The Sciences and Art of Adaptive Management

Innovating for Sustainable Agriculture and Natural Resource Management

Keith M. Moore, Editor

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Soil and Water Conservation Society
Ankeny, Iowa

Soil and Water Conservation Society
945 SW Ankeny Road, Ankeny, IA 50023
www.swcs.org

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The Soil and Water Conservation Society is a nonprofit scientific and professional organization that fosters the science and art of natural resource management to achieve sustainability. The society's members promote and practice an ethic that recognizes the interdependence of people and their environment.

Table of Contents

Preface

Keith M. Moore

Small farmers globally are grappling with the linked problems of poverty and environmental degradation. To address the multiple, complex factors shaping these conditions, this book presents an evolving, adaptive management approach to sustainable agriculture and natural resource systems. The goal is to provide development practitioners with the knowledge, understanding, and tools to improve the capacity of smallholders to better use and manage their assets. The principal objective is to empower natural resource managers at all levels through a participatory approach. In this way, smallholders themselves can learn to adapt their own practices for sustainable, food-secure livelihoods and environmental conservation. The book also aims to encourage policy maker and donor support for stakeholder innovation and adaptive management practices.

Adaptive management is a structured process of learning by doing. It is based on a flexible framework that allows managers to adapt their practices as the relationship between people and the environment changes. Scientific methods and disciplinary knowledge help to structure this experiential learning and to facilitate informed decision making; however, this process involves some degree of uncertainty. Adaptive management implies that current actions are based on the best available knowledge, but these trial-and-error actions involve risk. Thus, the actions and system responses must be monitored constantly to respond to new opportunities and risks. There is no "best way" or silver bullet. Rather, adaptive management presents a set of guiding principles that can be adapted to changing circumstances to improve system resilience and stakeholder livelihoods.

Effective adaptive management operates within dynamic networks of multiple agents—human, animal, vegetable, mineral, microorganic—each responding to others' actions in an emerging environment. The competition and cooperation among these agents constitute complex adaptive systems that continually reorganize themselves. To improve decision making for effective complex adaptive system management, five landscape systems—field, farm enterprise, community/watershed, ecosystem, and policy/markets—are used to differentiate networks of agents temporally and spatially. Each system requires a distinct set of expertise. Combining multiple disciplines and the tools they employ allows managers to move beyond a simple understanding of the immediate drivers of poverty and environmental degradation. Recognition of adaptive and nonlinear relationships allows managers to see opportunities for innovative practices that can reinforce sustainable development or reverse downward spirals. Improved technologies in themselves are not sufficient. The objective is to provide development practitioners with the knowledge to coach all resource managers to adapt those improved technologies for use in strategies to manage constantly evolving challenges and opportunities.

This approach is new in that it facilitates innovation and adaptation by integrating both scientific and local knowledge. Despite the introduction of Green Revolution technologies, smallholders still face poverty, while natural resource managers face new and growing environmental degradation. A second Green Revolution is needed. To sustainably achieve this revolution, small farmers, research scientists, development practitioners, and donors must work as a team. No one person, discipline, or administrative agent can master it all. Resource managers are involved in complicated systems that constantly evolve in response to both management decisions and external conditions. To manage these systems in a sustainable manner, thereby improving livelihoods and preserving and/or restoring essential ecosystem services, complex adaptive management techniques must be employed.

Part I introduces the Sustainable Agriculture and Natural Resource Management (SANREM) landscape systems, describes the principles for adaptive management for complex adaptive systems, and provides a historically based application of the approach.

Part II of the book includes a chapter on each of the landscape systems as well as chapters on governance and communication for innovation and adaptive management. Each of these chapters describes critical system components and their cause-effect relations and interactions, highlights the timeframe(s) for component processes, identifies links between system processes across temporal and spatial scales, and demonstrates how to act strategically to promote innovation.

Concrete examples illustrate system properties and principles of adaptive management, decision-making criteria, and cross-scale impacts and unintended consequences.

Each chapter operates at two levels. The first level provides insights and a conceptual framework for agricultural and natural resource management science, explains how properties and processes are relevant to sustainable improvements in livelihoods and environmental services, and reveals linkages among systems that may facilitate or hinder successful development.

At the second level, each chapter equips development agents and donors with a toolkit of innovation principles and options for adaptive management, a portfolio of techniques for dissemination of technological and institutional improvements, and project designs that empower stakeholders to be innovative.

Part III of the book presents a set of case studies that demonstrate the application of landscape system adaptive management principles. In particular, these chapters highlight the cross-scale interactions critical to reducing poverty and improving long-term sustainability through holistic, multisystem, and multiscale presentations of real cases: wetlands comanagement in Bangladesh; watershed management in Ecuador; and community-based natural resource management in Mali. These case studies show how the landscape systems adaptive management approach can lead to successful sustainable agriculture and natural resource systems.

Acknowledgements

This book has evolved from a collaborative effort originally stimulated by the Phase III Sustainable Agriculture and Natural Resource Management (SANREM) Collaborative Research Support Program (CRSP) systems coordinators (Paul Mueller, Peter Wyeth, Saied Mostaghimi, Andrew Manu, and Gerald Shively) and SANREM CRSP management entity (Theo Dillaha and Keith M. Moore). This group discussed and debated how agricultural sciences contribute to our combined potentials of adaptive management for sustainable agriculture and natural resource management. This work was initially supported by our first cognitive technical officer from USAID/EGAT/NRM/LRM, Chris Kosnik, and more recently our agreement officer's technical representative, Harry Rea.

This effort in collaborative adaptive management was truly a learning-by-doing experience. Not everyone was sure of where this complex adaptive collaborative effort would lead or even if it would succeed. However, the authors drafted and re-drafted their chapters and reviewed at least one other chapter. Often the newly revised chapters were substantially altered from their original form and content, and the persistence and dedication of these authors is to be commended. Together they have contributed to a greater understanding of the richness of their fields of study and the interrelationships among them.

Writing a book of this nature requires considerable support to the authors and to the editor. I would like to express my deep appreciation to SANREM CRSP Program Director Theo Dillaha for his active support and criticism throughout this process. I would also like to thank SANREM CRSP Administrative Principal Investigator S.K. De Datta, Program Coordination Assistant Jane Lee, and a series of research assistants, Jennifer Lamb, Heather Weeks, Sara Breakiron, and Latricia Easter. I would like to thank SANREM Communications Coordinator Deanne Estrada for her patience and care in editing, and sometimes re-editing, all chapters; and Tom Byers for his insights into the learning experience.

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Part I

Managing Adaptive Systems

Chapter 1
Landscape Systems Framework for Adaptive Management

Keith M. Moore

The Sustainable Agriculture and Natural Resource Management (SANREM) Collaborative Research Support Program landscape systems approach provides a holistic scientific framework. This framework is based on two fundamental assumptions. The first is that no single factor should be considered in isolation. Landscapes are the result of a combination of multiple interrelated factors, no one of which can be manipulated without affecting others. Second, system processes and changes in them routinely interact across the landscape, often in response to previous management decisions. Scientists describe these landscapes as complex adaptive systems (CAS).

Guiding systemic processes to obtain beneficial outcomes involves continual decision-making adjustments in response to multiple factors and their interactions. This is adaptive management. Effective development action implies that learning from previous decisions and their consequences is an integral part of managing landscapes. The SANREM nested landscapes systems approach to adaptive management is designed to facilitate understanding of these interactions and interdependencies as an aid in decision making. The framework shows how to use scientific expertise to formulate strategic and tactical choices, identify practical points of intervention, and provide a methodology for monitoring consequent human and biophysical behaviors.

Systems Approach

Scientists and resource managers use the systems approach to better understand the implications of management decisions. Systems help us trace the interconnections between our actions and the intended and/or unintended consequences of those actions. In general, a system can be described as an interconnected whole consisting of components that function in a generally consistent way. Systems have boundaries and can be distinguished from their environment. At the same time, they are open to influences from that environment.

While system components are largely determined by their role and function within a particular set of relationships, they also act as semiautonomous agents. These system agents can be biotic, abiotic, sentient, or unconscious. They may act on their own volition or in response to what other agents are doing and/or processes unfolding at other system levels. The apparent order generated by these actions and reactions is emergent, resulting from an ongoing process of agent learning and adaptation.

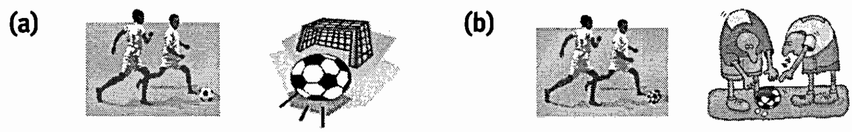

Figure 1. (a) Resilient system. (b) Nonresilient system.

