surplus of security cannot compensate for a deficit of freedom in a society. Second, only if the required minimum satisfaction of all the basic orientors is guaranteed, is it permissible to try to raise system performance by further improving the satisfaction of individual orientors.

Characteristic differences in the behavior ("life strategies") of organisms or of humans or human systems (organizations, political or cultural groups) can often be explained by differences in the relative importance attached to different orientors (i.e., the emphasis on freedom or security or effectiveness or adaptability) after the minimum requirements for all the basic orientors have been satisfied (Krebs and Bossel 1997). Such an emphasis may improve performance and provide a competitive advantage. Development, and in particular sustainable development, is therefore possible along many different paths, provided that minimum viability requirements are met.

Using basic orientors to guide indicator selection

Because it is obviously better adapted to its environment, the system that most effectively satisfies all its basic orientors will have better fitness and better performance (Krebs and Bossel 1997). Assessment of orientor satisfaction therefore provides a measure of system viability and performance in a given environment. This can be done by identifying the indicators that provide information about how well each of the orientors is being fulfilled at a given time. In this context, the basic orientors can serve as a checklist for asking a set of questions whose answers provide an assessment of viability and system performance.

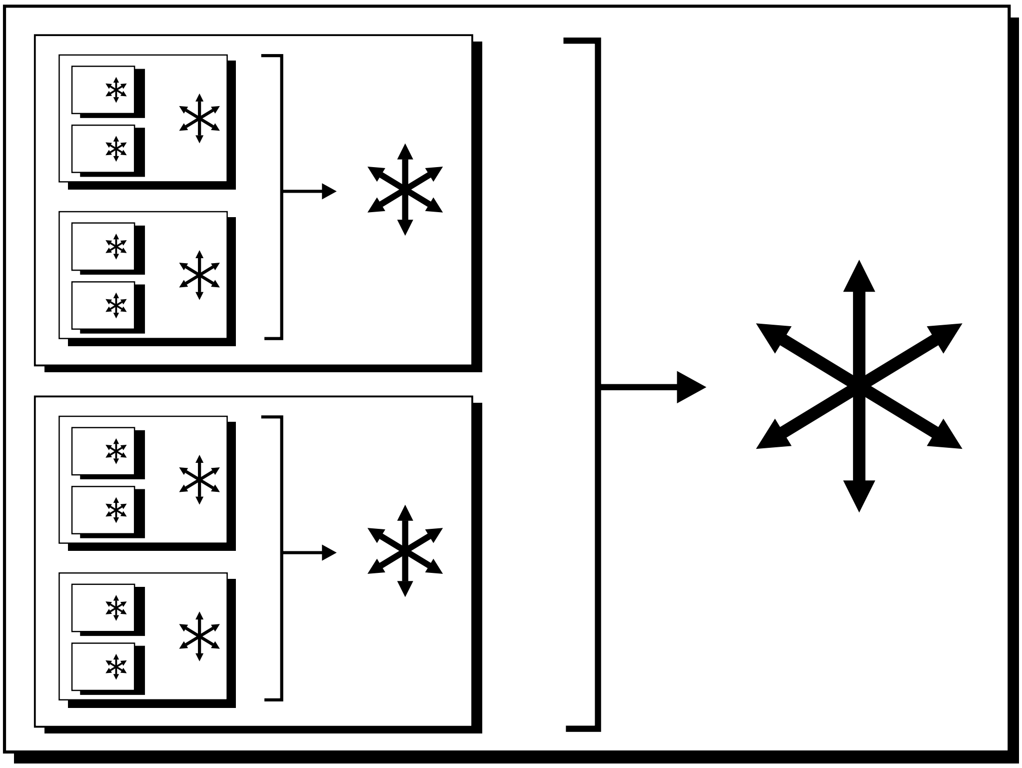
The application of these concepts is complicated by the fact that reality consists of webs of linked and interacting systems. The general relationship between two systems is always based on the fact that System A affects System B. Hierarchical dependencies (individuals support community schools, community schools supply qualified labor, qualified labor increases the gross national product, corresponding tax income pays for the health care system) and feedback loops (better health care benefits individual families) are possible. To assess sustainability, we have to find indicators for each essential system within the total system in each orientor category that can answer two sets of questions. First, how viable is each system, i.e., how satisfied is each basic orientor of that system? Second, how does a given system contribute to the viability (the basic orientors) of another system or the total system? For chains of dependencies, this scheme must be applied in a recursive fashion (Fig. 5). We find the same duality of indicators and assessment in all walks of life: the farmer is interested in the health of his cow and the amount of milk it produces for him, the forester checks the vitality of the forest and its timber production, the operator of a power plant keeps pressures and temperatures within a safe range and measures power output, the pilot has instruments that help him fly safely and indicate the direction to and distance from his destination, a minister of economics checks the health of the economy and its contribution to the GNP and government revenues.

The first set of questions that define relevant indicators of sustainability concerns the viability and performance of the (sub)system under consideration (Bossel 1999):

- *Existence.* Is the system compatible with and able to exist in its environment?
- *Effectiveness.* Is it effective and efficient in its processes and operations?
- *Freedom of action.* Does it have the freedom and ability to respond to environmental variety?
- *Security.* Is it secure, safe, and stable despite a variable and unpredictable environment?
- *Adaptability.* Can it adapt to new challenges from its changing environment?
- *Coexistence.* Is it compatible with interacting systems?
- *Psychological needs.* Is it compatible with the psychological needs relevant to this system?

The second set of questions defines the indicators that can be used to assess the contributions of a given system to the viability and sustainability of an affected system. These questions examine the contribution of the given system to the satisfaction of basic

Figure 5. Viability chains in nested systems. The viability and performance of the total system depend on its component systems, which depend on their own subsystems, which depend on sub-subsystems, etc. Each subsystem must not only be viable (symbolized here by the orientor star) but also contribute to the viability of its suprasystem (bracket and arrow).



orientor x (existence, effectiveness, freedom of action, security, adaptability, coexistence, psychological needs) of the affected system (see Bossel 1999).

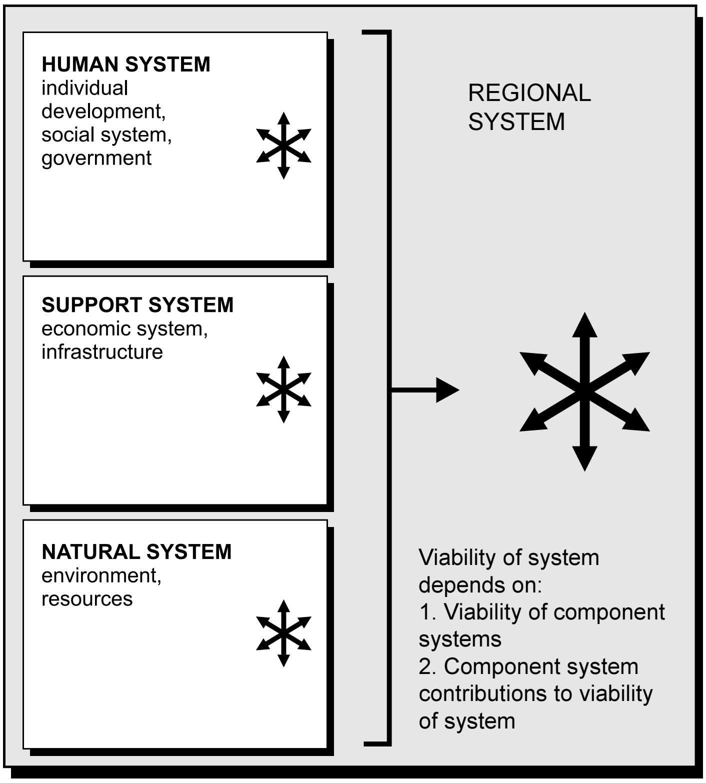
The number of indicators to be observed depends on the number of systems recognized as essential for the viability and performance of the total system and on the level of permissible aggregation. Using a functional approach, the essential component systems of human development are commonly distinguished by the capital assets (state variables, stocks) that supply human livelihoods. The widely used "livelihoods framework" recognizes five essential capitals: human, natural, financial, social, and physical (Carney 1998, Bebbington 1999, Campbell et al. 2001, 2002). Other authors add "organizational capital" as a sixth essential capital that has a particular relevance in development problems (Bossel 1998, 1999). The distinction between these component systems is made on system-functional grounds (in Bossel 1998) and does not coincide with traditional disciplinary boundaries. Each component system is defined by its relative autonomy and the much greater connectivity of variables within this system than across its boundaries (more details concerning these system aspects are available in Bossel 1998:100 ff).

For the sustainable development of human society on any spatial scale from village to global, it is necessary to observe indicators that represent all six essential systems or capitals. For many purposes, it is possible to aggregate to three essential subsystems (Fig. 6): the human system (the human, social, and organizational aspects), the support system (the physical and financial aspects, i.e., the infrastructure and economy), and the natural system (the environment and resources). To determine how sustainable each of these systems is and its respective contribution to the total system requires 7 x 3 x 2 = 42 indicators. This number is probably near the upper limit for practical applications.

A detailed analysis based on this scheme will, in most cases, produce a large number of component systems, long "viability chains" of nested systems, and many potential indicators. A typical example is presented in Fig. 5. Furthermore, there will generally be several, perhaps many, appropriate indicators that correspond to each of the assessment questions. It is therefore essential to condense the systems analysis and the indicator set as much as possible without losing essential information. There are several ways to do this:

- *Aggregation.* Use the highest level of aggregation possible. For example, when this type of analysis is applied to regional development (Fig. 6), the many subsystems are aggregated into only three component systems: human, support, and natural.
- *Condensation.* Locate an appropriate indicator that represents the ultimate cause of a particular viability problem and do not bother with indicators for intermediate systems (the intermediate viability chain). For example, fossil fuel use can serve as an indicator of threats to the global climate and the viability of the global system.
- *Weakest-link approach.* Identify the weakest links in the system and define appropriate indicators. Do not bother with other components that may be vital but pose no viability threat under foreseeable circumstances. For example, the availability of water (not fertilizer, labor, or farm machinery) is the weakest link in dryland agriculture, whereas, in another context, the weakest link might be the availability of sanitary waste disposal.
- *Basket average.* If several indicators representing somewhat different aspects of an orientor question should all be considered, define an index that provides an average reading of the situation. One such example might be the representative "basket" of consumer goods used in economic statistics.
- *Basket minimum.* If the satisfaction of a particular orientor depends on the acceptable state of each of several indicators, adopt the one with the worst performance at the time of the analysis as the representative indicator. Note that this indicator could change as the system develops. For example, soil nutrient content could be measured in terms of the least available nutrient, i.e., the one that most limits soil productivity.
- *Representative indicator.* Identify the variable that provides reliable information that is characteristic of a whole complex situation. For example, the relative abundance of

Figure 6. Performance indicators for regional systems. In studies of sustainable development, performance indicators for regional systems at any spatial scale must reflect the viability and performance of the three essential component systems (human, support, and natural) and their contributions to the total system. The three component systems are functionally distinct and autonomous to a certain degree.



lichen could serve as an indicator of air pollution. When using a representative indicator, it is particularly important to state clearly what it is supposed to represent.

- *Subjective viability assessment.* If little quantitative information for a vital component system is available, use a summary subjective viability assessment. For example, in many cases the viability of a system can be adequately assessed by a subjective impression of the "health" (or lack of it) of a component system such as a person, animal, forest, or company.

Note that each indicator has been chosen to represent only one particular aspect of orientor assessment. It must therefore be understood as representing certain orientor-relevant trends and judged under that particular aspect only, not under others to which it may also be related. Note further that the application of these rules for generating an efficient indicator set may result in a collection of indicators that represent very different scales (e.g., local waste disposal, the national judicial system). The important criterion is whether the indicator correctly represents current system viability.

Even with a solid scientific approach based on physical facts as well as systems theory and analysis, indicator sets cannot be defined without a significant amount of subjective choice. We therefore should not be surprised if researchers using the same data and scientific method produce different indicator sets. Although on the surface this may appear to be another of those cases where scientists cannot agree, these indicator sets are far from arbitrary selections. If indicators have been selected to represent basic orientor satisfaction of essential systems, sustainability assessments should produce comparable results even when the indicator sets are completely different.

It is useful to recall the areas in which subjective choice is inevitable in the process of determining an indicator set. Some of this subjectivity is due to differences in objective knowledge, whereas some is the result of divergent normative concepts, i.e., ethical preferences.

- *Knowledge about and perception of the total system.* What is our model of the total system? How are the subsystems organized and interconnected?
- *Perception of component systems and their interrelationships.* What are the parts and processes of the component systems? How do they interact? How important are they to the observer?
- *Scenarios of future development.* Which developments are possible, and which are likely?
- *Time horizon.* How far should we try to look ahead?
- *Systemic horizon.* Should only essential systems be observed, or should nonessential systems (e.g., rare species with no economic value) also be included?
- *Interests of the observer/manager.* What information is of interest for various reasons?

Ethics and normative preferences thus enter into the selection of indicators in at least three ways: (1) in the selection of the systems to be included in the assessment, including ourselves, our descendants (and even ancestors), and other species, organisms, and systems (human, political, cultural, technical, and ecological); (2) in the relative weights (importance) we assign to ourselves and to all the other systems; and (3) in the relative emphasis we put on the different interests corresponding to the basic orientors, particularly our own.

MEASURING VIABILITY AND PERFORMANCE

Although subjective qualitative assessment of viability and performance using the basic orientor scheme suffices in many cases, a more formalized quantitative procedure is required if results are to be reproducible or assessments compared. Quantification of the indicator/

orientor relationships (the impact functions) is essential, particularly if the assessment procedure is computerized and a time series of indicators is used to produce a dynamic assessment. Impact functions capture the subjective assessment of how a particular indicator state contributes to the orientor satisfaction of a system. Using these functions, a set of indicators reflecting the time-dependent system state can be mapped on the basic orientors to produce information about the dynamics of viability and performance, as described below.