The core concept of systems thinking is that changes in one system component or agent affect other system agents directly or indirectly. These effects in turn serve to maintain or reproduce the system or, if imbalances occur, change or transform that system. Reproduction or transformation of a system depends on that system's resilience, that is, its capacity to absorb shocks without transforming into a different or modified system where a new set of factors determines routine outcomes (Walker et al. 2002). Consider a soccer match with an inflated-rubber versus a newspaper-stuffed soccer ball as two examples of a simple system (figure 1). At the beginning of the match, both balls (abiotic system agents) can be kicked and will bounce and roll for a satisfying game (as exemplified by the resilient system in figure 1[a]). However, as the match progresses, the pace and flow of the game with the newspaper-stuffed ball will have declined noticeably as the ball flattens out and bounces and rolls only irregularly if at all (as in figure 1[b]). Some systems cycle through their processes in faster or slower fashion, as will be seen below.

A system's operation involves receiving and processing inputs through relationships among system agents, creating outputs that in turn generate new inputs. Following the soccer example above, a defensive player kicking the ball into the opponent team's half provides an input for his team's striker. System inputs, processes, and outputs can be informational or tangible, operating on various temporal and spatial scales. For example, the signal of the striker that he is open for a pass is an informational output, whereas receiving the ball from a teammate would be a tangible input. The trainer's signal to increase or slow the pace of the game involves a longer timeframe. Cumulatively, systems cycle through phases of growth and destruction. We can think of the offense mounting an attack as a series of passes and advances culminating in a strike on goal. Successful or unsuccessful, the team regroups for another strike or shifts to the defense. As the players do so, processes (game strategies and tactics) are modified and outputs (scores and penalties) achieved.

The fact that systems are open to their environments means a degree of risk and uncertainty in all actions. This can clearly be seen when two evenly matched soccer teams face off for 90 minutes. Different processes and cross-scale interactions may lead to reproduction or transformation of system agents or to changes in the resilience of the system itself. For example, leaving both our soccer balls out in the rain will lead to changes in comparative resilience even without use. Consequently, system agents are constantly adapting and evolving as they encounter new circumstances.

Holling and Gunderson (2002, p. 30) summarize an example of system adaptation from the forestry sector in this way:

> For long periods in a regrowing forest, the slow variable (trees) controls the faster (budworm or fire) and intermediate-speed variables (foliage or fuel) until a stability domain shrinks to the point where the fast variables for a brief time can assume control of behavior and trigger a release of the accumulated capital.

Holling (1986) provided a model characterizing the cyclical nature of these faster and slower processes applicable to both ecosystems and socioeconomic systems (Berkes et al. 2003). The

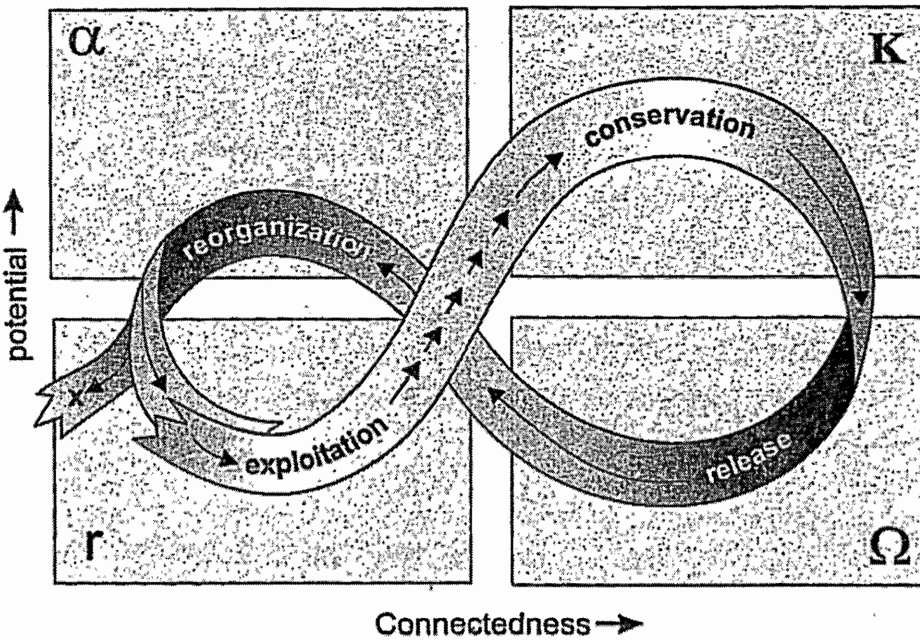

Figure 2. Holling's adaptive renewal cycle (from Holling and Gunderson 2002).

adaptive renewal cycle consists of four phases: exploitation, conservation, release, and reorganization (figure 2). Starting with the alpha phase, a reorganization of socioecological resources leads into a phase of exploitation or growth, which ultimately consolidates at what has been called the climax in classical ecology or empire in historical sciences. Depending on the time scale of this conservation stage, sooner or later a disturbance releases the pent-up energy and resources in a rapid process. Given adequate time for conservation, customary slash-and-burn agriculturalists learned to take advantage of this adaptive renewal cycle in tropical forests. Opening up forest land releases the pent-up energy stored during the period of conservation. This energy is reorganized and exploited as a productive agricultural system for a few years before it is exhausted. New opportunities may be realized as renewal or reorganization begins. At this phase, innovations have the greatest potential for success. Once the productive resources have been fully exploited, the land must be left to rest for the conservation stage before a new cycle of exploitation may begin.

Building a functional understanding of CAS conditions and dynamics can be facilitated by adaptive management. Two sets of system processes should be considered. During routine circumstances of exploitation and conservation, adaptive management applies a repertoire of practices adapted to local climatic and market conditions. Given the changes in larger-scale systems (globalized markets, increasing human population pressures on the ecosystem), slash-and-burn management can no longer afford the long fallows necessary for the conservation stage. Under transforming conditions (release and reorganization), adaptive management utilizes the opportunities for new learning that may result in innovative adaptations to strengthen the resilience of the natural resource base. Poor management such as frequent clearing of forest land will lead to a degradation of the tropical forest system, often yielding a nonproductive resource that may take either extensive external inputs for revitalization or decades of rest. Also, fostering technological change in agriculture not only requires understanding the principles of system dynamics; it must also be combined with open, participatory communication among multiple stakeholders for innovations to be adopted and system resilience assured. This learning generates knowledge that can be invested at appropriate system levels in new cycles of management, learning, adaptation, and innovation.

Organizing the Complexity of Landscape Systems

Because resources and organisms are not evenly distributed across the landscape, appropriate technologies and practices, as well as optimal technology communication strategies, must vary accordingly. These decision-making contexts are differentiated by faster and slower processes of biophysical phenomena, flora, and fauna, as well as various priorities, incentives, disciplinary perspectives, and types of stakeholders that make up complex adaptive systems (Holling 1974, 1992). For this reason, the SANREM landscape systems framework (figure 3) was designed in a nested formation to account for and effectively manage the diversity and lumpiness of CAS. The landscape systems composing this nested framework range from field systems nested in farm enterprise systems, which in turn are nested in community-watershed, ecosystem, and policy-market systems. While the designation of these systems is arbitrary, their identification is relatively straightforward. Each corresponds to commonly accepted (i.e., socially constructed) systems occupied by different stakeholders and used to differentiate among operational scales by agricultural, natural resource management, and environmental decision makers. Precise definition requires specific knowledge of historical and ecological circumstances.