Relative (nondimensional) quantification of orientor satisfaction is simple if two numerical indicators can be meaningfully related. To stay viable, a system must be able to respond or adapt to threats before they do serious damage. This suggests that it is advisable to concentrate on indicators that relate the rates of viability threats (threats to a system's basic orientors) to the rates of evasive system response, or their respective inverse, the respite time to the response time (Biesiot 1997, Bossel 1999). These two quantitative measures will often be available from system observations. They can be combined in a nondimensional indicator by taking the ratio of the rate of system response to the rate of system or environmental change caused by a particular threat. If this measure is greater than one, the system is viable (with respect to that particular orientor); if it is less than one, the system's viability is threatened. Viability means that the system can cope with challenges and will not be overwhelmed by them, i.e., that its responses can outpace the threats to it. For example, the regeneration rate vs. the harvesting rate can be used to measure the "existence" of a basic orientor such as a vital resource.

RESULTS

Indicators of sustainable development for a region

As a general rule, indicators of sustainable development will be region-specific, with "region" defined using an ecoregional scale of analysis. These indicators will express the specific characteristics of the systems under study and their particular environments. Comprehensive indicator sets for sustainability assessment have been developed for many cities and regions (Hardi and Zdan 1997). Examples of recent applications of orientation theory to the development of comprehensive indicator sets of sustainable development are found in Bossel (1999) and Ömer (2000) for Austria, Mothibi (1999) for Botswana, and Peet and Bossel (2000) for New Zealand. In earlier applications of orientation theory, indicator sets were derived for the energy supply system, the health care system, information and communication technologies, and agricultural production, among others (Bossel et al. 1989).

A famous and often cited example of indicators of sustainable development is the set derived for the city of Seattle. This set was the result of a long process of discussion and development that involved intensive citizen participation (Hardi and Zdan 1997). The Seattle indicators are all quantitative, on a local scale, and based on locally available data. Their relative changes are reported at regular intervals, pinpointing corresponding improvements or declines in the viability and performance of the Seattle system.

This set of indicators (short names only) is presented in an orientor-based scheme (Fig. 7) that corresponds to the three essential, functionally defined subsystems, i.e., the human, support, and natural systems seen in Fig. 6. In Fig. 7, the three sets of indicators on the left provide information about the viability and performance of each individual subsystem. Consider, for example, the indicators for basic orientor adaptability (A), in which the indicator "adult literacy" is used as a measure of the adaptability of "human capital" because it correlates with level of education and the ability to adapt to new challenges. The indicator "vehicle miles traveled and fuel consumption" is used to represent the adaptability of "built capital," where the dominance of road transportation indicates a limited ability to adapt the support system to, say, a fuel shortage. The indicator "biodiversity" measures the adaptability of "natural capital," i.e., species and genetic diversity, when it comes to maintaining the functions of the natural environment under changing conditions.

The three sets of indicators on the right express the contributions of each of the three subsystems to the viability and performance of the total system, i.e., the anthroposphere composed of the three essential subsystems: human, support, and natural. For example, the indicator "youth involvement in community service" is chosen to reflect the contribution of the human system to the adaptability of the total system, and a more caring, active, flexible, and future-oriented attitude can be expected if this value is high. The indicator "library and community center usage" measures the quality and quantity of the contribution of the support system to the adaptability of the total system, i.e., the potential for ongoing education, innovation, and social (re)organization. The indicator "wetlands" is a measure of the contribution of the natural system to the adaptability of the total system: wild, uncultivated areas represent adaptive potential for the total system and for its human, built, and natural capitals.

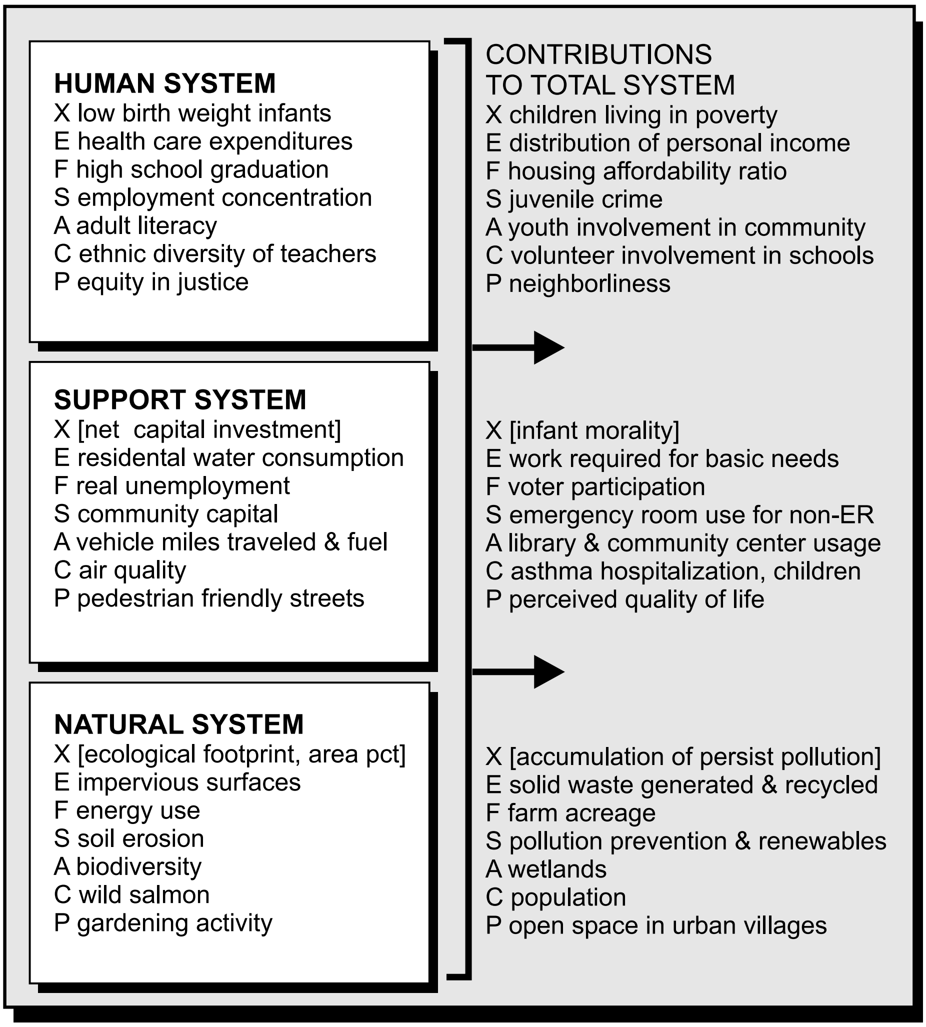
There is excellent correspondence between the Seattle set and the orientor-based scheme, although the original indicators were derived without reference to orientation theory. This seems to indicate that the Seattle indicators are indeed comprehensive, covering all important aspects of basic orientor fulfillment for viability and sustainability.

Formalized quantitative performance assessment

In Bossel (1999), the formalized method of dynamic orientor assessment is demonstrated using empirical time-series data for selected indicators from the database of the Worldwatch Institute (1999) for 1950–2000. A set of 21 indicators is used (seven basic orientors and three component systems: human, support, and natural). The 21 indicators from the Worldwatch database were chosen for their ability to provide answers to the corresponding 21 orientor assessment questions.

What each of the indicators means for the respective orientor must be expressed in terms of the impact function. Except for simple cases and Biesiot-type indicators, there is currently no method to objectively measure indicator impact on orientor satisfaction (e.g., how does a particular groundwater level contribute to the "security" of the "natural system?"). These impact functions must therefore be generated by subjective assessments. To capture the spectrum of subjectivity, it will often be essential to incorporate the viewpoints of different

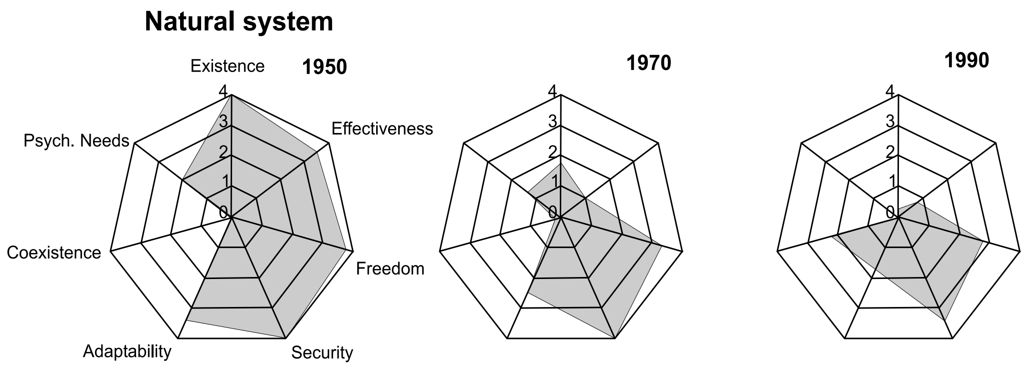
Figure 7. Indicators of sustainable development for the city of Seattle in an orientation-theoretical framework after Bossel (1999). Only two of the original Seattle indicators are not used in this scheme: public participation in the arts and arts instruction. Indicators in square brackets [...] are suggested additional indicators that were not on the original list. In this context, the basic orientors or fundamental interests of the system are as follows: X = existence, E = effectiveness, F = freedom of action, S = security, A = adaptability, C = coexistence, P = psychological needs.



stakeholders in competing assessments and to compare the results, which will often not differ substantially.

Orientor star or "radar" diagrams can be used to reflect orientor satisfaction for each of the component systems and the total system (see Fig. 8 for orientor stars for the natural system). This time sequence clearly brings out the dynamics of stresses and threats to a system and makes it possible to trace their origins. In another approach (Peet and Bossel 2000) that is particularly well-suited for spreadsheet assessments, the degree of basic orientor satisfaction is color-coded: green for good or excellent, yellow for satisfactory, red for unsatisfactory or bad.

Figure 8. Orientor stars for the natural system (the environment and resources) resulting from a viability assessment using the Worldwatch data series for 1950–2000 after Bossel (1999). Assessment scale: 0–1 = unacceptable, 1–2 = dangerous, 2–3 = good, 3–4 = excellent. The axes represent the seven basic orientor states described in Fig. 7.



DISCUSSION

The systematic and theory-based nature of the orientor method of determining indicators is important. We are not simply asking people to find and agree on a set of indicators; we are asking them to find answers (indicators) to very specific questions concerning all the vital aspects of viability and system performance, i.e., the basic orientors. In this structured approach based on systems theory and empirical evidence, we can be reasonably confident of obtaining a comprehensive set of indicators that cover all important aspects of systems viability and performance. The method avoids both unnecessary "bunching" of redundant indicators in some areas and gaping holes resulting from oversight and neglect in others.

Although it is advisable to choose indicators that allow unambiguous quantification, and hence comparison with conditions at other points in time or in other regions, this is not a necessity with the method proposed here. The important point is that the indicators chosen provide us with reliable answers to the different orientor assessment questions. If satisfactory qualitative answers are obtained in all categories for all the subsystems and the total system, we can conclude that the system is (currently) viable and performing satisfactorily. Even if only one of the categories is in an unsatisfactory state, this could indicate the existence of a problem with the potential to endanger viability and development.

From the many applications to date, it can be concluded that a systems approach using orientor concepts can be a very useful tool, not only for defining comprehensive indicator sets for system viability and performance, but also for checking existing indicator sets for completeness (in the mathematical sense of covering all essential aspects) and possible redundancy. It provides systematic guidance for a comprehensive indicator search, thus minimizing the danger of overlooking essential areas or overemphasizing others.

In a broader context, regarding indicators as reflections of the fundamental interests (basic orientors) of all participants and affected systems puts a solid foundation under the search for indicator sets and removes much of the arbitrariness implicit in current and proposed indicator sets. It turns the focus from an uncertain ad hoc search and bargaining process to a much more systematic procedure with a clear goal: to find indicators that represent all the important aspects of viability, sustainability, and performance.

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14.

Assessing the Performance of Natural Resource Systems

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ABSTRACT

Assessing the performance of management is central to natural resource management, in terms of improving the efficiency of interventions in an adaptive-learning cycle. This is not simple, given that such systems generally have multiple scales of interaction and response; high frequency of nonlinearity, uncertainty, and time lags; multiple stakeholders with contrasting objectives; and a high degree of context specificity. The importance of bounding the problem and preparing a conceptual model of the system is highlighted. We suggest that the capital assets approach to livelihoods may be an appropriate organizing principle for the selection of indicators of system performance. In this approach, five capital assets are recognized: physical, financial, social, natural, and human. A number of principles can be derived for each capital asset; indicators for assessing system performance should cover all of the principles. To cater for multiple stakeholders, participatory selection of indicators is appropriate, although when cross-site comparability is required, some generic indicators are suitable. Because of the high degree of context specificity of natural resource management systems, a typology of landscapes or resource management domains may be useful to allow extrapolation to broader systems. The problems of nonlinearities, uncertainty, and time lags in natural resource management systems suggest that systems modeling is crucial for performance assessment, in terms of deriving "what would have

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happened anyway" scenarios for comparison to the measured trajectory of systems. Given that a number of indicators are necessary for assessing performance, the question becomes whether these can be combined to give an integrative assessment. We explore five possible approaches: (1) simple additive index, as used for the Human Development Index; (2) derived variables (e.g., principal components) as the indices of performance; (3) two-dimensional plots of indicators and cases emerging from multivariate techniques used to visualize change; (4) graphical representation of the five capital assets using radar diagrams; and (5) canonical correlation analysis to explore indicators at two different scales.

KEY WORDS: capital assets, conceptual models, decision support, livelihoods, modeling, multivariate statistics, natural resource systems, performance, Zimbabwe.

INTRODUCTION

There is wide agreement that the goals of eradicating poverty, attaining food security, and conserving the environment are highly interdependent. It has been suggested that integrated research on natural resource management is needed to address the emerging challenges, and that component research (e.g., on commodity crops) needs to be set within the context of natural resource management (Izac and Sanchez 2001, Costanza and Jorgensen 2002, Campbell et al. 2002). Integrated natural resource management (INRM) is a process of incorporating the multiple aspects of natural resource use (biophysical, sociopolitical, or economic) into a system of sustainable management to meet production goals of producers and other direct users (e.g., food security, profitability, risk aversion) as well as goals of the wider community (e.g., poverty alleviation, welfare of future generations, environmental conservation). The conceptual basis of INRM has evolved in recent years through the convergence of research in diverse areas such as sustainable land use, participatory planning, integrated watershed management, and adaptive management (Holling 1978, Pretty 1995, Holling and Meffe 1996, Walters 1997, Ashley and Maxwell 2002, Luzadis et al. 2002).

Research institutes and funding organizations have finite resources that they seek to allocate most efficiently. Therefore, they need to identify and assess priorities for research, monitor the progress of ongoing research, and evaluate the impacts of completed research. This is a difficult enough process in highly focused technological research projects, but is even more of a challenge for INRM research. Impact assessment of INRM research is in its infancy. For example, within the international research centers of the Consultative Group on International Agricultural Research (CGIAR) impact assessment has largely focused on germplasm adoption, with relatively little attention given to institutional impact, and almost none to INRM (e.g., Collinson and Tollens 1994; but see P. Frost, *unpublished report*, 1996). Impact assessment of INRM research would have to be based on an assessment of the performance of the natural resource management system, together with an assessment of the role that research plays in changing the development trajectory of the system.

The aim of this paper is to propose some methods for assessing system performance. In the first section, we conceptualize INRM and identify the role for performance assessment within a broader learning cycle. In the next two sections, we consider the importance of bounding natural resource management problems and using conceptual models. In the subsequent section, we turn to selection of indicators, suggesting that selection should be based on a sustainable-livelihoods approach. We make the case for systems modeling as a key component of INRM and the assessment of system performance. The problem of context specificity of INRM is then addressed. Finally, we look at some methods of integrating the indicator data.

CONCEPTUALIZING A FRAMEWORK FOR ASSESSING SYSTEM PERFORMANCE

We envisage INRM occurring within a specific geographical area, but at a number of scales, from farmers' fields to entire catchments. Invariably, INRM would have to concern itself with sociopolitical, economic, and ecological variables (Fig. 1). The decision-making process and subsequent action take place within the context set by these variables. Almost all natural resource management systems involve multiple stakeholders, with multiple perceptions and objectives. There is likely to be a series of mechanisms by which stakeholder interests are integrated and traded off. To be effective and relevant, INRM has to be carried out at an appropriate scale and in a realistic context. At the level of smallholder farming systems, for example, research should be carried out mainly in farmers' fields, where their problems reside, rather than on research stations. This would invariably involve a participatory component. Such a conceptual model for INRM indicates the numerous entry points for interventions and performance assessment.

Many interactions may need to be considered, e.g., upstream–downstream effects in a watershed; farm-level trade-offs among cash income, food security, risk aversion, and environmental conservation; and household choices about allocation of effort (e.g., as divergent as gold panning, out-migration, cropping particular species, building social capital). Complexities for INRM arise from:

- multiple scales of interaction and response;
- the high frequency of nonlinearities, uncertainty, and time lags in complex systems;
- multiple stakeholders with often contrasting objectives that complicate the task of identifying research and management aims and finding trade-offs among them;
- the context specificity of INRM sites; and
- the problem of maintaining integration in the face of numerous components and interactions.

It is these characteristics of INRM systems that we address in our proposed approach for assessing system performance (Table 1). The following sections of the paper look at each of our suggested actions.

Figure 1. Components of INRM (modified from Swift et al. 1994).

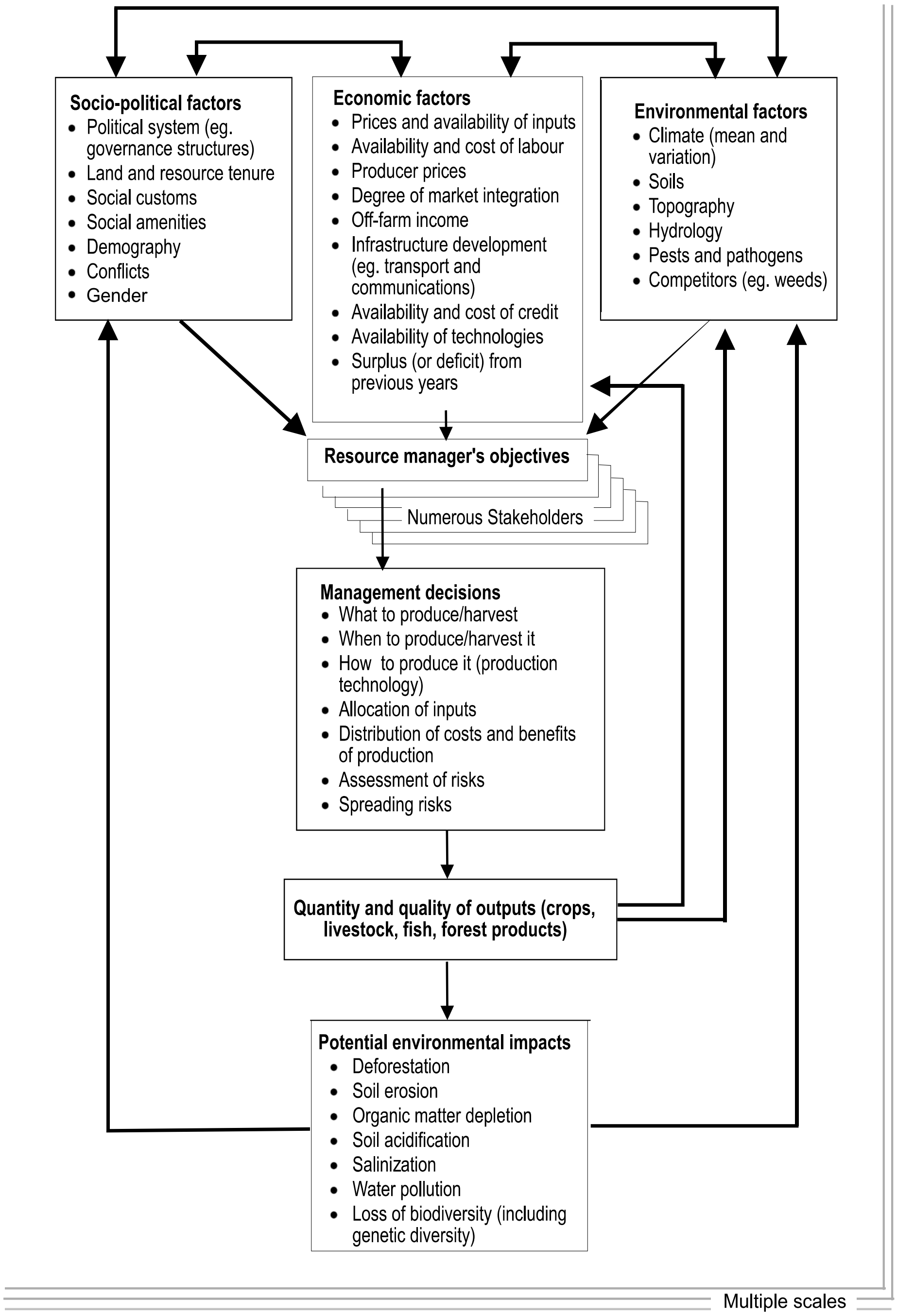


Table 1. Key problems faced in assessing system performance in INRM.

Problem/characteristic	Way forward	Comments
1. INRM systems are complex (multi-scales, multi-stakeholders, multi-sectoral, feedbacks, time delays, non-linearities)	Bound the system (clarify the objectives, scale of the research and particular intervention possibilities)	While any reference to "clarification of objectives" is self-evident, it does stress the fact that performance assessment is an integral part of the whole research and learning cycle
	Develop a conceptual model that simplifies the system and makes explicit the key components and interactions	This conceptual model would be at the level of the particular system being studied, e.g. it could be based on a site like Chivi (Fig. 2).
	Ensure careful indicator selection-covering different scales; basing selection on the sustainable livelihoods approach (Carney 1998)	There is a need to strike a balance between simplicity and complexity.
2. Feedback, time delays, and non-linearities mean that performance assessment is complex	Develop simulation models as part of the performance assessment procedure	Simulation modeling may be essential to understanding systems performance
3. Participation is central to INRM, but external actors may have very different information needs from local stakeholders	Incorporate participatory assessment as well as more conventional systems	The participatory component is an ingredient in a feedback or learning process that is likely to increase the effectiveness of NRM
4. INRM is context specific and yet for general lessons we need cross-site comparability	Situate INRM sites within a landscape or resource management domain typology	
5. Remaining integrated in the face of numerous indicators	Use techniques that can synthesize the numerous indicators that may have been measured: multivariate statistics, radar diagrams	

One of the key lessons in dealing with complex systems is that management must be structured to promote active and conscious individual and social learning. Because of the inverse relationship between the complexity of systems and our ability to make significant statements about their behavior, an adaptive-management philosophy has been advocated (Holling and Meffe 1996, Oglethorpe 2002). The steps within adaptive management are: design; act; monitor and observe; and reflect and revise. Maarleveld and Dangbégnon (1999) and Daniels and Walker (2001) characterize social learning as a continuous dialogue and deliberation among stakeholders that incorporates adaptive management as well as political processes related to conflict between stakeholders. Research thus becomes part of an ongoing cycle of planning, action, and evaluation (Hagmann et al. 2002). In performance monitoring and assessing research impacts, we envisage using an indicator-based approach within a social learning process. Many indicator approaches are based on a series of hierarchical concepts. The CIFOR Criteria and Indicator (C&I) team (1999) use a four-level hierarchy: principles, criteria, indicators, and verifiers. A similar hierarchy is envisaged for assessing the performance of natural resource management, although we would envisage a simpler hierarchical structure.

BOUNDING THE SYSTEM

INRM can become a catch-all term for unfocused activities in which numerous system components are considered. Even assuming the same overall management objectives (e.g., “sustainability” or “equitable distribution” of benefits), the most appropriate indicators will vary with the scale at which management takes place and the scale at which prevailing social and economic processes operate. Interventions at one scale may have impacts at a different (higher) scale. Additionally, system performance might be assessed as being negative at one scale but positive at another; e.g., soil and water conservation interventions may improve crop yields at a specific site, but may show significant negative impacts at a larger scale by reducing water yields downstream. What, then, is the most appropriate level at which to judge the overall benefits? The answer depends on what types of impact are anticipated, the objectives of a specific assessment, the time scale used, the level of accuracy required, and the value system that is chosen by the evaluator.

Focusing INRM and assessing system performance therefore requires clearly stated objectives, a well-reasoned definition of spatial and temporal scales, and clear identification of particular intervention possibilities. The key to bounding the problem is the development of a conceptual model.

DEVELOPING CONCEPTUAL MODELS OF NATURAL RESOURCE MANAGEMENT

In implementing INRM, the starting point should be developing a conceptual model of the particular system under study, with a focus on identifying the key relationships among components of the system and the constraints operating on them. The model would be expected to address issues of spatial and temporal scale. A conceptual model could be viewed as a series of hypotheses about the processes operating. Thus, variables in the model should be theoretically and logically linked. The process of developing a conceptual model clarifies the nature of the problem itself, the bottlenecks to agricultural and natural resource production, the potential negative effects of resource development, and the possible entry points for interventions. The conceptualization should also identify the potential impacts resulting from interventions and management, and thus guide the selection of indicators. In this way, indicators can be selected that are causally and theoretically linked.

A conceptual model has been developed for Chivi, southern Zimbabwe (Fig. 2). This is a box-and-arrow conceptualization of livelihoods within the area. The model reflects the diverse livelihood options in the area, and some of the key "external" variables, such as AIDS and climate (in particular, drought). It was developed through a series of meetings involving various combinations of scientists, local people, and district officials. Although it is appropriate to initiate this activity at the start of the learning cycle, it should be revisited throughout the project, thus allowing for changing foci, interventions, etc., within the spirit of adaptive management. The model itself forms the basis for identifying key variables for assessing performance, but the process of developing the model is important in achieving a common understanding of the problems. Viewing indicators overlaid on a conceptual model illustrate their interconnectedness, an essential viewpoint if one is to achieve integration and understanding of the state of a natural resource management system.

SELECTING INDICATORS: USING THE SUSTAINABLE-LIVELIHOODS APPROACH

The literature indicates that there is no shortage of different indicators: in fact, the wealth of indicators is likely to mystify rather than enlighten. Thus the selection of indicators is a key step to be undertaken, preferably at the start of the INRM process. Simple indicator sets are desirable, but it would be foolish to expect simplicity when dealing with complex systems. Meaningful indicator sets will generally have to be extensive.

The sustainable-livelihoods perspective

In situations in which long-term gains in human welfare and maintenance or improvement of environmental quality are the goal, assessment of system performance could be based on the sustainable-livelihood concept. The concept integrates social, economic, and ecological dimensions (WCED 1987, Chambers and Conway 1992, Carney 1998, Bebbington 1999). The livelihoods framework identifies five core asset categories: physical, financial, social, natural, and human capital (Fig. 3). Principles for each of the five capital assets can be derived (Table 2), and indicators could be selected to cover each of the principles. The tendency to bias indicator selection to one particular discipline is thus avoided. The advantage of using the sustainable-livelihoods approach is that the concept has been vigorously debated in the literature and forms a relatively sound theoretical basis for indicator selection. In many indicator approaches, choice of indicators may be relatively ad hoc. Indicator selection would normally involve experts from different disciplines and the various stakeholders.

Figure 2. A conceptual model of a site in Chivi, Zimbabwe.