The science behind the landscape systems framework has already produced substantial bodies of literature addressing these multiple system levels. Two scientific schools have made major con-

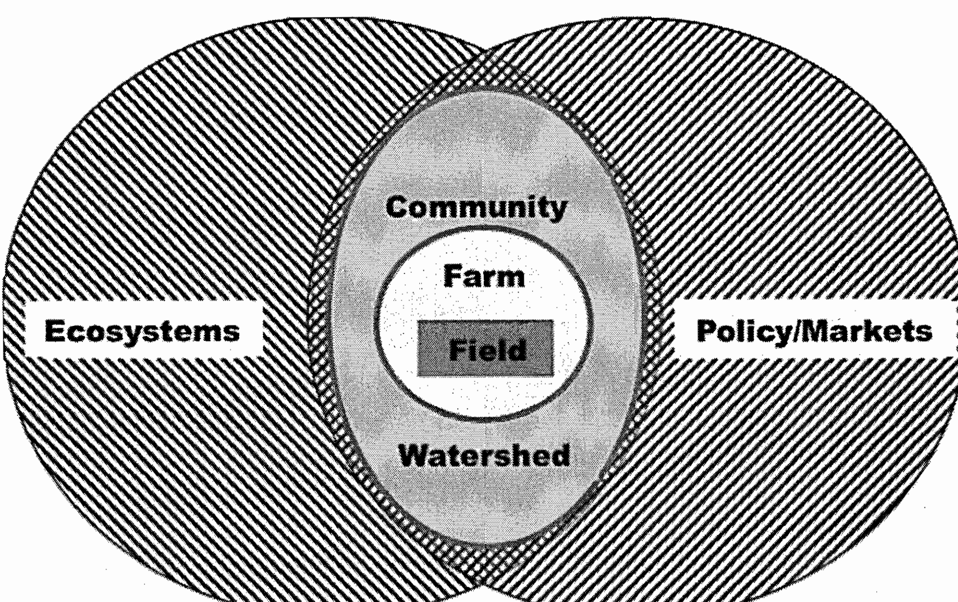

Figure 3. SANREM landscape systems framework.

tributions to various elements of this adaptive management approach: farming systems research and extension; and ecological systems analysis or sustainability science. The first is production-oriented, emphasizing the transformation of natural resources into food and fiber for human health and livelihoods (Collinson 2000). The other is conservation-oriented, stressing the preservation of ecosystems in their natural state for long-term sustainability (Maltby et al. 1999). Building on smaller scale processes and components in cropping systems studied by conventional agronomists, farming systems analysis of crop production, livestock husbandry, and forestry has integrated a wide range of scientific disciplines, including the social sciences. Ecosystems analysis has also been holistic, focusing on interactions among plant and animal species and their geophysical environment, and emphasizing technical mastery to understand and enhance the biophysical dimensions of the natural environment. Both disciplines have come to recognize that the immense complexity of system interdependencies requires the inclusion of social, economic, and institutional factors if sustainable solutions are to be achieved (Röling and Jiggins 1998; Kinzig et al. 2000; Hagmann et al. 2002; Sayer and Campbell 2004).

Recent work indicates a cross-fertilization of approaches between the applied, production-oriented farming systems and the conservation-oriented sustainability sciences (Colfer 2005). Applied scientists within the farming systems approach have expanded their scales of reference to account for the effects of slower processes/cycles resulting from earlier interventions (Harwood and Kassam 2003). This includes recognition of the role that national policies play in shaping local landscape decisions and incentive systems. Environmental scientists have recognized the role and divergent interests of local stakeholders in ecological management and are urging increased investments in interdisciplinary environmental research emphasizing the new sustainability science (Pirot et al. 2000). The mix resulting from these approaches has been called CAS by both camps. CAS is seen as a holistic framework for understanding multiple interacting systems within and across various scales (Sayer and Campbell 2004).

Overview of Nested Landscape Systems

This section presents the nested landscape systems for sustainable agriculture and natural resource management. While system boundaries are fuzzy, identifiable combinations of intrinsic capability and external input can be distinguished. These system levels provide learning contexts where resource managers can practice adaptive management by applying disciplinary, administrative, commercial, and local knowledge. The key stakeholders, the reception and processing of inputs, production of outputs, their export or reinvestment in the system, its predominant processes, timeframes, and the sources of knowledge needed to understand functional components are briefly outlined.

Field Systems

Field systems represent the building blocks of the landscape systems framework, an elemental unit of the landscape mosaic. This level consists of the biotic (plants, animals, microorganisms) and the abiotic (soil, water, sunlight, moisture, temperature). These components interact to form a system of matter and energy transfers. The system can be manifest as a field of one or more crops, a pasture, a forest plot, a pond, or a stream with more or less uniform management practices. It is thus the fundamental management unit. The human component often appears as separate from the field system, but the two are inextricably linked. Stakeholders—men and women farmers, herders, fishers—are the primary decision makers, determining how and when fields are plowed, timber and fruit are harvested, and what components such as fertilizer and straw are added to the soil.

The basic processes are controlled by the biological, chemical, and physical properties of the soil or water system and the extent to which it provides nutrients and a suitable growing environment for plants and animals. Climatic, material, and labor inputs favor certain processes and outcomes over others, leading to particular combinations of material and energy gains or losses. Soil organic matter may be enhanced or depleted. Moisture may be used, stored for future use, or lost through evaporation and runoff. Bodies of water may become rich or poor in oxygen or nutrients. These processes lead to the proliferation of certain species of vegetation and fauna while others are diminished or even eliminated. The pattern of vegetative growth will shape the potential for livestock and wildlife to utilize the field. Grazing and browsing, in turn, further shape soil, moisture, and vegetative composition. Stakeholder management tends to focus on the direct benefits to be reaped from the field system: fruit, grain, pasture, visual landscapes.

For the most part, field system productivity is measured over seasonal or annual cycles, but it may extend to decades. The regeneration or degradation of soil can fluctuate over time depending on external inputs such as organic matter, nutrients, and water. Regeneration or degradation may take decades, depending in part on the rate of harvesting or grazing. The regeneration rates for trees and wetlands may also require decades. Productivity can be enhanced through improved use of a field's natural resources or by strategic application of external inputs. The disciplines most likely to provide critical knowledge for field systems management include agronomy, ecology, agricultural engineering, animal science, entomology, plant pathology, forestry, fisheries, wildlife management, biochemistry, and agricultural economics. Mueller et al. (chapter 2) provide a detailed introduction to field system processes and characteristics.

Farm Enterprise Systems

Farm enterprise systems provide the fundamental institutional building blocks in complex adaptive systems. They define the primary level of social relations on which stakeholder livelihoods are built. This level consists of households and businesses structured by the norms, roles, and values of the local culture and economy. The farm enterprise system determines primary access to resources and the means by which those resources may be transformed into use and exchange values. Decision making focuses on tradeoffs between field systems alternatives and exchangeable resources; it is shaped by various arrangements of family, gender, and class power relations.

The basic processes are founded on the production and consumption of resources obtained at the field system level or in the market. Complicated strategies may develop that integrate complementary and sometimes competing crop, livestock, forest, aquaculture, and nonfarm activities. For small stakeholders, there is a quasi-identity of the household as a production and consumption unit. However, individual members may also operate independent enterprises or sell their labor. This leads to a growing separation of production and consumption to the extent that the enterprise systems are differentiated in function, particularly in the industrial and services sectors.

Productivity is measured in two ways over seasonal, annual, or family-life cycles: through exchangeable outputs transformed or harvested from the field system; and through livelihood reproduction as measured by the health and wellbeing of individual family members. Farm enterprise system units, to the extent that they are linked to household consumption units, often pass through stages of growth, high production, and decline over a family-life cycle: a young married couple, family establishment, adult children contributing labor, and finally, old age without children. Prosperity or poverty of the farm enterprise unit is a function of access to resources or lack thereof, capacity of the farm household to mobilize labor to transform inputs into exchangeable goods or services, capacity to adapt to changing relationships with other systems, and relations of exchange within the community, market, and state. The disciplines most likely to provide critical knowledge for working with this primary stakeholder system would be sociology, anthropology, agricultural economics, nutrition, health, industrial relations, and business. Wyeth (chapter 3) describes farm household system components and their dynamic interdependencies.

Community Watershed Systems

Watershed systems represent an aggregation of field systems, including fields, ponds, streams, woodlands, hills, and valleys on one hand and an aggregation of farm enterprise systems, including neighborhoods, communities, and local administrative units on the other. Watershed systems are delimited by hydrologic boundaries. Communities are primarily identified by common location and other cultural characteristics. These boundaries rarely coincide, and their poor alignment with administrative boundaries poses critical problems for coherent management. Multiple stakeholders are involved in decision making and share responsibilities, but not all benefit equally from the consequences of their actions. Uplanders are typically the providers of ecosystem services or the polluters, while people downstream experience the consequences of their actions. Consequently, incentives and consequences for resource conservation by responsible parties upstream are often not directly linked to benefits. Collective decision making may range from unilateral to highly participatory, often involving higher levels of governance and other extra-local stakeholders.