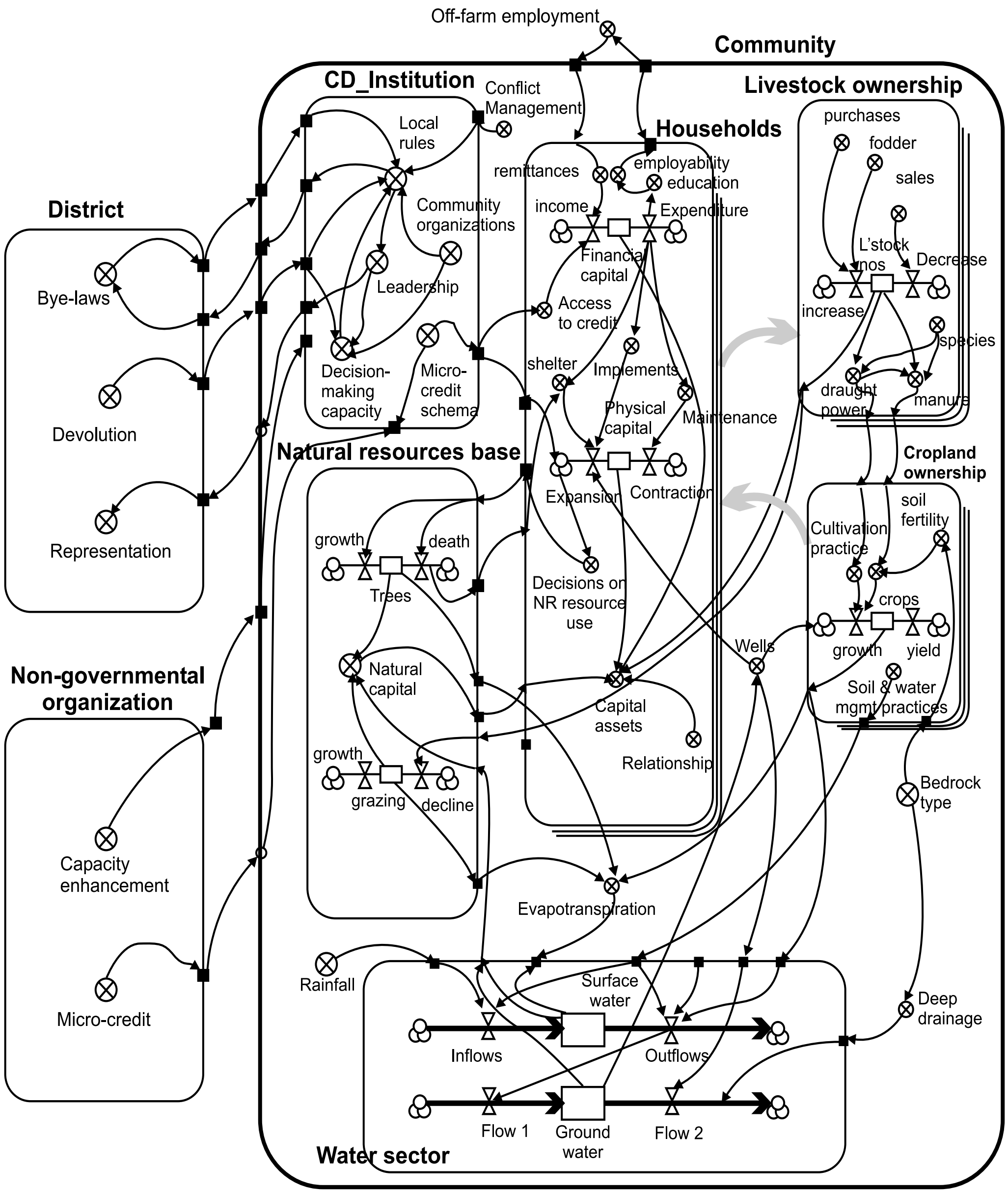


Figure 3. The five capital assets (modified from Bebbington 1999 and Carney 1998).

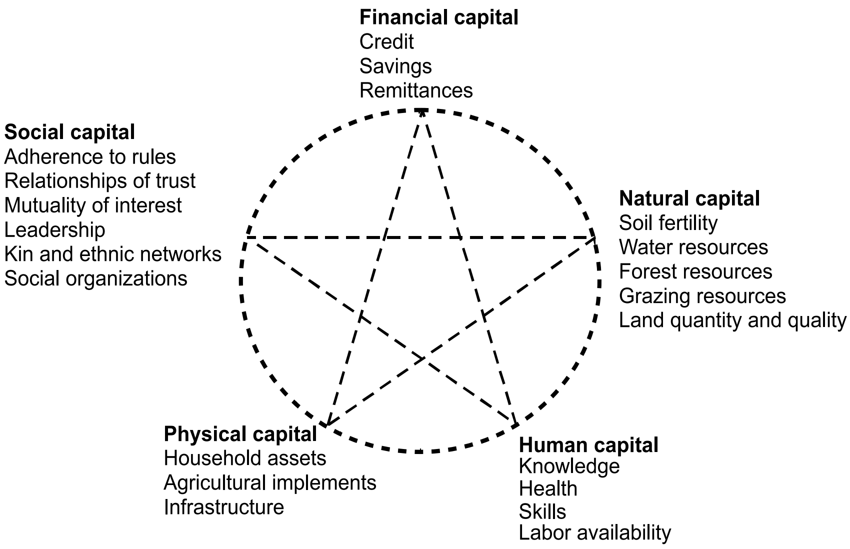
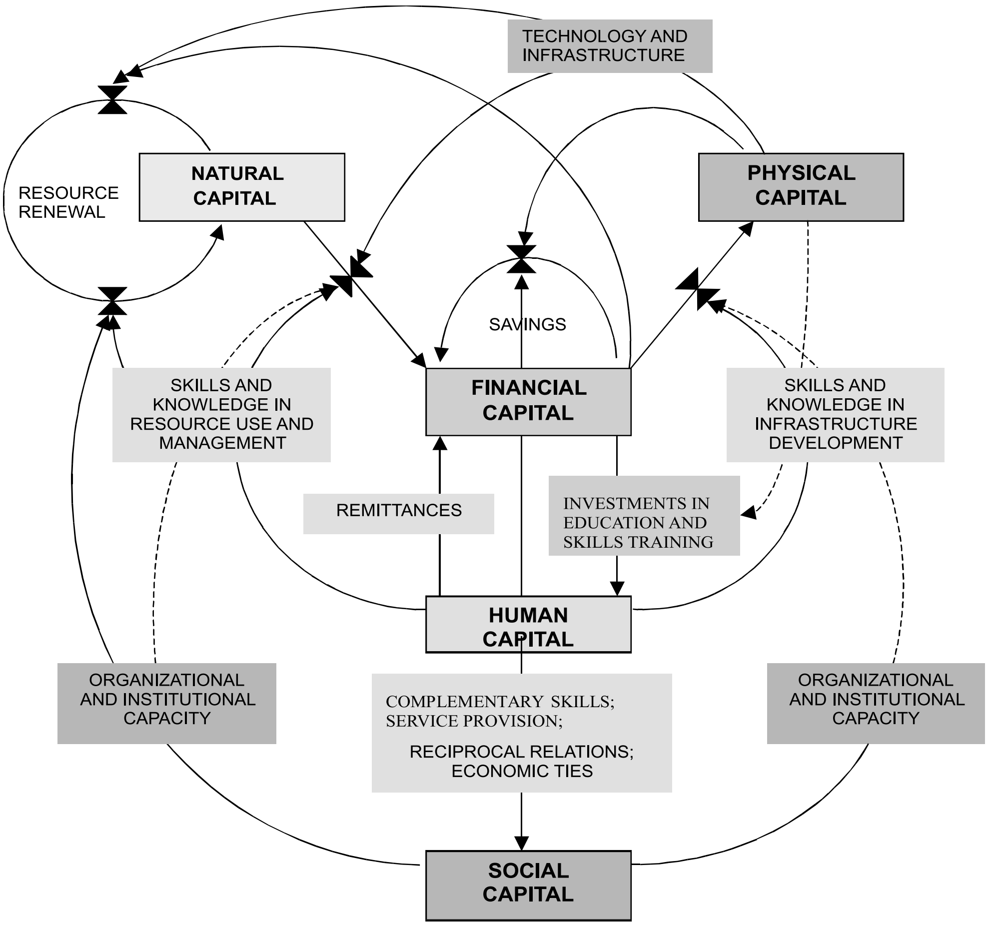


Table 2. Some suggested principles for each of the capital assets, with examples of criteria for each of the principles. The example is for illustrative purposes only: the principles should not be seen as definitive.

Capital asset	Principle	Examples of a criterion for each of the principles
Natural capital	Options for future use are maintained	Processes that maintain biodiversity are conserved
	Yield and quality of natural resource goods and services are maintained or improved	Ecosystem function is maintained
Financial capital	Financial capital is circulated within the system	Service and commodity outlets expand in the local and district centers
	Financial capital grows and is equitably distributed	Residents have a reasonable share in the economic benefits derived from resource use
Physical capital	Physical capital is maintained or improved over time	Housing physical status is maintained or improved
Human capital	Ability to provide added value is improved over time	Greater array of value-added products are produced locally
	Improved and equitable distribution of human capital	Level of skills with respect to running committees and organizations is improved
Social capital	Maintenance of systems of social reciprocity	Economic and other shocks are buffered by systems of social reciprocity
	Maintenance of a set of dynamic rules and norms	Local rules are effective in controlling access to resources

The capital assets are closely linked to each other (Fig. 4). This figure focuses our attention on the dynamic nature of natural resource management, clarifying the interacting and integrated nature of indicators. Selecting indicators that do not represent the full spectrum of capital assets is inappropriate. For example, if financial capital is very low because it has been mobilized to improve human and physical capital, then the system may be judged to be more acceptable than systems in which financial capital is higher, but in which no financial resources have been transferred into other capital assets. It may be appropriate to develop the concept of lowest permissible limit, beyond which there would be a "capital bottleneck" limiting the achievement of a sustainable livelihood.

Figure 4. The dynamic nature of capital assets.



Coping with different spatial scales

Hierarchy theory indicates that work at a particular scale of organization often requires insights from at least two other scales (Allen and Starr 1982, O'Neill et al. 1986, Kolavalli and Kerr 2002, Lovell et al. 2002). Thus work at the farm/household level may require component studies at lower levels, such as the plot level or the intrahousehold level, to understand the important processes that lead to the emerging characteristics at the household level. Work at the farm/household level will also require work at higher levels, e.g., into the institutional framework established by local government. Comprehensive assessment of natural resource management will invariably require that indicators be selected from a number of scales. More commonly, however, assessments focus on a single scale; although this might fulfill objectives defined by the evaluator, it results in an incomplete assessment. For example, assessments that focus on productivity gains from the application of insecticide, but ignore any deleterious effects of the herbicide on human health or the environment, are incomplete assessments.

Criteria and indicators attempting to capture similar phenomena will vary according to the scale of analysis (Noss 1990), as is demonstrated for Chivi (Table 3). Much of the work in Chivi is being conducted at the scale of a 4.5-km^2 micro-catchment. This catchment supports a well (Bromley et al. 1999), but the social catchment for the well extends beyond the focus catchment into others, one of which supports a small dam. In spite of the focus on the micro-catchment, scale issues are being considered, both for larger biophysical units (e.g., what are downstream impacts of the developments in the micro-catchments) and for

Table 3. Different scales at the Chivi site and some potential criteria for those scales, with one criterion shown for each of five capital asset principles.

Principles for each	Potential criteria		
capital asset	**Household/farm fields**	**Village/micro-catchments**	**District**
Natural capital: yield and quality of natural resource goods and services is maintained or improved	Soil fertility in garden fields is maintained or improved	Groundwater resources for community well are maintained or improved	Siltation levels in main dams are reduced.
Financial capital grows and is equitably distributed	Household savings grow and are equitably distributed	Micro-credit scheme is maintained and expanded	Council budgets increase
Physical capital is maintained or improved over time	Housing condition is maintained or improved	Water availability is improved	Road infrastructure is maintained or improved
Improved and equitable distribution of human capital	Educational status of households improves	Level of skills with respect to running committees and organizations is improved	Budgetary control is maintained and improved
Social capital: maintenance of a set of dynamic rules and norms		Local rules are effective in controlling access to resources	Leadership at the district level is respected

larger institutional scales (e.g., how do the three traditional villages in the micro-catchment interact with the larger administrative units, up to the district-level government, and with water governance units established at national, catchment, and subcatchment levels). At lower scales, some key processes are being studied, e.g., tree–soil water relations (because trees are hypothesized to be a major cause of groundwater recession in the catchment). The need to use GIS tools within the context of multiple scales is self-evident.

Using qualitative indicators

Performance assessment of natural resource management will invariably include a qualitative component. Conventional monitoring systems often only help to inform us of outcomes that are expected or predictable. Many outcomes may not be covered by monitoring systems because they are not expected. In Chivi in 1981, it would have been difficult to predict that gold panning, which had been all but absent, would become one of the most important livelihood options by the end of the decade. It would have been difficult to predict that there would be over 25 woodcraft markets on a 100-km stretch of road by 1995 (a nearly fourfold increase from 1991), and that AIDS would wreak havoc in the community in the last five years of the millennium. Performance assessment may have to rely on qualitative indicators for unexpected phenomena that occurred and for which quantitative data were not initially recorded.

During the course of INRM, local people's feelings about the direction of change can be recorded (given that some outcomes may only be measurable many years after a management intervention). By capturing local people's perspectives, albeit often qualitative, we would be integrating numerous variables. In addition, considering that the political arena in any local venture is highly charged (and that researchers are stakeholders with particular agendas that are challenged and modified by local people), it becomes particularly important that performance assessment is informed by anthropological perspectives, which usually provide qualitative data.

INCORPORATING SYSTEMS MODELING

The outcome of natural resource management can be defined as the difference between what happened (as a consequence of the management) and what would have happened anyway. In many cases, baseline data are collected at the start of a management cycle in order to assess change in system characteristics. This is an inadequate approach, as the baseline data do not reflect the dynamics of "what would have happened anyway." Alternatively, assessment of management interventions could be based on large-scale experimentation (i.e., implementing components of a program in some localities but not in others), in conjunction with a statistical sampling program. Such an approach is also unrealistic because of the high expense (Walters 1997). Given the dynamism of natural resource management systems, and the fact that large-scale experimentation is usually not feasible, one of the few solutions for performance assessment is the use of systems modeling. It will often be more appropriate to compare measured indicator values with values derived from systems models for the "what would have happened anyway" scenarios than to compare them with baseline data.

The need for systems modeling is clear in savanna regions, where biological productivity depends, to a large degree, on rainfall, and where each year brings markedly different rainfall conditions. Any attempt to monitor change, and to attribute such change to management, is fraught with difficulty, because many changes will be driven by rainfall patterns. Under these circumstances, systems models are ideal for exploring systems performance. Similar arguments can be applied to many of the external drivers of natural resource management systems.

Systems modeling has diverse functions within INRM. There are two major applications, first to compare observed changes with those expected in the absence of particular management interventions, and second to gain insights regarding likely future impacts of different kinds of management. In both cases, the emphasis is on improving understanding to increase the efficiency and effectiveness of natural resource management. In terms of the learning cycle, systems modeling is implemented soon after the initiation of INRM, with data inputs being best bets and the modeling results being used to set priorities and guide the action phase of the work. Later in the learning cycle, or in subsequent cycles, the models may become more sophisticated, allowing greater confidence in the exploration of likely impacts of management. Systems modeling is thus a tool for understanding the consequences of both short- and long-term changes in the components of a system, at a range of scales. In the evaluation phase of the learning cycle, the systems model, combined with indicator measurements, becomes a tool for assessing systems performance.

Systems analysis can be conducted as a multistakeholder participatory process, as in the case of the systems models of van den Belt et al. (1998) and Lynam et al. (2002). Although systems modeling was, until recently, relatively inaccessible to the non-expert, the software that is now available makes it highly accessible to stakeholders in natural resource management systems, as indicated by the building of a land-use and forestry model for Mzola State Forest and adjacent communal areas in a two-week period during a modeling training course (Campbell et al. 2000).

DEVELOPING A PARTICIPATORY APPROACH TO ASSESSMENT

The need for a participatory approach within INRM is implicit, almost by definition, but here we focus on the assessment component of that participation. There is an extensive literature on participatory assessment, the process by which indicators are identified and used, and the negotiation of a shared understanding of what constitutes "favorable outcomes" (e.g., Abbot and Guijt 1998, Guijt 1998, Probst 2002). Participatory assessment becomes a vital ingredient in a feedback or learning process that, in turn, increases the effectiveness of the overall process of participatory management. The Landcare program in Australia (Campbell 1998) is an example in which conservation extension groups involving a broad cross-section of rural people with a stake in catchment planning are using techniques such as GIS and aerial surveys for assessment. For researchers, there is also a pragmatic component to using a participatory approach: it provides a cost-effective alternative to expensive statistical sampling programs.

In our view of participatory assessment, local stakeholders are involved both in the design of the assessment system, including the selection of indicators, and in the collection of information from it. Thus a fundamental aspect of the design and use of indicators requires negotiating a common framework that allows for maximum overlap between the information interests of the concerned stakeholders.

Local systems of assessment can be rich in detail and incorporate indicators that satisfy several of the information demands of complex systems. There is, however, one fundamental problem with local information systems: they are developed in the context of a community of local users, with shared interests and paradigms, managing resources that they consider their own, and isolated from the needs and demands of other stakeholders. Thus feedback from utilization other than their own is inadequately captured, downstream impacts may be considered unimportant, planning takes little account of external demands and needs, assumptions about rights become controversial, and the language and idiom of communication tend to shut out external stakeholders.

For particular components of the system, detailed data may be required to assess system performance. The data may be more or less meaningless without further analysis (e.g., they may act as points to calibrate a systems model; they may require detailed statistical analysis to detect trends). To expect a community to participate in data collection that requires a considerable time outlay, without clear benefits to them, is unrealistic. In the Chivi site, local people were hired to collect hydrological data that were considered critical to assessing the impacts of land use (Bromley et al. 1999). The local monitors benefit financially from this work, and use some of the information to change their own activities or to convince others to change, but they would not collect such information without financial reward. Thus, although we see a component of the assessment of natural resource management being undertaken within a participatory framework, another component would involve more extractive data collection systems.

USING TYPOLOGIES OF LANDSCAPES OR RESOURCE MANAGEMENT DOMAINS

Although selecting indicators to address general features of natural resource management systems will be necessary for effective cross-site comparisons, this may not be sufficient for effective natural resource management, as particular problems and sites have specific contexts that also need to be addressed. What we have suggested as principles (Table 2) may apply to a wide variety of natural resource management systems, but a generic set of indicators must take into account the context of the particular site. Indicators vary widely across different ecosystem types in southern Africa (see Table 4). The problem of defining indicators for systems performance must be addressed at two (or more) levels: a broad level of indicators that help to evaluate the effectiveness of management generally; and a narrower, more context-specific set of indicators that relate to the particular sociopolitical, economic, and ecological conditions of a defined system.

Table 4. Examples of criteria for each of five principles drawn from different capital assets for three landscape types in southern Africa.

Principles for each capital asset	**Criteria**		
	Arid woodlands on Kalahari sands	**Miombo woodlands on nutrient poor soils**	**Dry woodlands on rich soils**
Natural capital: yield and quality of natural resource goods and services is maintained or improved	Frequency of hot fires reduced	Soil fertility levels in garden fields are maintained or improved	Key resources for grazing are maintained
Financial capital grows and is equitably distributed	Revenues from logging and hunting are increased and equitably distributed	Revenues from communal water points are increased and cover maintenance costs	Livestock fund for recovery programs after droughts is maintained
Physical capital is maintained or improved over time	Firebreaks are maintained	Numbers of bore holes for irrigation are increased	Dip tanks are maintained
Improved and equitable distribution of human capital	Community business skills in dealing with tourism operators is improved	Community skills for running micro-credit and water point committees is improved	Community skills for dealing with livestock diseases is improved
Social capital: maintenance of a set of dynamic rules and norms	Rules of access to the forest and fire control rules are maintained and improved	Rules of access to communal water points are adhered to	Rules of access for grazing in different key resources are maintained

In this regard, and within a global research agenda, it would be useful to develop a landscape typology or a typology of resource management domains. Land use is an expression of both the opportunities and constraints presented by the interactions among biophysical, economic, social, and technological components operating in an environment at a particular time, with a particular history. It should be possible to produce a typology of land-use systems that focuses on the key relationships among these components and the constraints that they impose on the predominant land uses. Then one can identify the more context-specific indicators that are sensitive to, and reflective of, the particular features of a given land-use system. Many international research centers have already gone some way toward producing appropriate landscape typologies.

MAKING AN INTEGRATED INTERPRETATION OF THE INDICATORS

Given that a number of indicators are necessary for assessing systems performance, often at a variety of spatial and temporal scales, the question then becomes whether these can be used to give an integrative summary of performance. By using conceptual and systems models in INRM, in which indicators are explicitly linked, some degree of integration across spatial and temporal scales will be achieved. We examine five further methods, not mutually exclusive, that can assist in ensuring integration. The data for these illustrations have been derived from systems models. In actual performance assessment, observed values would also be used and compared to simulated values for the "what would have happened anyway" scenario.

Combining indicators: simple additive indices

Approach

A simple additive index can be calculated in much the same way as is done for the Human Development Index (UNDP 1994). For each indicator considered, a maximum and a minimum are defined. These can be the actual minima and maxima expected in the data or, where the data under consideration do not cover the full spectrum of possible variation, expected values can be based on theory. For example, a measure of minimum woody basal area could be the minimum permissible limit that is required to satisfy basic household livelihood needs. A standardized value for each indicator is then calculated, using the formula: (indicator value at time x – minimum)/(maximum – minimum). For each indicator, the potential values run from 0 (least desirable) to 1 (most desirable). A composite index is calculated as the average of the indicator values.

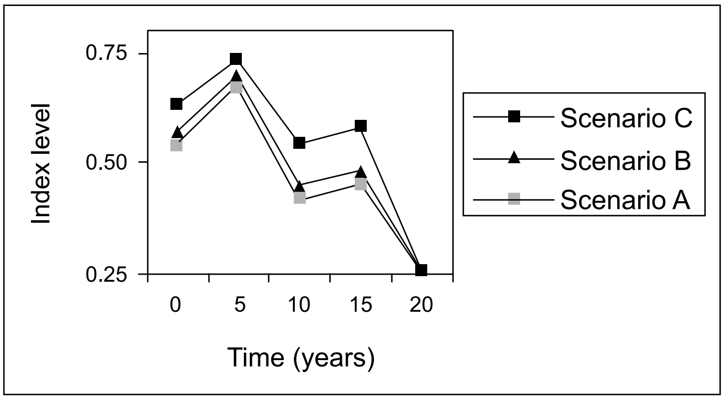
Example application

The method is illustrated using variable values derived from a systems model of Chivi. This model was produced using the Stella modeling package. The model included crop and livestock keeping, forest product collection, and various ecological sectors: rainfall, vegetation dynamics, and fire. To keep it simple, we selected only four variables, two representing natural capital (basal area of woody plants, area of cropland per household), one representing physical capital (numbers of livestock per household), and one representing financial capital (disposable income, i.e., cash income minus cost of inputs for crop and livestock production). The values were generated for every fifth year from the time of project implementation for a 20-yr period. Three simulation scenarios were run: (1) no interventions (Scenario A); (2) crop yield and livestock pen feed raised by 20% per year, and 10% of all trees removed in year 2 (to stimulate grass production for rough grazing) (Scenario B); (3) crop yield and livestock pen feed raised by 50% per year, and 20% of all trees removed in year 2 (Scenario C).

Example results

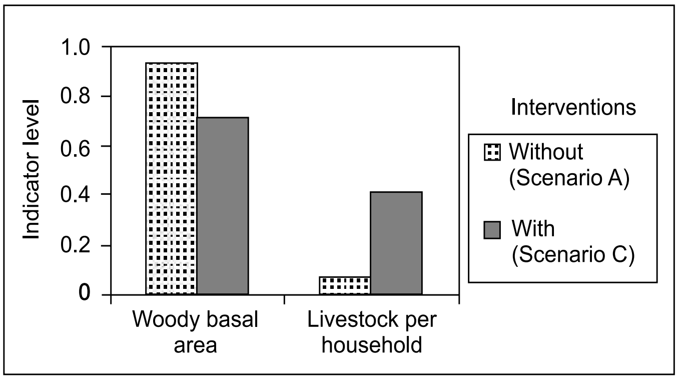
The additive index of capital assets fluctuates widely, but generally declines over time (Fig. 5). A less marked pattern is due to the intervention, with higher index values for scenarios with interventions. The fluctuations are largely related to rainfall and its impacts on agricultural production. The decline reflects the long-term trend toward smaller land holdings and lower numbers of livestock per household, given the rise in household numbers in an already heavily populated landscape. It is predicted that the interventions will make a difference, but their impact can be masked by other phenomena.

Figure 5. Change over time in Chivi for three scenarios (rainfall patterns in the different scenarios are the same) using a simple additive index. Scenario A, no interventions; Scenario B, crop yield and livestock pen feed raised by 20% per year, and 10% of all trees removed in year 2; Scenario C, crop yield and livestock pen feed raised by 50% per year, and 20% of all trees removed in year 2. The index is derived from average values for four variables, with the values being derived from a Stella simulation model.



The problem with the additive index is that the variation in individual indicator values is reduced to a single number for a particular time period. To understand this single figure, one has to go to the original data and look at the values for each of the indicators that make up the index. This may not be a problem when there are only four indicators, as in the example, but is problematic when there are numerous indicators. In the example, differences between intervention scenarios are largely due to changes in livestock holdings and woody plant basal area. Because these variables show opposite trends, the simple index may be hiding important differences among variables (Fig. 6).

Figure 6. A comparison of the variable values for year 15 for Scenarios A and C (see Fig. 5) for woody plant basal area and livestock numbers. The variable values were derived from a Stella simulation model.



Combining indicators: derived variables using principal component analysis

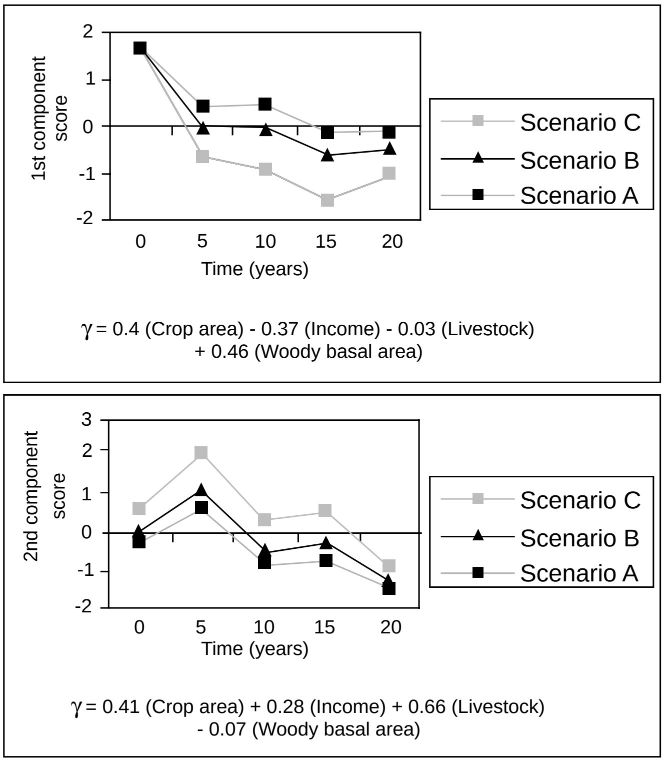
Approach

A more sophisticated method of combining indicators into a single variable is to use principal components analysis (PCA), or a related multivariate technique. PCA-type methods are often used in data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of variables. The first new factor (first principal component [PCI]) or derived variable, Y_1, is a linear combination of the original variables, i.e., $Y_1 = aX_1 + bX_2 + cX_3$ ..., where X_1, X_2, X_3 ... are the standardized original variables, and a, b, c are the fitted coefficients (it is not necessary for the analyst to standardize the variables prior to analysis; the standardization procedure is routine within statistical packages). Y_1 is constructed so that it accounts for the maximum possible information in the original set of variables. Further factors can be derived, each explaining some residual variation in the matrix (Y_2, Y_3 ...).

Example application and results

The same data used to illustrate the additive index were submitted to a PCA, using a data matrix of the four variables and 15 cases (stimulated data from five different years for each of three scenarios; Fig. 7). Measured data on the variables could be included as additional cases. The first PC is dominated by the woody plant basal area variable, while the second PC is dominated by the influence of livestock numbers per household (the equations are illustrated in Fig. 7; the higher the coefficients for a variable, the higher the influence of that variable in the component). Both PCs show a decline over time (largely a result of declining natural and physical capital). It is predicted that the intervention will cause a greater decline than the non-intervention for the first PC (largely related to natural capital, loss of woody plant biomass), but will result in higher values than the non-intervention for the second PC, illustrating the positive effect of the intervention on physical capital (livestock numbers). Such multivariate techniques become particularly powerful when more variables are being used.

Figure 7. The changes in the derived variable (principal component I and principal component II) over time. The make up of these derived variables from the original variables is indicated; the larger the absolute values of the displayed coefficients in these equations, the more effect that variable has in the derived variable. The original variable values were derived from a Stella simulation model.



Combining indicators for each capital asset

Each capital asset comprises a number of different variables (e.g., social capital is a function of the size of the extended family, connectedness to other members of the community, membership of groups, extent of reciprocal relations, social indebtedness). We have illustrated the use of PCA-type tools to combine all possible indicators into an overall index (e.g., Fig. 7). The procedure would only be recommended when dealing with relatively few indicators (e.g., less than 20), or when there is not a pressing reason to maintain a capital-assets perspective. A conceptually neater technique would be to use a PCA-type method with the set of indicators that fall under social capital to get a single, derived variable for social capital, and so on for the other capital assets, and then to display the capital-asset situation as a radar diagram.