The basic processes of watershed systems are driven by surface and subsurface hydrology. Watershed systems manifest nonlinear relationships as the combined effects of spatially and temporally varying land management practices and weather continually affect hydrology. Energy and matter may be accumulated, deposited, or exported from the system as eroded soil and nutrients. Productivity is measured primarily in terms of stream flow, economic output, and loss of sediment and nutrients from the field and farm enterprise systems that make up the watershed system. Timeframes can be measured over seasons, years, or decades, but of typical interest is rainfall and subsequent runoff, when rapid changes may occur within hours. Landscape degradation through deforestation, overgrazing, soil erosion, and pesticide accumulation can be analyzed most effectively at the watershed level. Walker and Mostaghimi (chapter 4) present an analytic framework and tools for watershed management.

Effective social organization involving consensus building/conflict resolution capacities is a precondition for optimum planning, decision making, and provision of watershed services such as flood control, provision of water supplies, water-quality protection, and maintenance of aquatic habitats. Community prosperity is indicated by the growth of commercial and service enterprises as well as the provision of primary health care facilities and schools. Flora and Thiboumery (chapter 5) introduce etiquette for building the coalitions to address these issues. The disciplines most likely to provide critical knowledge for adaptive management of this system would be agricultural and civil engineering, hydrology, sociology, economics, political science, agronomy, forestry, fisheries, wildlife management, and meteorology.

Ecosystems

Ecosystems form the overarching biophysical and landscape environment, both biotic and abiotic, structured in mosaics of ecologies, either natural or built, scattered across mountains, forests, deserts, plains, valleys, rivers, lakes, wetlands, estuaries, seas, and oceans. These ecologies, the habitats of flora and fauna around the globe, include the built environments of human communities. Other than solar energy and geologic processes, there are no external inputs. Ecosystem processes are rarely congruent with spatial governance boundaries or timeframes; consequently, ecosystem management relies on consensus building among diverse stakeholders. The ecosystem does, however, interact at multiple scales with stakeholder governance. Stakeholders are organized into farm enterprise, community, watershed, and other natural resource management systems.

The basic processes of the ecosystem involve the interactions of organisms and the cycling of energy and matter between and within other systems. Biological diversity and structural complexity support the dynamic character of ecosystem processes such as decomposition, and hydrologic and biogeochemical cycles. These processes are variously interconnected and operate over a wide range of spatial and temporal scales. Ecosystem activities are shaped by industrial, commercial, transportation, and residential land uses.

The productivity of the ecosystem is measured in terms of goods such as food, fiber, and medicines; services such as biodiversity and aesthetics; and maintaining hydrologic cycles, clean water and air, soil generation, and storing and cycling of essential nutrients. This productivity is provided through a shifting pattern of landscape mosaics altered by natural—including human—processes in a patchwork evolving at faster rates (days and weeks) and slower rates (decades and centuries). The prosperity or poverty of a particular ecosystem is in large part a function of the surrounding patches. The disciplines most likely to provide critical knowledge for working with ecosystems include ecology, geology, biology, geography, climatology, forestry, and range science. Haas et al. (chapter 6) present an overview of ecosystem processes that organize the dynamic interactions between system elements.

Policy and Market Systems

Policy systems provide the institutional framework for interaction within complex adaptive systems involving civil society, markets, and the state. Policy-market systems are ultimately shaped by the national or local government, which defines the conditions under which markets and communities operate, as well as the rules and standards by which access to and use of resources are legally determined and monitored. Although state-level decision making may directly address resource allocation, most often it does so indirectly by framing the conditions under which resources, goods, and services are exchanged and resource property rights determined. Civil society, including communities of place, interest groups, and nongovernmental organizations, serves as a buffer between the formal rules of the state and the market and farm enterprise systems.

The basic processes are founded on rules and norms for group interaction and relationships among systems. Existing relationships to natural resources often determine the relative power of various groups of stakeholders, who in turn consume them, negotiate further to improve them, and make adaptations for future success. Communities and nations may vary according to their resource assets, including natural capital and socially built capital—cultural, human, political, financial, and structural. These assets can be transformed through the state or market into improved community wellbeing or impoverishment.

Productivity within policy-market systems is measured in terms of societal wellbeing such as gross domestic product per capita, democracy, life expectancy, gender equity, and proportion of the population living in poverty; and ecological wellbeing such as biodiversity, air and water quality, and scenic beauty. For the most part, the processes generating these effects change slowly, but they can reach thresholds where warfare or rapid transformations in the local or global economy can bring about cataclysm within a short time. The disciplines most likely to provide critical knowledge for working with governance-policy systems include political science, economics, and sociology. Shively and Birur (chapter 7) describe the role of policy and provide a framework for market policy analysis.

Innovation Systems

Innovation systems are generated at the local level through a purposive organization of the interaction between biophysical resources and socio-economic capabilities. In large measure innovation involves structured learning and communication within landscape systems. It is the essence of social learning.

Adaptive behavior for innovation is by its nature collaborative. It involves not only primary producers but also others along the commodity chain, including regulators and downstream users in addition to other public and private actors in the community. Collaboration needs leadership in the form of individuals who facilitate linkages among different sectors and groups in the landscape.

The social learning is based on a variety of mechanisms for connecting these multiple actors and facilitating their communication. Networks foster communication among those with common interests so that they can share knowledge, perspectives, ideas, and techniques. Platforms provide forums for actors to focus their discussion, negotiate solutions, and take decisions in common. Buck and Scherr (chapter 8) highlight the role of innovation in adaptive management and describe a wide range of tools fostering the growth of landscape system innovation.

Managing for Success: A Case Study

The following section presents an application of the SANREM landscape systems framework and its adaptive management. This brief historical account describes events at various system levels and traces their cross-scale interactions. It by no means describes more than a small fraction of the system processes and interactions that actually occurred.

The recent history of Indonesia provides excellent examples of the interaction between complex adaptive systems and adaptive management. In the past 40 years, the Indonesian state has had considerable success in maintaining relatively steady economic growth and reducing absolute poverty (Booth 1992; Hill 2000; Lewis 2007; tables 1 and 2). This retrospective highlights the conscious and unconscious social learning that contributed to the achievement of these goals. It also showcases unintended consequences of system processes and lessons yet to be learned.

The 1965 coup to overthrow President Sukarno was a moment of chaos and near societal collapse that threw the nation's policy and governance system into disarray. While these crises were immediately driven by corruption and mismanagement, at their core was the country's inability to feed itself.

Table 1. Economic growth in Indonesia, 1961-2005.

	1961-1965	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005
5-year average economic growth rate	2.02	6.34	7.84	7.92	5.66	7.16	7.86	0.98	4.72

Source: Five-year averages are based on World Bank estimates (code = 29921) at http://unstats.un.org/unsd/cdb/.
Note: On May 20, 2002, Timor-Leste became an independent country. Data for Indonesia include Timor-Leste through 1999 unless otherwise noted.

Table 2. Poverty trends in Indonesia, 1970-1996.

Year	Percentage of population below the poverty line	Population below the poverty line (in millions)
1970	50.6%	60.0
1984	21.6%	35.0
1996	11.3%	22.5

Source: Booth 2000. Data are based on Biro Pusat Statistik standard poverty-line measures.

Through the 20th century, successive regimes—both colonial and national—subsidized rice production and consumption through input subsidies, price supports, and rice imports (Young 2003). Rice has been the critical factor conditioning Indonesian poverty and consequently the stability of the state and the society. At the village and watershed levels, food security meant good harvests from irrigated rice paddies or *sawah* (Geertz 1963; Henley 2005). Because rice is synonymous with food security at all levels, its production clearly demonstrates the interactions among nested landscape systems.

Policy, Markets, and Recovery

In response to the 1965 coup and subsequent crises, the new regime, led by Soeharto, reorganized the nation's policy and market systems. A newly installed economic management team designed and implemented a three-pronged development program to restore societal stability and economic progress (Prawiro 1998). The first element of the program was a policy of tight monetary control, which reduced triple-digit inflation to single digits in three years. The second element focused on generating economic growth through free-market policies. Despite diehard monetarist and market liberal perspectives, the technocrats designing these changes were not convinced by the individualism of the free-market system associated with the West. They argued instead for an Indonesian way to market prosperity. Consequently, the third element of their program emphasized equity as captured in the Indonesian phrase *gotong royong* (mutual self-help).

Implementation of this economic policy package reestablished control over inflation and sufficiently reorganized the Indonesian economy to set it into an extended period of growth. Signaling the importance of self-sufficiency in rice, the agricultural sector was targeted to lead the way. Government investments favored infrastructure development such as roads and warehouses, which facilitated transport of fertilizer and pesticides to the countryside and harvested grain to consumers. During the 1970s, newly opened oil fields provided foreign exchange to build buffer stocks of rice for consumption and to produce fertilizer within the country at subsidized costs. Irrigation was subsidized at more than 75%, fertilizer at 55%, and pesticides at 60% to 85% (Young 2003; Thiers 1997). Monetization of the rural economy was required if these inputs were to improve economic performance. Thus rural credit services were encouraged, and savings programs increased. Innovating in adaptive management fashion, government planners adjusted the fiscal calendar to the rice production cycle and its peak demand for liquidity. This improved financing capabilities for rice production and distribution as well as captured potentially inflationary excess cash in rural savings banks (Prawiro 1998).