Visualizing change: two-dimensional plots derived from PCA-type analyses

Approach and example application

With a multivariate technique such as PCA, we also have a visual means of displaying the results, which does not require that we deal with indices or derived variables. The method is displayed for the simple four-variable Chivi case (Fig. 8). The points on the graph are coded A for Scenario A, B for Scenario B, and C for Scenario C, and the time when the data were collected is coded 0 for time 0, 5 for 5 years after the start, etc. Actual measured indicators could be incorporated into the data matrix and would thus also be displayed on the diagram. The distance between the points on the two-dimensional graph (A0, A5 ..., C20) represents the degree of difference between these cases, in terms of their values. Thus, A0, B0, and C0, all being closely placed at the right of the *x*-axis, have very similar values, whereas C15 is very different. The technique also displays the variables used in the analysis (in this case, basal area, income, cattle numbers, and crop area). Thus A0, B0, and C0 at the right-hand extreme of the graph have high values for woody basal area and low values for income, whereas points at the left-hand extreme (e.g., C15) would show the opposite pattern. The *y*-axis is largely related to livestock numbers, with points at the top of the graph (e.g., C5, B5) having high numbers, whereas points at the bottom of the graph (e.g., A20) have low numbers. In this example, for any specific time period, the cases with the interventions are toward the top of the *y*-axis, primarily indicating higher livestock numbers.

Figure 8. Scatter diagram showing the distribution of cases in two dimensions, with the distance between the case positions representing the degree of difference of the cases. The cases are coded as: A, Scenario A (no intervention); B, Scenario B (intermediate intervention); and C, Scenario C (large intervention; see Fig. 5); with numbers from 0 to 20 indicating the start (Year 0) to 20 years. Also shown are the four variables used to produce the diagram, with the variable positions indicating the cases (those near that position) that have generally high values of the variable. The variable values were derived from a Stella simulation model.

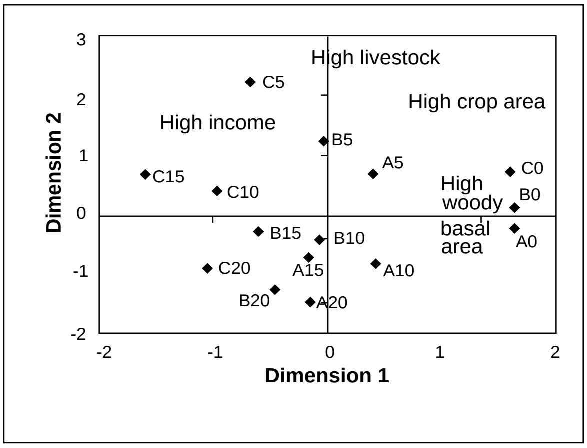
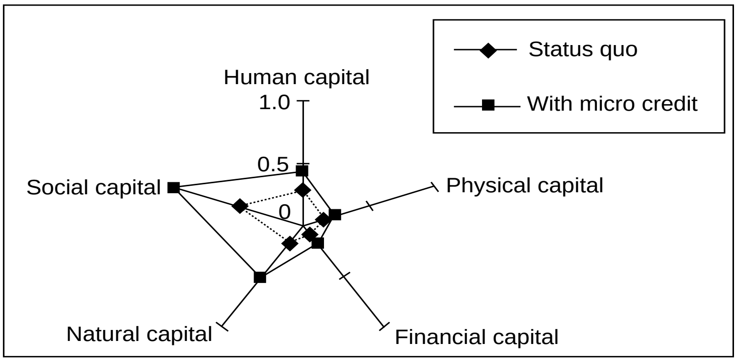


Figure 9. Radar diagram showing the impact of a micro-credit scheme on capital assets. The values for the assets are standardized values (running from 0 to 1) derived from variables in a decision support system based on a Bayesian Belief Network.



Example results

The results indicate that the main trend (first PC) is the decline with time of woody plant basal area and cropping area, a decline that is greater in the intervention scenarios because of the reduced woody plant basal area. The interventions maintain higher livestock numbers than the non-interventions. The lack of simple patterns in the diagram (e.g., C0, C5, C10, and C15 are not neatly in order) is due to fluctuations in the variables, caused by rainfall.

Visualizing change: radar diagrams

Approach and example application

Radar diagrams, available in Microsoft Excel, for example, can be used to display the state of all capital assets (Fig. 9). We have used another model for Chivi, on the impact of micro-credit schemes, to illustrate the use of a radar diagram. The numbers were generated by a decision support system based on a Bayesian Belief Network (derived from that of J. Cain, *unpublished data*, 2000). For each of the capital assets, a proxy variable was selected: (1) *physical capital*, percentage of households with "improved roofing" (income generated from activities sponsored by the micro-credit scheme are often used to improve household holdings); (2) *financial capital*, percentage of households achieving a "high" level of savings; (3) *natural capital*, percentage of households having soil-improved fields; (4) *social capital*, percentage of households adhering to community-based rules; and (5) *human capital*, percentage of committees exposed to, and practicing, improved methods of organization.

Results

For these simulations, some degree of soil moisture security (e.g., irrigation or high rainfall years) was envisaged; without such security, the impacts of micro-credit are very limited. The results indicate that the impact of the micro-credit scheme is likely to be improved social capital, and to some extent, improved natural capital, rather than improved financial capital (Fig. 9). The broader research program has focused on developing social capital as a precursor to common property resource management; hence, the impact on social capital. Actual measured indicator values could be compared to the simulated values by including a third pentagon on the radar diagram.

One challenge to using a radar diagram is that a single indicator must represent a capital asset (as used for Fig. 9), or that we must collapse all of the individual indicators under a particular capital asset into one index of that asset. The latter can be done using principal component analysis, or a related technique, as described earlier.

Combining indicators across scales: canonical correlations

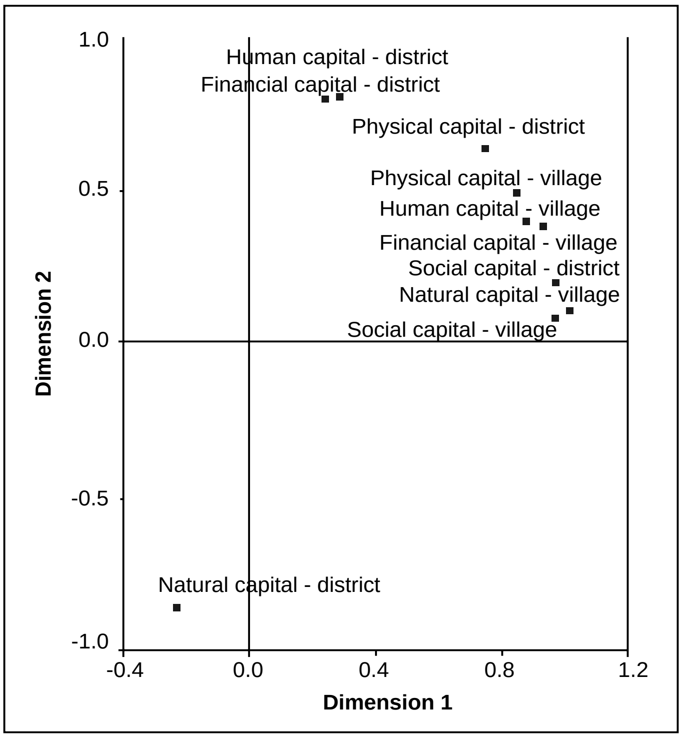
Approach

Although the methods that we have mentioned are suitable for one of the spatial scales within a system, they are not easily extended to multiple spatial scales, as is necessary in INRM. The indicators from different scales could be entered into the same data matrix. In this way, where there are two scales, there are two sets of indicators, and techniques very similar to principal components analysis can be used. Additionally, however, the relationships between the two sets of indicators can be explored. The limitation is the numbers of indicators that are generated, requiring ever increasing observations for each of the indicators. With five capital asset indicators and two scales, there are 10 indicators, requiring more than 10 observations (e.g., with and without simulated scenarios for five time periods plus one measured set of values for one time period would give sufficient cases). If one has such data, then canonical correlation can be used.

Example application and results

In the example, we look at the impact of the micro-credit scheme on the village where it is implemented, as well as the larger district in which the village falls. Data for the first two years for the village have been derived from the decision support model used in the previous section, but data for the other years and for the district have been made up. The nonlinear canonical correlation analysis shows the relationships among the variables (Fig. 10) and the cases (different scenarios and year) (Fig. 11). Many of the village-level variables are correlated with each other and with social capital at the district level (Fig. 10). This is because there was a conscious effort by the researchers to involve the district government in building governance systems. The second dimension indicates that natural capital at the district level is negatively correlated with human, physical, and financial capital at the district level. Cases with the micro-credit scheme (B1, B2 ...) are on the right of the *x*-axis, with high levels of most of the capital assets, whereas cases without the credit scheme have low levels and are on the left side of the *x*-axis (Fig. 11). Time is captured by the *y*-axis, with early observations at the bottom (high natural capital) and late observations at the top (higher levels of other types of capital).

Figure 10. Incorporating variables from two scales. Scatter diagram showing the distribution of variables in two dimensions, with the distance between the variable positions representing the degree of correlation between variables. The figure is illustrative only because, although the data for the first two years are from a decision support system based on a Bayesian Belief Network, the subsequent year's data have been made up.



Results suggest that the micro-credit scheme will make a difference, but mostly at the village level, except that district-level social capital will be built up through the stakeholder negotiations and district-level governance efforts that are part of the research. However, the positive impact at the village level must be set in the context of other changes at the district level, notably the decline in natural capital, but improvement in other capital assets.

CONCLUSIONS

We advocate an approach to the assessment of systems performance that is part of a learning process fully integrated within participatory research. This has a number of implications, most notably the need for constant iteration between management and assessment. The approach requires the use of many qualitative indicators. Many components of performance assessment need to be initiated at the start of the INRM learning cycle, e.g., bounding the system, developing a conceptual framework, selecting indicators, initiating the development of a systems model, and situating the site within a typology of landscapes or resource management domains. Although many of these activities are part of the learning cycle for reasons other than performance assessment, they are also crucial for assessment. During the evaluation phase of the learning cycle, data from numerous indicators will generally be available: a challenge is to remain integrated. We suggest various tools for making integrated statements about trends in indicators, across scales, including the use of radar diagrams and multivariate techniques. Given the numerous external influences on natural resource management systems, simply viewing indicator data collected from the field may prove meaningless because they may be reflecting trends unrelated to management. Thus indicator values measured in the field may have to be compared with values derived from systems models. This should not be interpreted to mean that assessing the impact of INRM research will, itself, constitute a major research undertaking. In reality, most of the data required would have been collected anyway in the course of INRM. What is advocated in this paper is the organization of data on indicators into an adaptive-management framework that will allow for constant enhancement of the performance of the system. Well-conceptualized performance assessment frameworks should render research and management more efficient and may reduce data requirements by suggesting redundancies in the overall process. What we suggest is a radical departure from conventional impact assessment studies, as they have been applied to agricultural research. It is, however, consistent with moves toward greater use of action research, greater participation, and a general move down the research–management continuum. We believe that this sort of INRM will be needed to address the complex natural resource management problems that will determine the development options for the world's poor in the 21st century.

ACKNOWLEDGMENTS

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15.

Integrating Research on Food and the Environment: an Exit Strategy from the Rational Fool Syndrome in Agricultural Science

Jacqueline A. Ashby

ABSTRACT

The thesis of this paper is that the "rational fool" syndrome can be applied to mainstream public sector agricultural research that is conducted in a way that is rational in the short term, but acts against its own long-term viability. Historically, a main concern of such research has been to maximize high levels of food production together with low prices to consumers. As a result, mainstream agricultural science has ignored negative impacts or externalities, which has contributed to a crisis of credibility with the general public and politically sensitive decision makers. A long-term strategic research agenda for the public sector is being defined that is new and relevant to present efforts to integrate natural resource management and sustainable agricultural production. Such an agenda must be understood as a way of managing natural resources for the production of food and environmental services essential to human well-being. If agricultural systems are viewed and managed as parts of whole ecosystems, the key properties of complex systems that need to be taken into account will force researchers to consider long-term effects and environmental externalities. Research products will then be increasingly strategic in nature, and the research process will be "democratized" as it involves and gains the support of a broad set of stakeholders. Private sector research cannot be expected to meet this need because strategic studies of resource management are required that cannot be made exclusive or proprietary and are, in other words, public goods. Several innovative research initiatives are under way that signal opportunities for change. This paper first elaborates on this argument and then illustrates

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key elements of the integrated natural resource management approach, with examples of approaches that show promise as alternatives to mainstream agricultural science. Although numerous and diverse, integrated approaches manifest several properties that can be defined as the keystones of a new paradigm.

KEY WORDS: ecosystem health, human health, natural resource management, rational fool syndrome, strategic research, sustainable agricultural production.

INTRODUCTION

Amartya Sen described the "rational fool" as a person who makes self-interested decisions that are advantageous and logical in the short term, but ignores the personal negative effects of those decisions over the long run (Ridley 1996). This syndrome is commonly used to describe the environmentally destructive behavior of individuals and societies (Hardin 1968, Ostrom 1990). Although it is not usually applied to the way food is produced, the syndrome can nevertheless be seen in action across the world in food production and consumption systems that ignore the negative effects of farming on human and environmental health. This does not mean that farmers are fools, but that mainstream agricultural science has organized information and developed technologies for food production in a way that provides society as well as farmers with a rationale for ignoring environmental, economic, and social costs over the long run.

Mainstream agricultural science treats natural resources as a storehouse of raw materials whose yields are to be maximized in the short term. Environmental goods such as clean water, flood protection, healthy soil, wildlife habitats, and biodiversity are not traditionally valued by mainstream agricultural science. The negative impacts of agriculture on the environment and other long-term effects of technical innovation are treated as external to the process of production and are not part of the costs for food paid by producers or consumers. In the short run, this science has proved to be enormously successful in increasing food production in high-income countries as well as in those low-income countries that have benefited from the agricultural production technologies of the Green Revolution. However, the long-term damage to the environment and human health that has resulted from this success is now being documented, and its cost is being calculated (Fowler and Mooney 1990, Pimentel et al. 1992, Constanza et al. 1997, Costanza and Jorgensen 2002). These findings provide a good illustration of the consequences of the rational fool syndrome.

Public goods research is defined as research that provides benefits for individuals and society that cannot be made exclusive or proprietary. When focused on the management of ecosystems to produce food, these research efforts should build a stock of useful knowledge that will enable human societies to sustain production and well-being over the long term. However, governments, agricultural research bureaucracies, and policy-making agencies in the public sector are no longer investing in long-term strategic research and, as a result, agricultural science is no longer creating the public goods needed to manage agroecosystems sustainably. This lack of support for strategic long-term research products that are also public goods is fueled by agricultural scientists' treatment of agricultural productivity as a separate issue from natural resource management and ecosystem health (Anderson 1998, Luzadis et al. 2002).

Low-income countries, in which support for public sector research is traditionally low and the institutions that provide research services are weak, are bailing out of public sector agricultural research at an ever faster rate. A recent survey of 208 sustainable agriculture projects in Latin America, Africa, and Asia showed that finding an alternative to mainstream agricultural science is just as much a preoccupation of farmers in low-income countries as it is of those in high-income countries. This survey found that nongovernmental and grass-roots initiatives were beginning to succeed in addressing the need for a type of agriculture that not only supplies food and other goods to farm families and consumers but also contributes to a range of public goods such as clean water, biodiversity conservation, and landscape enhancement. In these projects, most of which are in low-income countries, some 8.98×10^6 farmers have applied novel agriculture practices to 29×10^6 ha, up from an estimated 100,000 ha a decade ago. These innovative practices have been founded mainly on the experiences of farmers themselves as they experiment with and adapt technology, combined with efforts to build their capacity to apply ecological and biological principles that allow them to make better use of natural resources (Pretty and Hine 2001, Campbell et al. 2002, Oglethorpe 2002).

Research on managing ecosystems so that they continue to produce the food, fiber, and environmental goods and services on which human well-being and, ultimately, all life depend has to be done in the public sector. In the absence of exclusivity, the private sector has little incentive to invest in improved technology or management for the long run, because others who have not contributed to the cost of the investment will share the benefits. Ingenious schemes proliferate for creating private incentives for private individuals and firms to internalize environmental externalities. However, private enterprise by definition does not have a long-term interest in creating the type of long-term, strategic, public goods research products that are required to ensure a continuous stream of benefits from natural resources to society at large.

Strategic research products can be defined as those that have explanatory power, i.e., that explain why and how things work, as well as applications beyond the solution of a specific problem, need, or circumstance. In contrast, applied research products are developed primarily to produce a specific product or solve a specific problem in a well-defined set of circumstances. Strategic research also tends to be more of a long-term investment, and there is no time frame for the expected payoff, whereas applied research tends to be managed with relatively well-defined limits on expected length before completion. Finally, strategic research products are often public goods that maintain their value independent of the number of users and that cannot be made exclusive, i.e., no one can be barred from their use.

This paper argues that the persistence of a short-term, reductionist perspective on food production, together with an artificial separation of the management of human food systems from that of natural ecosystems, is rooted in a paradigm of science and organization of research that serves the interests of some, but not all, stakeholders. Those who benefit include food companies, agribusinesses, and producer groups who profit from the political economy of cheap food at the expense of environmental health. Worldwide, producers and consumers are becoming increasingly disenchanted with modern agriculture in both high- and low-income societies. A radical change is called for in the way that public goods research on food and the environment is carried out. The emergent properties of new approaches can already be detected in new ways of doing science and in new kinds of research organizations.

RESEARCH AND TECHNICAL INNOVATION IN MODERN AGRICULTURE

Public disillusionment with agricultural research

Compared to the Nobel prize-winning heights of the Green Revolution, the status and credibility of conventional or mainstream agricultural science have fallen drastically over the past decade, to the point that many people now see agriculture as a threat to the environment and to human health. The health concerns that the general public associates with agriculture fall into several areas:

- failures of modern agricultural science, such as the BSE (mad cow) disease and the foot-and-mouth outbreaks in the United Kingdom;
- bioengineered crops that introduce new allergens into the food chain, as occurred with Starlink corn, which contained a protein whose characteristics were associated with allergens and which was not approved for human consumption but nevertheless entered the human food chain;
- threats to the environment by genetically improved animals and fish such as salmon, which, were they to escape from their commercial pens, have a mating advantage that would threaten the genetic integrity of wild stocks;
- the possible toxicity of genetically engineered crops to other life forms, e.g., BT corn, which could decimate Monarch butterfly populations;
- the development of herbicide resistance in weeds, e.g., generated by genetically engineered, herbicide-resistant soybeans that require the application of only a single herbicide.

These concerns are not restricted to high-income countries. For example, the large-scale spread of integrated pest management among thousands of small farmers in the tropics, where pesticide use has been greatly reduced, is motivated by their experience of the serious ecological imbalances and human health problems that pesticides can cause (Pingali and Roger 1995, Thrupp 1996). The way food is produced, the role of science in food production, the effects of new food production technologies on human health, and the well-being of ecosystems have become major political issues and topics for headline news. At local, regional, and global levels, the capacity of ecosystems to support human consumption of food and environmental goods and services is seen as threatened by modern agricultural practice.

Advances in agricultural science have the potential to significantly increase production in response to the globalization of trade and the food needs of a burgeoning world population. However, many perceive these advances as sources of undesirable changes in land use, climate, biodiversity, and the evolution of new diseases. As a result, a number of countries have based their national agricultural strategies on the World Conservation Strategy, which has an explicit priority requirement to " ... reduce excessive yields to sustainable levels ... " (Adams 1990:44).

Concern for the negative effects of agriculture on natural capital stocks is both an expression of the conservation ethic and a response to international poverty, famine, and disaster. This critique of mainstream agricultural research in the public sector is also applicable in societies in which national science bureaucracies are weak and research has been dominated by international entities financed by overseas development aid. The capacity of poor countries to withstand external shocks such as war, climate variations, and indebtedness depends partly on their natural capital. The diversity of natural capital gives it an important advantage over man-made capital in enhancing the survival of poor farmers in low-income countries, given that diverse ecosystems are more resilient to shocks and stress (Conway 1985, 1987, Pearce et al. 1990).

As a result of this critique of mainstream agricultural science, political support for mainstream agricultural research in the public sector is in decline (Anderson 1998), whereas increasing amounts of resources are now being devoted to environmental conservation and disaster relief for low-income countries. This loss of support reflects the disenchantment with modern agriculture in high-income countries and with research and advanced agricultural technology in both high- and low-income countries. Agricultural research is not unique in this loss of credibility: practitioners of rural development have also gone through a process of being proved consistently wrong (Chambers 1997). Critics of mainstream agricultural science find the research establishment " ... incapable of delivering social equity, economic efficiency, and ecological integrity in response to the decline of rural society and deepening crises in the depletion and degradation of water, soils, flora and fauna ... " (Campbell 1998:232–233). The rates of return on investment in agriculture in developing low-income countries are very disappointing. Much evidence is cited to support the view that returns on agricultural development projects have been lower overall than in other sectors such as health or education; in addition, the capacity of agricultural development projects to sustain momentum after external donors withdraw is seen as relatively low (Pretty 1995). Proponents of institutional change to support the development of sustainable agriculture find it hard to identify a clear role for agricultural research in this process. Röling and Jiggins (1998:297) state that " ... the old role of developing technologies FOR farmers seems to clash with the logic of ecologically sound farming, while a new role [for research] ... seems not to have clearly emerged."

Short-term success vs. long-term failure

For many years, mainstream agricultural science has been committed to a reductionist treatment of agricultural productivity and agriculture's role in development, as if these can be managed separately from natural resource management and ecosystem health. For example, one analysis of mainstream agricultural science equates natural resource management with location-specific adaptive research of little strategic value that is unlikely to produce internationally useful public goods and unworthy of significant levels of public sector investment (Anderson 1998).

A different type of analysis shows that, although discounting externalities may be a rational, albeit shortsighted, outcome of managing food production to maximize productivity and provide the lowest possible prices to consumers, it has significant costs in terms of human and ecosystem health (Pretty et al. 2000). Externalities related to agriculture affect the production and consumption behavior of individuals, households, interest groups, business firms, and governments. When producers shift some of the costs of production, whether health or environmental, onto other stakeholder groups, it becomes possible for them to produce at a higher level of output and profitability than if they had to offset the full costs against the gains. An important consequence of this is that, when negative externalities are present and costs shift away from producers onto others, the output that producers consider optimal is actually higher than the output deemed optimal by society as a whole.

A choice has been made to increase production and keep food prices low rather than provide a transparent accounting of the costs of care for human and agroecosystem health in agriculture (Pretty et al. 2000). With this in mind, conventional agricultural research has focused on the short-term goals of increasing yields and economic returns to producers and on delivering relatively low-priced food to consumers. Good historical reasons explain this focus, and extensive critiques, justification, and refutations of it abound, and will not be repeated here.

The main point is that agricultural research that focuses on increasing productivity and ignores externalities is largely built on technologies that maximize biological uniformity and sidestep, minimize, control, or destroy the natural biological processes that are essential to the stability and resilience of natural ecosystems (Folke et al. 1998). This is an issue for farmers in low-income as well as high-income countries. For example, small farmers in low-income countries are demonstrating how food production can be increased by enhancing the biological productivity of the soil, microenvironments, and even whole catchments (Pretty and Hines 2001). Ironically, perhaps the most powerful interest groups driving popular disaffection with the reductionist approach away from biological uniformity and toward diversity are well-off consumers who have the luxury of choice and whose preferences are expressed via specialized global markets. Their heightened concerns about the health and environmental implications of agriculture are creating significant demands for organic farming and niche products in subsegmented markets, and are encouraging farmers to diversify and integrate their activities with natural resource management (C. Wheatley, *personal communication*).

Research that treats environmental resources such as land, water, and biodiversity as discrete factors of production has, in fact, succeeded in increasing productivity in the short term. From this perspective, it is possible to maximize the productivity of individual factors of production by focusing research on improving management efficiency with new technologies. Because it works against, rather than building on, natural diversity, mainstream agricultural science is identified with processes that undermine ecosystem capacity to withstand or recover from shocks and stress. Increased production based on reducing variability slowly changes the functioning and resilience of the ecosystem that sustains the production of food and of the resources on which it depends. If variability and disturbances are not allowed to enter the system, they accumulate and return at a later stage on a much broader scale. Diminishing variability tends to increase the potential for larger-scale, less predictable, and less manageable disturbances that can have devastating effects on ecosystems (Ludwig et al. 1997); it also reduces the capacity of the ecosystem to provide the environmental services that are essential to material and energy stocks and to the flows that are important for food production. Agriculture based on blocking out variability or "disturbances" that are endogenous to the cyclic processes of ecosystem development is an expression of the rational fool syndrome, and the reductionist treatment of natural variability is the " ... short-term success that leads to long-run failure ... " (Folke et al. 1998:458).

Integrated approaches to research on agriculture and resource management have to bring about three critical changes to achieve the paradigm shift needed to lever food production and ecosystem and human health out of the current unsustainable syndrome. First, research for agriculture must be understood as one way of managing natural resources to support human livelihood. As such, it must build a strategic research agenda that is based on working with variability and view functional ecosystem disturbances as desirable features of sound resource management and food production. Second, research needs to be linked to active processes of adaptive management in ecosystems of high priority to important stakeholders engaged in both research and management. Third, the appropriate organizations for carrying out this research need the support of the emergent interest groups and learning communities that are propelling a paradigm shift outside of and virtually despite mainstream agricultural science.

An example of working with variability

A classic example of a paradigm shift lies in the history of the management of African pastoral systems (Ellis and Swift 1988). Recommended methods of reducing overgrazing in these pastoral systems included group ranches, grazing blocks, and associations in which pastoralists were confined to particular tracts of land to better regulate the interaction between animals and plants and raise productivity. Over time, these new management methods were found to destabilize grazing systems that are characterized by intra-annual variability resulting from frequent drought. In contrast, pastoralists using traditional methods cope with multiyear drought by dispersing into small herds and groups over a wider area, thus expanding the spatial scale of exploitation. In nondrought periods, pastoralists ensure that unused space or an ungrazed reserve is available for periods of drought by stocking some areas in the ecosystem well below their average carrying capacity (undergrazing) while overgrazing others. This stabilizing mechanism relies on mobility, whereas the modern management strategy is based on confinement. In other words, recommendations that do not factor in variability and disturbance in the ecosystem often lead to long-term failure. Research had to define alternatives to conventional management of grazing systems that functioned at the ecosystem level, took into account hierarchies of interdependent subsystems, and were effective over the long term. Technical packages designed for a reduced spatial scale and short time horizon could not cope with the variability in the system, and indeed became associated with increased degradation in the long run (Ellis and Swift 1988).

An example of working with adaptive management

The experience of the Forages for Smallholders Project (FSP) (P. Kerridge et al., *unpublished manuscript*) with the introduction of legumes and grasses into small-farm production systems in Southeast Asia illustrates how a mixture of participatory learning and research can support an integrated approach to food production and natural resource management. This type of approach fosters adaptive management that is responsive to and supportive of variability in ecosystems.

The project is introducing a large variety of optional, new, multipurpose legume and grass species using participatory methods that enable farmers to learn about diversity and devise a variety of niches for different species in their systems. The use of a menu of diverse options for participatory learning is fundamental to this approach. Farmers learn, invent, and validate new ways of using diverse species, and the ways they choose are becoming more complex as the farmers gain experience.

Over time, farmer preferences for varieties and characteristics have changed. At first, animal feed, contour hedgerows, and intensive cut-and-carry plots emerged as the main ways in which farmers integrated several species into their agricultural systems. Subsequently, other ways of integrating legumes and grasses into living fences, ground covers, and small grazed plots evolved for many different end uses. Species and genetic diversity as well as new ways of coupling plants and animals in the system, e.g., growing shrub legumes for forage as part of contour rows for soil erosion control, have been developed as a result of farmer innovations. Participatory research fostered adaptive management that enabled the project to encompass the diversity and complexity of entire agricultural systems. The researchers, whose initial ideas about appropriate options for each farming system did not agree with those of the farmers, eventually revised their opinions to reflect the fact that the farmers' grasp of complexity was different than their own.