Technology and Infrastructure for Agricultural Transformation

This intensification of rice production required dramatic changes in field, farm-household, and watershed systems. Indonesian farmers were encouraged by the price supports to expand production, but new technologies and practices developed in the 1960s and 1970s by national agricultural researchers and the International Rice Research Institute were needed to transform their production systems. To ensure that farmers effectively adopted these new inputs, a series of successive government programs beginning in the early 1970s established local cooperatives at the watershed level to deliver Green Revolution technologies such as high-yielding varieties, fertilizers, and pesticides supported by input credit programs. Extension agents introduced new techniques and technologies through a top-down transfer model in collaboration with the government-organized village and district cooperatives. These mass mobilization programs created and sustained an input supply system from the national to the local level.

Initially the credit programs jump-started the use of purchased inputs, but in the long run only a few farmers really benefited, and often local officials were accused of profiting unduly (Santoso 1993). Social differentiation was advancing in the countryside despite the national policy of *gotong royong*. Local supervision of these organizations was poor, and there was little accountability by the cooperatives to the farmers. Sometimes extension agents supplemented their incomes by becoming agents for input suppliers. Nevertheless, this incentive system worked quite well to increase productivity and farm incomes. It also created opportunities for surpluses to be captured along the commodity chain by nonfarm people.

Subsidized fertilizers and pesticides were being used by most farmers across Indonesia by the early 1980s. Farm households were being effectively integrated into the cash economy. Fertilizer consumption per arable hectare tripled between the early 1970s and the 1980s. The new technologies had been successfully introduced, assuring steady increases in Indonesian paddy rice production from the late 1960s through 2000 with only occasional reversals of the trend (table 3). Farm household welfare increased for both rich and poor, if for different reasons (UNDP 2001).

Unintended Consequences on a Small Scale

At the field system level, the recommended practices of improved water control, high-yielding varieties, use of fertilizers and pesticides, and better cultivation methods were increasing the productivity of paddy rice. Soil chemistry had been enriched by the addition of inorganic fertilizers, and the pest ecology had been suppressed. But beyond increased productivity, perhaps the most significant impact involved changing insect community dynamics and diminishing habitat diversity. A previously unremarkable insect, the brown planthopper (BPH), was evolving into a major insect pest, devouring rice plants. Infestations of BHP were devastating entire watersheds, severely reducing national production levels. In 1977, crops lost nationally to BPH would have been enough to feed two million people for a year (Settle et al. 1996). Increased application of pesticides appeared to be needed. As another step in adaptive management, scientists identified the pest and began screening improved varieties for resistant strains. Resistant varieties were identified and introduced through the district cooperatives. Farmers experiencing crop damage and reduced yields were pleased to accept resistant varieties. Infestations were diminished, and production continued to rise. Disaster was averted and field system resilience maintained.

Table 3. Paddy rice production in Indonesia, 1961-2006 (in kilotons).

	1961	1966	1971	1976	1981	1986	1991	1996	2001	2006
Paddy rice production	12,084	13,650	20,190	23,301	32,774	39,727	44,688	51,102	50,461	54,400

Source: FAO STAT (http://faostat.fao.org/site/340/DesktopDefault.aspx?PageID=340).

Nevertheless, the intensive use of subsidized insecticides and large-scale synchronous planting of rice paddies continued to disrupt reproductive processes in a wide range of species that had previously provided biological pest control. Under historical conditions of tropical flooded rice in Southeast Asia, natural enemies such as spiders and egg-laying bugs had kept BPH populations in check. Unfortunately for intensified rice production, pesticide spraying reduced natural enemies. Indeed, spraying seems to have stimulated pesticide-resistant variants of BPH, which flourished in an environment lacking predators. The consequence was increased populations of BPH in subsequent generations. Each successive spraying increased the size of the next generation. This phenomenon is called resurgence (Settle et al. 1996). Through the massive application of pesticides, BPH had become a chemically induced pest (Aquino and Heinrichs 1979, in Settle et al.)

Cross-Scale Action to Restore Resilience

The improved BPH-resistant rice varieties introduced in the late 1970s helped Indonesia achieve self-sufficiency in rice production in 1984 for the first time. But resurgence led to the buildup of BPH strains adapted to the new varieties, resulting in renewed BPH outbreaks in the 1985–1986 growing season. Once the International Rice Research Institute and Indonesian scientists fully verified the relationship between pesticide applications and BPH population dynamics, they met with President Soeharto. When the scientists explained the phenomenon of resurgence at the field level and how it was brought about by policies promoting and subsidizing pesticides, a program of adaptive management at the national level was immediately established by presidential decree. It banned the importation and use of 57 broad-spectrum pesticides for rice, removed pesticide purchase subsidies, and mandated that integrated pest management (IPM) be taught to all rice farmers in the country (Thiers 1997).

Adaptive Management and Its Local Infrastructure

The banning of pesticides reduced the volume applied in Indonesia from a high of more $160 million worth in the early 1980s to less than $16 million by the early 1990s. These figures had swung back to levels of $40 million and $30 million in 1997 and 2001, respectively. However, adaptive management was not so easily implemented at lower system levels. While pesticide sales began to decline after 1986, the introduction of IPM through the district cooperatives and the extension service failed to fully materialize. Indeed, extension agents not trained to monitor pests and use biological pest-control methods—and whose incomes depended in part on commissions from pesticide sales—could not be expected to effectively transmit the reduced pesticide application methods. Farmers whose production systems had been transformed were not prone to taking the perceived risk of reducing insecticide applications when confronted by crop-destroying insects.

In response to this system failure, the United Nations Food and Agriculture Organization (FAO) helped the Indonesian government's planning agency to introduce farmer field schools (FFS) in 1988 (Röling and van de Fliert 1998). Although an element of adaptive management at the policy level, the FFS program itself was designed to function at the field, farm, community, and watershed levels, building on the adaptive management capacities of farmers. In FFS, farmers are identified as equal learners with IPM facilitators who agree to interact over the course of a growing season to produce a healthy crop. Farmers are encouraged to observe and experiment with the ecology of their crops, learning about population dynamics, distinguishing pests from beneficial species, and estimating the relationship between crop damage and yield. Through this guided learning, farmers devise their own pest management solutions, and village organizations often are formed, strengthening farmers' capacities to participate effectively for coordinated management.

With FFS training and a significantly reduced supply of pesticides, BPH populations returned to manageable levels. However, the field system ecology continued to evolve. When the white rice stem borer appeared as the next significant pest, many farmers reverted to intensive pesticide applications (van de Fliert and Winarto 1996). The stem borer had not been the focus of study during the FFS, although it could be managed by natural parasites, and tiller damage seems to have had minor impact on productivity. Other outbreaks of pests, including black bug, whirle, rice slender bug, and the green leafhopper-vectored tungro virus, also appeared (M. Shepherd, personal communication, January 9, 2007). An outbreak of tungro virus was particularly virulent during the early 1990s (Chancellor et al. 1998). Uncertain how to respond, farmers sought more information. After the schools ended and the FFS trainers moved on, the only support available was from extension agents and pesticide vendors.

While the FFS approach was fundamentally based in systems thinking, the supporting system infrastructure had not been put in place. The introduction of FFS in Indonesia was conducted without involving the existing extension system, with its lack of IPM training and predisposition to the pesticide industry. This end-around approach had an immediate impact on farmer practices, but it left the established information and input-supply system in place. When the FAO finished launching the FFS program, the infrastructure supporting FFS groups largely disappeared. Ultimately, the pesticide industry moved in to fill the training void with its own programs (CropLife International 2005).

Growth and Development at the Ecosystem Level

Green Revolution technology transformed and diminished the ecological diversity of the *sawah* field system, reducing its resilience. Nevertheless, rice production continued to increase, mostly due to rises in productivity and only partially from increased cropping frequency (Hill 1998; FAO country profile; FAO STAT 2007). At the ecosystem level, these watershed system changes have interacted with a much larger-scale transformation. By 1990, Indonesia had lost more than 40 million hectares of forestland since the end of World War II, a decrease of more than 25% (Kartasubrata 1993). Forest losses were due to natural resource extraction such as logging and to population pressures. Population densities on Java led the government to promote a policy of transmigration. By the late 1980s, more than 5 million people had been resettled from Java to the outer islands and provided with new land to farm—2 to 3 hectares per family on average. Unofficial in-migrant expansion of farmland has followed along the logging roads, also increasing forest loss (Rudel 2005; Sunderlin and Resosudarmo 1999; Sandbukt 1995).

Slash-and-burn agriculture had long been a customary land-management practice in Indonesia, conducted on a limited scale that recycled patches of trees through full high-forest regeneration with little effect on overall forest cover. In-migrant colonies on the outer islands short-circuited this regenerative process and instigated a new one. Permanent removal of forest cover contributed to both watershed system degradation through soil erosion and transformation of much of the forest ecosystem to grasslands of *Imperata cylindrica*, an invasive broad-leafed grass. Secondary forest regrowth has been prevented for the most part by permanent agriculture without a fallow period, though in some locations rubber trees were introduced and have sustained some forest cover.

Failure of Policy Adaptation and System Transformation

While all other Southeast Asian countries curtailed land colonization policies after 1990, Indonesia continued on a major scale. Driven by stagnating rice productivity increases, the government determined that the supply of rice for the growing population would have to be achieved by expanding the area under production, particularly irrigated production. The policy response was to implement the Mega Rice Project in the province of Central Kalimantan. This project involved transforming one million hectares of peat swamp into an irrigated rice bowl and transmigrating poor farmers from Java (Young 2003).

The peat swamps of Central Kalimantan have varied between being a major carbon sink—a reservoir removing carbon dioxide from the atmosphere—and a major carbon source over their 26,000-year history (Page et al. 2004). With the Mega Rice Project's land-use practices of installing irrigation canals, logging over the lowland forest, and burning the remaining debris, the area experienced a phase of rapid release, an ecological event of global magnitude. In just three years, the canals drained the swamp, allowing the peat to dry so that it would easily ignite. In drought conditions driven by El Niño Southern Oscillation in 1997, fires lit for land clearing quickly spread to adjacent forest areas, destroying orangutan habitat and burning 730,000 hectares—more than 20%—of the peat swamp forest of south Central Kalimantan. These fires released as much as 40% of the amount of carbon dioxide produced globally in a typical year by emissions from burning fossil fuels. They also created a noxious smog that hung over 15 million square kilometers of Southeast Asia for more than two months (Boehm and Siegert 2001; Page et al. 2002).

Humans have inhabited the forests of Kalimantan for at least 35,000 years (Alcorn et al. 2003). In recent centuries, the currently resident Dayak population developed systems for managing its biologically diverse forest resources. The low population densities and varying degrees of shifting agriculture, hunting, fishing, and gathering allowed for the maintenance of a symbiotic relationship with the rich environment. The Indonesian state, however, viewed these territorial resources as national wealth to be used for development of the entire nation. Hence the Mega Rice Project and transmigration policy to enhance economic growth and increase social equity by providing "manufactured" *sawah* to landless farm households from the densely populated islands of Java and Bali. Fire, historically used to temporarily transform small forest patches in slash-and-burn systems, became the chief tool in the permanent transformation of the ecosystems at the core of Dayak livelihood and culture. Consequently, the introduction of half a million Javanese and Madurese into native Dayaks' watershed systems led to interethnic conflict in 2001 (Alcorn et al. 2003; Rudel 2005).

Adaptive Innovation at Field and Watershed Levels

At the watershed, farm household, and field levels, the local populations of Kalimantan are learning to cope with their transformed ecosystems, though rice production in the drained peat swamps never got going because the soil was too acidic for cultivation. Reorganization and adaptive innovation have taken various paths. Some villages have attempted to reverse the degradation of the swamplands and restore their watershed by building dams across the irrigation canals to raise the water table. Where *I. cylindrica* established itself in dry-land ecosystems transformed from forestlands, some farmers are claiming the grasslands for agroforestry by using herbicides followed by the planting of cacao trees, which create a canopy to shade out the invasive grass (Ruf 2001).

Complex Adaptive Systems in Indonesia: A Recap

The rice self-sufficiency policy stimulated the economy through subsidized inputs and institutional structures that transformed the functioning of community, watershed, farm household, and field systems with apparently successful results. System dynamics at the field level, however, adapted to the new inputs and created production problems that ultimately led back to changes in economic policy. Resulting changes in pesticide importation and subsidy policies and FFS training of farmers reduced both the supply and demand for pesticides. Once highly productive ecosystems were suffering not only from a lack of natural predators due to pesticide applications but also from weakened nutrient cycles in which natural fertility systems were depleted. Into these transformed ecosystems were entering a series of agents, including chemical fertilizers to compensate for declining nutrient levels resulting from short-circuited natural cycles. This has fostered an externally dependent resilience for the field system. At the community and watershed levels, FFS supported the adaptive learning of farmers but ultimately did not modify input market functions. The rice self-sufficiency policy had implications for the ecosystems of the outer islands as well. To expand rice production, new lands were converted, reducing overall productivity per hectare. The quick release of the fire stage appears to be leading back to a slower phase of reorganization and exploitation.

Implications for Decision Makers

Managing CAS simultaneously for food, fiber, income, and conservation of the natural resource base is challenging. The Indonesian model for assuring sustainable livelihoods for a growing national population emphasized improving the quality of one system component, increasing rice production, while maintaining a balance in other factors. If any lesson can be drawn from Indonesia's experience, it is that one should expect the unexpected and prepare for it by treating all policies and practices as experimental.

Making a decision about what factor to change presumes knowledge about the interrelationship among all factors. To be manageable, this requires some form of simplification. One approach is to frame the problem in terms of a single ecosystem for learning, management, and innovation. This was the approach of the centralized planners in Jakarta using largely macroeconomic policy tools. However, such a top-down approach obscured alternative system drivers such as ecological dynamics, local institutions, and power relations at the community, farm household, and field levels. Controlling in the first instance for the system level (field, farm enterprise, community-watershed, ecosystem, or policy-market), the SANREM landscape systems perspective allows development practitioners to understand the potentials of innovations and where they might be most usefully applied. However, cross-scale interactions should also be considered. At any given moment, decisions and actions are being taken at other system levels. Grassroots approaches must also take into account macrosystemic factors.

Managing CAS requires an ongoing process of learning on the part of decision-making agents. Adaptive management is a collaborative approach that incorporates multiple sources of feedback, often in the form of research, into stakeholder management decisions and actions. Specifically, it is the integration of design, management, and monitoring to systematically test decision-making assumptions to better manage the system through continual adaptation and learning (Salafsky et al. 2001). Testing assumptions involves using the best available knowledge to develop a conceptual model of the system of interest and to identify actions that the conceptual model suggests will achieve the desired outcomes.

Three core ideas form the theoretical foundations of the SANREM landscape systems approach to managing CAS. The first is that there are multiple ways of viewing and valuing these systems and their interactions. On one hand, there is the need to integrate various disciplinary perspectives. Specialized expertise alone does not provide a sense of the whole. When each discipline separately describes its subject using different premises, theories, and terminology, the integration of perspectives is inhibited. A methodology for bridging this sectarianism is necessary if construction of the systems approach is to succeed. Specialists are beginning to make connections across disciplines and systems. On the other hand, disciplinary expertise needs to be merged with local knowledge. The abstract nature of much science used to study CAS provides management principles but does not translate them into action at the local level. Dialog and negotiation are necessary. Such interaction needs to be built on respect for the insights and advantages of both expert and local knowledge. Improving relations between resource users and public infrastructure providers (Anderies et al. 2004) may well require new institutional structures, adapted roles for those who populate those structures, and often alternative behavioral and technical skill sets. Furthermore, interactions may also involve value conflicts, power relationships, and prioritization of interests. The quality of the local knowledge generated needs to provide a counterbalance to the influence of more powerful socioeconomic interests.

The second idea is that agricultural and natural resource development processes evolve on multiple scales and interact across those scales. The emergent trends may exhibit breaks and reversals. CAS approaches make comprehensible the interplay among sometimes unpredictable changes in rapid and slow processes across temporal and/or spatial scales. Such interactions can have significant impact when radical deviations from current trends occur, leading to the release of tightly bound resources as in the case of forest fires, pest infestations, and social or technical revolutions. Events viewed as random from one system's perspective may well be the unfolding of routine processes from another system. Indeed, disciplinary specialties and specific systems involve different types and ranges of scales. Geography emphasizes the importance of spatial scale, while history stresses temporal scales. Microbiology draws our attention to minute organisms, while climatology directs our focus to the horizon.