Researchers' innovations have also been adapted in unexpected ways. For example, on steeply sloping lands, farmers introduced contour plantings of *Paspalum atratum*, which establishes much more rapidly and cheaply than the heavily promoted vetiver grass and can also be used for fodder. *P. atratum* competes with associated crops, but not to the same extent as other types of barriers. The farmers took an integrated approach to managing small areas planted with legumes for forage and also used alternative feed sources from adjacent forest and waste areas. In this way, they highlighted for the project the potential of managing both types of land use for the preservation and increased use of indigenous species.

New organizational concepts

Eighteen projects in geographically representative regions of the United States make up the Integrated Farming Systems (IFS). These projects are linked in a network that makes it possible to share knowledge and experience among farmers, scientists, consumers, policy makers, bankers, and producers and distributors of agricultural inputs. The goals of the IFS are to help farmers discover and use more sustainable farming practices and to help communities identify and overcome barriers to adopting more sustainable practices and systems (Fisk et al. 1998). A highly important feature of the network is that it also seeks and creates leverage for catalyzing policy change on the basis of experience gained in the context of an adaptive management approach to sustainable agriculture. The use of formative evaluation to document progress, reflect on what works, and determine the next steps to take has been crucial to this catalysis (Fisk et al. 1998).

As stated above, one goal was to help farmers find and use more sustainable farming practices with the support of their communities and of policy makers. To achieve this, the IFS set out to establish a "learning community" that practices the five disciplines identified by Senge (1990) as the requisites of a learning organization. By self-consciously working together around the idea of creating a learning community, the IFS has successfully built a support structure for farmers and community spokespersons that favors sustainable farming. Farmer-driven research and educational organization are key elements: farmers conduct on-farm research, educate other farmers and community members, and provide laboratories that foster leadership. As a result, a cadre of community-based spokespersons has been developed who can effectively carry messages about their needs and achievements to decision makers and opinion leaders in their own communities and centers of policy activity. Policy makers in the United States are looking to community-based organizations for information about the effects of policy changes at the farm and community levels. Among its 18 projects, the IFS has provided some powerful demonstrations that have helped to educate policy makers (Fisk et al. 1998).

An important ingredient of this success is an effective strategy for working across different organizational scales. To achieve this, the IFS helps communities to engage large institutions by finding the constituency that these organizations are most likely to listen to and building a relationship with that constituency. The IFS has been highly effective in communicating information and developing leadership skills to catalyze action on national policy issues. One result of this is that the U.S. Department of Agriculture now uses the IFS model.

Agriculture as a way of managing natural ecosystems for human well-being

Several novel approaches are helping to integrate agriculture and natural resource management, although there is still no coherent unity of thought or organization. Scientists have called for a broader focus and created new names for these approaches, all of which emphasize a balance between productivity and environmental health objectives and, to varying degrees, view agriculture as one way of managing natural ecosystems for human well-being. Much of this thinking parallels the processes that have been developing for many years within applied research projects and programs focused on adaptive farming systems (D. Gibbon, *unpublished manuscript*).

These new perspectives are built on the premise that human health and livelihood depend on the functioning of ecosystems that generate essential natural resources and environmental services, play a fundamental role in supporting life, and are essential to the material cycles important for food production. Environmental services include regulating climate variability, water quality, and water quantity; controlling floods and pests; assimilating wastes; recycling nutrients; generating soil; pollinating crops; and maintaining the composition of the atmosphere, biodiversity, and the landscape (Conway 1997).

The idea that the methods used by traditional cultures to manage food production are integral to natural resource management has also helped to break down the reductionist separation of agriculture and ecosystem management. Many documented examples illustrate indigenous systems for managing whole landscapes as integrated farming systems; these range from the upland forest all the way to the coral reef (Folke et al. 1998).

Once agricultural systems are understood to be parts of, and managed like, ecosystems, research needs to take into account the effects of agriculture on the environment. Ecosystems are "holarchies" made up of many different components or "holons" that operate together. A holon is a whole system that is made up of smaller parts and at the same time forms part of a larger system (Allan and Starr 1982, Giampetro and Pastore 1999). This concept is useful in illustrating how agriculture involves interventions in component systems that are hierarchically organized on several scales: soil microorganisms, populations of species, fields in a landscape, etc. In contrast to mainstream agricultural science, new approaches that integrate food production and environmental health objectives analyze agriculture as a set of interventions in a hierarchical system. This helps to emphasize the fact that ecologically sound conditions for growing healthy animals and plants must usually be created at more than one system level, that is, higher than the plot or even the farm, and must be managed on a landscape scale (Holling et al. 1995). This was the approach used to define a successful management strategy for African pastoral systems.

Agricultural systems manifest an important characteristric of holarchies or hierarchies of interdependent subsystems: what is good in the short term is not necessarily good in the long term (Giampetro and Pastore 1999). Understanding the holarchic structure of agricultural systems is crucial to the recognition that knowledge of what goes on at one level of a holarchy does not necessarily provide sound information about what is going on at other levels. For example, increasing productivity at the level of individual plots can reduce the overall productivity of a whole landscape such as a watershed, and pest and disease control to improve plant health in the farming system can jeopardize human health in the larger production-to-consumption system.

Research on agriculture treated as one component of human intervention in complex ecosystems will need to be increasingly strategic in nature. This type of research must deal with a high level of uncertainty based on patterns that are repeated in an irregular way. These are also known as fractals: generic patterns repeated in a self-similar way at many different levels that are always recognizable but never exactly the same. In principle, research can design an agricultural system or subsystem with a generic pattern and potential, establish the conditions required for it, and predict the dynamics that will produce a recognizable variant of this system. Action research is an approach that has potential applications in this kind of situation because it allows researchers to intervene in an agroecosystem, study the effects of the intervention, and apply this understanding to a second intervention. Research efforts of this type can be conducted to push a system into a phase of instability and change within certain constraints, monitor the resulting adaptive management process, and use the feedback to develop management principles. However, research cannot determine the specific form of the generic pattern that may emerge. For this reason, research that builds on variability will not produce technological "silver bullets" in the way that reductionist agriculture has: its focus by definition must be on the strategic and the generic, on "how" rather than "what" to change in agriculture. The adaptive management of species diversity in the Forages for Smallholders Project is an example of this shift in approach.

In agriculture, new technologies based on the active reduction of variability in the flow of a resource or a natural capital have, in fact, succeeded in increasing productivity at one level of the holarchy or in one of a series of interdependent systems. In mainstream agricultural science, new technology is designed to reduce and overcome fluctuations and variability in nature and to block out the natural disturbances that are functional and necessary for sustaining ecosystem resilience (Folke et al. 1998). To a very large extent, the anomalies that are fueling public disenchantment with mainstream agricultural science are instances in which success in overcoming variability in the short term in one part of the system has led to failure in the long term at another level.

ORGANIZING FOR INTEGRATED RESEARCH APPROACHES

Once it is understood to be a form of natural resource management, agricultural science must definitely be subject to the value-driven preferences of diverse interest groups or learning communities. Resource management involves negotiating goals and acceptable trade-offs among multiple stakeholders, including the different learning communities. For poor farmers in semisubsistence agriculture, there are trade-offs between satisfying the family's daily food and income needs and maintaining the viability of the natural resources required to produce them. For better-off farmers in commerical agriculture, there are trade-offs between cutting costs to capture slender profit margins and long-run investment in the management practices and technology needed to sustain productivity. Research aimed at improving the management of ecosystems for food production and other purposes has to incorporate the management objectives of the different stakeholders with regard to how best to use natural processes, cope with disturbances, and internalize externalities.

This has several implications for the organization of research intended to integrate the objectives of food production and environmental health. The democratization of science, which in this case is understood to mean the inclusion of lay expertise and values in the process of planning and carrying out research, may be a prerequisite to improving the quality of scientific understanding and obtaining support for the research. In particular, extended peer communities, especially the stakeholders affected by an environmental problem, need to be involved in science when cause-and-effect relationships are unclear and when research measurement and ethical aspects have a high level of uncertainty (Funtowicz and Ravtz 1993, Irwin 1995). The present debate about integrated approaches heightens the need to include lay expertise and to cease restricting the conduct of research to technical specialists. Including citizen expertise when reforming science bureaucracies is essential, because research that integrates the objectives of food production and environmental health will require input from various realms of knowledge. New kinds of organizations that aim to carry out research based on integrated approaches must be prepared to consider knowledge that has not been scientifically generated, deal with a plurality of knowledge forms rather than a unitary consensus, take into account stakeholders' concerns, and be extremely flexible. The IFS illustrates this type of institutional approach.

Institutional flexibility is required to enable diverse stakeholders to carry out a paradigm shift toward integrated approaches. Research organizations must be learning organizations that can not only conduct strategic research but also monitor and provide feedback on adaptive management projects for agroecosystems. In this respect, there is a notable lack of fit between conventional management institutions and ecosystems, in particular agroecosystems that require adaptive management, and some observers see this lack of fit as a " ... crisis of institutional learning ... " (Folke et al. 1998).

An important organizational feature needed to implement integrated approaches is a flexible hierarchy that enables decision makers to interact at different ecosystem levels. Researchers need to interact with the nonscientists who form part of extended learning communities. This organizational feature is missing in conventional agricultural science bureaucracies. An organizational type with this potential for flexibility and learning was identified in the mid-20th century as an "adhocracy" (Mintzberg and McHugh 1985), but it was not formally used to manage agricultural science until recently. An adhocracy is characterized by the production of complex outputs that demand sophisticated innovation by combinations of experts deployed in temporary teams to work on projects. In an adhocracy, coordination is achieved less by direct supervision, performance controls, and rules than by selective decentralization. The power to make decisions is decentralized in uneven ways, and devolves to the level or person most likely to have the expertise needed to deal with the issue at hand.

Three elements of organizational change in an adhocracy are well suited to the current need to promote organizational change in support of integrated research approaches in agricultural science. First, management usually allows patterns of working together to emerge in a self-organizing way. Second, strategies can be developed by unusual nodes in the organization and adopted by the collectivity. Third, management has to create a climate in which a wide variety of strategies can grow, watch what comes up, and tolerate the unexpected. This approach to change is consistent with the needs of research linked to the adaptive management of ecosystems.

Many of the organizational features of the adhocracy coincide with those identified with learning organizations. Senge (1990) mentions these characteristics: a willingness to take risks and experiment, decentralized decision making, systems for sharing learning and putting it into practice, frequent use of cross-functional work teams, opportunities to learn from experience on a daily basis, a culture of feedback and disclosure, and collective vision building. Finally, the learning organization is closely connected to its environment, which includes legislators, regulators, clients, competitors, and communities.

The disestablishment of science bureaucracies, which have been the home of agricultural research over the past 100–150 years, is occurring at breakneck speed in both high- and low-income countries, largely as a result of public disenchantment with, and the subsequent loss of political support for, the reductionist type of agriculture described earlier. The design of new organizational forms for carrying out alternative integrated approaches to research is also under way in a highly decentralized and self-organizing process. Participatory research approaches provide alternative ways to democratize science. Social and institutional issues of strategic importance to the future of ecosystems and human health care have only recently begun to emerge as a research topic (Folke et al. 1998). Although a systematic overview of this process of self-organizing change is lacking, its main features, which can be determined from the projects already in place, correspond to the principles embodied in flexible learning organizations.

Keystone properties of research that integrates food production and environmental health objectives

Emergent alternative approaches have in common an integrated approach, which treats agriculture as one element of human intervention in ecosystems. Although numerous and diverse, these integrated approaches manifest several common elements; in particular, they:

- integrate research and adaptive management of food production with ecosystem and human health by taking ecosystem and human health externalities into account in food production and marketing;
- recognize that agricultural science is not the exclusive domain of scientists and that internalizing environmental and human health externalities involves negotiating trade-offs that depend on value judgements by different stakeholders;
- conduct strategic long-term research that works with and for sustained ecological, economic, and sociocultural variability;
- assign priorities to strategic research based on an understanding of the dynamics of cause and effect in ecosystems (including agroecosystems) across hierarchical system levels;

- approach agriculture as an element in ecosystem management, from an area perspective, and not exclusively as commodity-based or as factor research;
- incorporate adaptive management into research so that these domains interact to provide rapid feedback to the relevant learning community responsible for food production and for ecosystem and human health;
- carry out adaptive management experiments that include interventions of different types (e.g., policy, technology, collective action) at various scales to achieve understanding when scale and uncertainty make positivistic experimentation difficult;
- support the development of information management decision support and other ways of being responsive to and supportive of ecosystem variability as premium strategic research products (e.g., good monitoring and diagnostic tools able to detect change);
- ensure that their scientific method and research organization are diverse and responsive to variability and built on the principles of learning organizations, so that both provide capacity for enhancing the resilience of ecosystems;
- organize decision-making hierarchies that involve scientists, managers, and other kinds of stakeholders in research and adaptive management that match the ecological hierarchy of scales affected by the pertinent stakeholder objectives and ecosystem management issues;
- incorporate into agricultural research explicit considerations of the preferences of competing interest groups in different kinds of trade-offs between productivity and environmental health;
- foster learning communities with research and adaptive management functions, ensure interaction between research and management expertise, and break down barriers between different kinds of knowledge (e.g., expert and layman); and organize learning communities to work with multiple stakeholders in areas such as negotiation platforms, conflict resolution, facilitation, participatory research, and learning to make the value judgements required to arrive at acceptable trade-offs among competing goals for the same resources.

CONCLUSION

A powerful critique of mainstream agricultural science is gaining currency based on the broadly perceived anomaly of cheap, plentiful, but purportedly unhealthy food produced by environmentally destructive farming practices in combination with persistent global poverty and inequity in access to food. Farmers in low-income countries as well as producers and consumers in high-income countries are demonstrating in various ways their desire for a different approach that balances the need for food with environmental health.

Mainstream agricultural science has traditionally treated food and fiber production as a separate domain of enquiry from the management of natural resources and the environment; this attitude facilitated increases in productivity that ignored the negative effects of agriculture on the environment and human health. A long-term strategic research agenda for the public sector is being defined that is new and relevant to integrated natural resource management and sustainable agricultural production. Such an agenda must be understood as a way of managing natural resources for the production of food and the environmental services essential to human well-being. This paper has identified a number of keystone properties of emergent approaches that suggest the future directions needed for change and innovation in agricultural science.

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