Interactions among these system levels are not reducible to a single scale of measurement. One may get a sense of this irreducibility through consideration of figure 3, where each system is presented on a two-dimensional field and given a relative location spatially and temporally. Field system dynamics play out within restricted limits of time (e.g., crop growth cycles) and space (e.g., a few hectares). But ecosystem, policy, and market dynamics have a much greater range of action. Consider the spatial and temporal variation between draining an extensive wetlands system versus the immediacy of a tornado touching down in a small town. It is at the farm-household and community levels where these scales most frequently intersect, shaping life cycles, livelihoods, and community infrastructure. System disturbances, either planned or unexpected, may initiate chain reactions across scales. Cross-scale issues become critical in two ways: when management is not targeted at the appropriate system level to address the source of a particular problem, and when effects of system processes on one level affect conditions on another.

This leads to the third core idea: Adaptive management is a learning process. Using the SANREM landscape systems framework, how can knowledge be turned into action and action into knowledge? Adaptation involves taking new actions to improve desired outcomes based on monitoring of results from previous actions. Monitored results, both positive and negative with

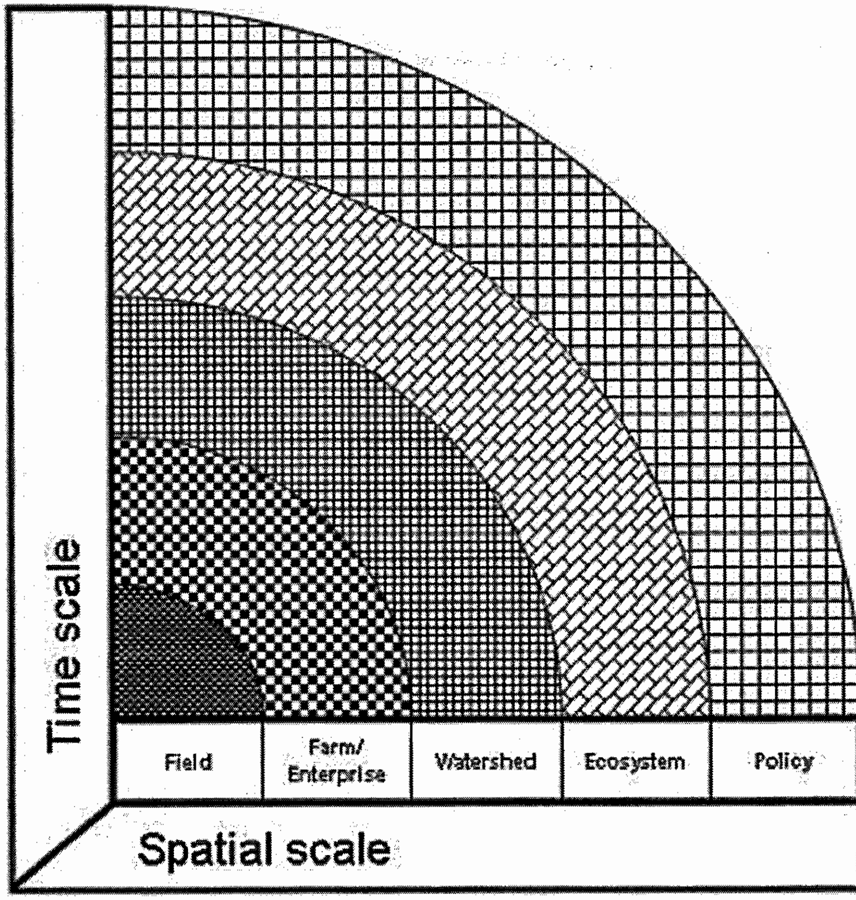

Figure 4. Scalar dimensions of SANREM landscape systems.

respect to desired outcomes at multiple system levels, contribute to better understanding of system dynamics and responses to changes in management actions. Experimentation is critical, but not all learning involves working in replicable conditions. We might not have all the information desired for management decision making. Modeling is often used to predict outcomes of treatments under conditions where observations cannot be obtained. This is particularly useful when experimental treatments are not reversible. With this understanding, new actions can be initiated in an attempt to improve outcomes.

Learning leads to innovation. Innovation is the combining of disparate sources of knowledge and practice to provide solutions for problems in specific circumstances. It is a messy process in which each innovation generates the seeds of its own demise, and the changes set in motion ultimately cycle through slower or faster processes and across scales transforming and/or reproducing the circumstances initiating the innovation. Learning operates on several levels involving the development and practice of new models for knowledge and decision making, flexible institutional roles, and the skills necessary to implement new practices. Documenting the assumptions, circumstances, processes, and results used to obtain desired system outcomes is the primary research role. Experimentation and modeling are required to successfully apply the best available knowledge. By what disciplinary or local standards are experiments and models to be evaluated? Adaptive management provides a framework to negotiate the process of social learning that can both build local decision-making capacity and contribute to disciplinary knowledge.

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Part II

Complex Systems and Development: The Science

Chapter 2

The Field System

J. Paul Mueller, Denise Finney, and Paul Hepperly

The field system represents the most basic socio-ecological system through which human communities interact with the biosphere. Field systems are complex, comprising both biotic components (plants, animals, fungi, and bacteria) and abiotic components (chemical and physical elements such as soil minerals, sunlight, moisture, and temperature) that interact through biogeochemical cycles and ecological processes. Energy from the sun flows into the field system and flows out as crop and animal products. Field systems affect natural ecosystems that surround them and, when aggregated, influence regional and global systems.

An agricultural plot is an excellent example of a field agroecosystem. For many smallholders, a single plot is the entire farm enterprise. For others, multiple plots make up a farm enterprise. The mosaic of fields that create a farm is, together with adjacent or adjoining natural areas, part of a local watershed and a larger regional ecosystem. Natural processes as well as decision making at these larger spatial scales affect processes and decision making within the single field and vice versa. For example, a farmer's decision to plant corn intercropped with beans enhances diversity of the field and creates positive benefits for the field system such as additional nitrogen and host plants for beneficial insects. Furthermore, should one of these crops fail, the other may still be marketable. This provides an economic buffer for the farm system. Activity in an agricultural field also influences and is influenced by related social systems such as markets and governance. A good example of the relationship between policy and field systems is the application of subsidies—government inducements for farmers based on production. Often subsidies are given to farmers for specific crops, which can decrease the incentive for maintaining a diversified mix of crops in the field system. This, in turn, can have devastating effects on biodiversity in the field over the long term. In the Philippines, price supports have led to severe erosion and water quality problems as hillsides once covered by forests have been converted to corn and temperate zone vegetables (Coxhead et al. 2001). Given this interrelatedness, sustainable management of individual field systems is a priority in sustainable agriculture and natural resource management development programs.

Field System Components and Processes

A field may be nested within a farm, forest, or other terrestrial landscape system, or may be part of a larger aquatic ecosystem. The following description characterizes the components and processes of an agricultural field system. The components and processes discussed, however, are present in similar or equivalent forms in most field systems. The description provided here should inform an assessment of any field system.

Continuing with the example of an agricultural plot as a field system, the primary components are soil, water, living organisms, and energy.

Soil is the foundation of an agricultural field and mediates processes essential to the functioning of the system, including: biogeochemical cycling of elements such as carbon and other mineral nutrients; provision of habitat for soil organisms; movement, storage, and decontamination of water; and promotion of plant growth (Brady and Weil 2002). The term "soil quality" reflects the capacity of the soil to carry out ecological services such as resisting erosion, and limiting the negative impact of agricultural production on water and air resources (Karlen et al. 2001). Low soil quality can significantly constrain both the productive capacity of a field system as well as the capacity of the system to provide critical ecosystem services to higher system levels.

Water is essential for crop and animal maintenance and growth, thus representing a basic component of an agricultural field system. For many field managers, water is a limiting factor in the production of crops and livestock. Water is a transient component of the field system, entering naturally as rainwater or applied through irrigation. Regardless of how water enters the system, conservation of water within the field is critical to supporting crop and animal growth. Management of water in a field system also has a significant influence on the quantity and quality of the global water supply.

The living organisms in the agricultural field system play a critical role in its resilience and productivity. Most importantly, living organisms fill ecological niches that sustain the field system. For example, soil biota are key drivers of biological processes that mediate nutrient cycling, efficiency of plants' water use, and the impact of pests such as insects and disease. These organisms also support ecological services in other systems. Living organisms are also present in the field system as crops and/or animals that represent important components of net primary and secondary production, for example, the consumable and/or marketable products produced in the field. Also present in the field system are competitive and parasitic agents such as weeds, insect pests, nematodes, and diseases that can interfere with or threaten the health and agricultural productivity of the system.

Energy is a primary driver of activity within an agricultural field system. The most important source of energy is sunlight, which is transformed during photosynthesis. Through this process, plants convert carbon dioxide into simple sugars that in turn provide the energy that living organisms need to function. In most natural systems, sunlight represents the only source of energy required to maintain the system. Managed systems, in contrast, often require external sources of energy to produce and/or extract desired products. In an agricultural field, external energy is commonly used for mechanized tilling, planting, weeding, and harvesting; and to manufacture and apply chemical fertilizers and pesticides. Today, many field managers are dependent on finite fossil fuel resources to provide these external energy inputs.

As illustrated in figure 1, the four components of an agricultural field system are linked through biogeochemical processes. The cycling of carbon, nutrients, water, and energy are processes in which each field component plays an important role. Microorganisms, for example, drive terrestrial carbon cycling by decomposing organic materials in the soil. Through this process, nutrients from organic materials are mineralized, carbon is released to the atmosphere as carbon dioxide, and byproducts are formed. The byproducts from decomposition of organic matter undergo the process of humification to become soil humus, a stable sink or reservoir for carbon. Plant species in a field system may also serve as a sink for carbon through the conversion of sunlight energy to

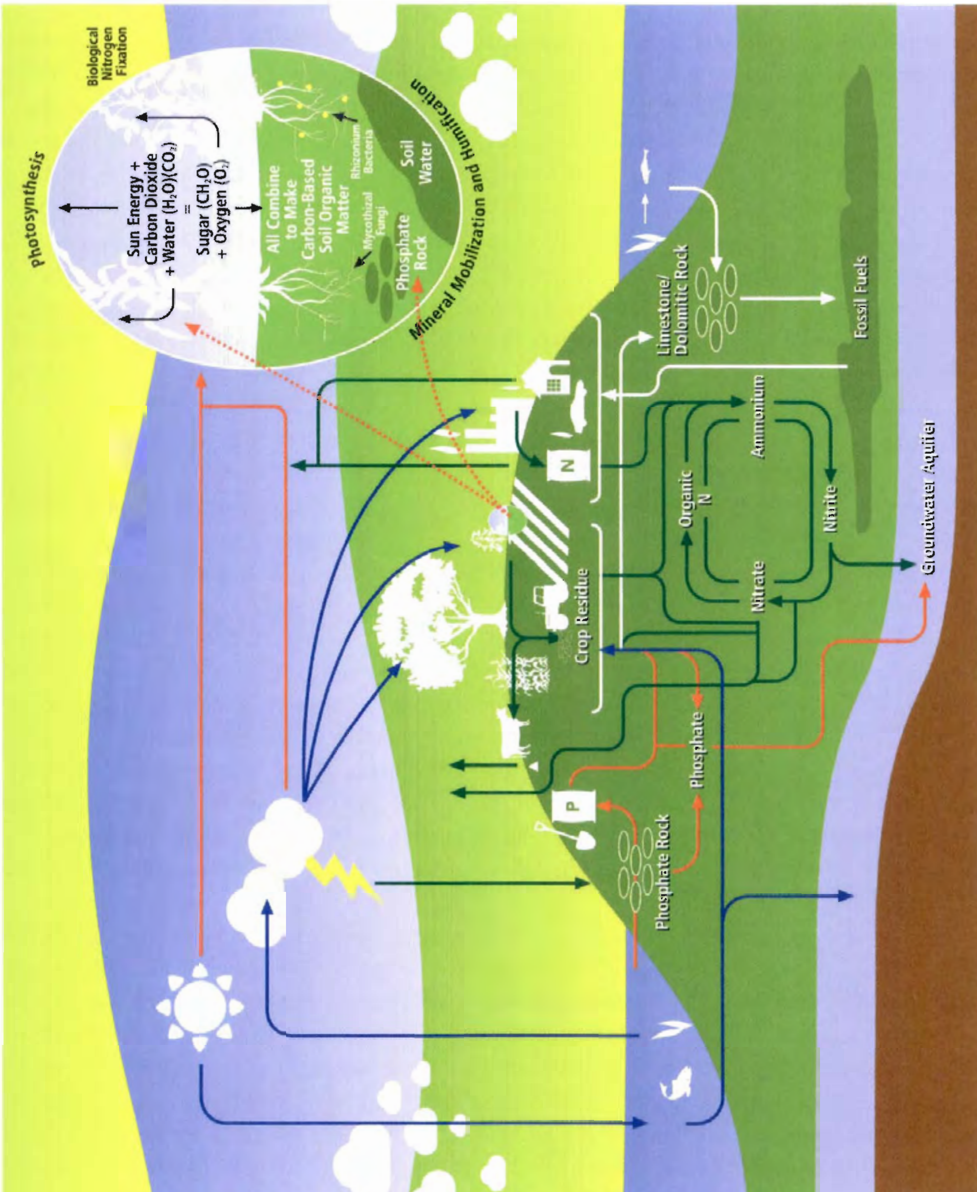

Figure 1. Four components of an agricultural field system linked through biogeochemical processes (reprinted with permission from the Rodale Institute).

sugars during photosynthesis. The carbon cycle, therefore, is driven by soil, living organisms, and energy in the field system. Figure 2 illustrates several carbon sources and sinks.

Soil, particularly soil organic matter (SOM), plays a central role in mediating the transformation and cycling of nutrients essential to plant and animal growth. SOM encompasses living microorganisms as well as plant and animal tissues in various stages of decomposition (Craswell and Lefroy 2001). There are several mechanisms through which soil organic matter regulates nutrient solubility and plant uptake. First, soil organic matter influences the composition, size, and activity of the soil microbial population, which in turn determines the rates at which materials are decomposed and nutrients from those materials are mineralized, or made available for plant uptake. For example, soil microbial populations mediate the cycling of nitrogen in a field system. As living organisms die and return to the soil, microorganisms break down these materials into their components, including organic nitrogen. Organic nitrogen in the soil is further processed by other species of soil microbes and converted to ammonium, a process called mineralization. In this form, nitrogen maybe consumed by soil microbes, immobilized but stored in the soil for future use; taken up by plants; or converted to nitrate, which can also be utilized by both microbes and plants. Figure 1 illustrates the nitrogen cycle and nitrogen transformations carried out by soil microbes. Each of these nitrogen transformations is dependent on the microbial population present. If soil microbes are deficient or lacking a source of carbon from which to derive energy, nitrogen transformations may be suspended, resulting in the unavailability of the nitrogen needed to support crop growth.

Second, soil organic matter has a high cation exchange capacity (CEC). Soils with a high CEC are able to bind and hold positively charged cations such as potassium (K+), ammonium (NH_4+), calcium (Ca^2+), and magnesium (Mg^2+), many of which are essential nutrients for plant growth. In addition, soils high in organic matter stimulate chelation, or reversible binding, of minerals that are not readily soluble. Both of these qualities improve the availability of minerals already present in the soil so that they may be taken up by plants. Finally, increasing soil organic matter enhances the capacity of soils to resist changes in pH (also called pH buffer capacity) that can adversely affect crop growth. Increases in SOM generally have a positive impact on long-term soil fertility from biological and chemical mechanisms. Like the cycling of carbon, the transformation, uptake, and transfer of nutrients represent a relationship between soil, living organisms, and energy in the field system.

As a resource essential to the survival of all living organisms in a field system, from soil microorganisms to livestock, water has an indirect influence on the cycling of carbon and nutrients. If water were not available to the organisms that drive carbon and nutrient cycling, these processes would not take place. Water itself is also mediated by other components within the field system, namely, soil and living organisms. Organic matter is the key soil component mediating the water-soil relationship. Soil organic matter provides the glue that causes the aggregation of soil particles. Aggregation, in turn, can increase water infiltration, percolation, retention, and availability to crops, all of which favor conservation and efficient use of water. As demonstrated in figure 3, soil water content is directly proportional to the quantity of soil organic matter when soil water is at field capacity (saturated) and wilting point (the point at which plants are no longer able to extract water from the soil). As figure 4 illustrates, cycling of water through the field system is also closely linked to plant life of the system. Water moves through plants as part of the hydrological cycle, entering primarily through the root system and leaving through transpiration—the evaporation of water from the leaf through openings in its surface. Plants can also intercept rainfall, influencing the quantity and distribution of water that reaches the soil.

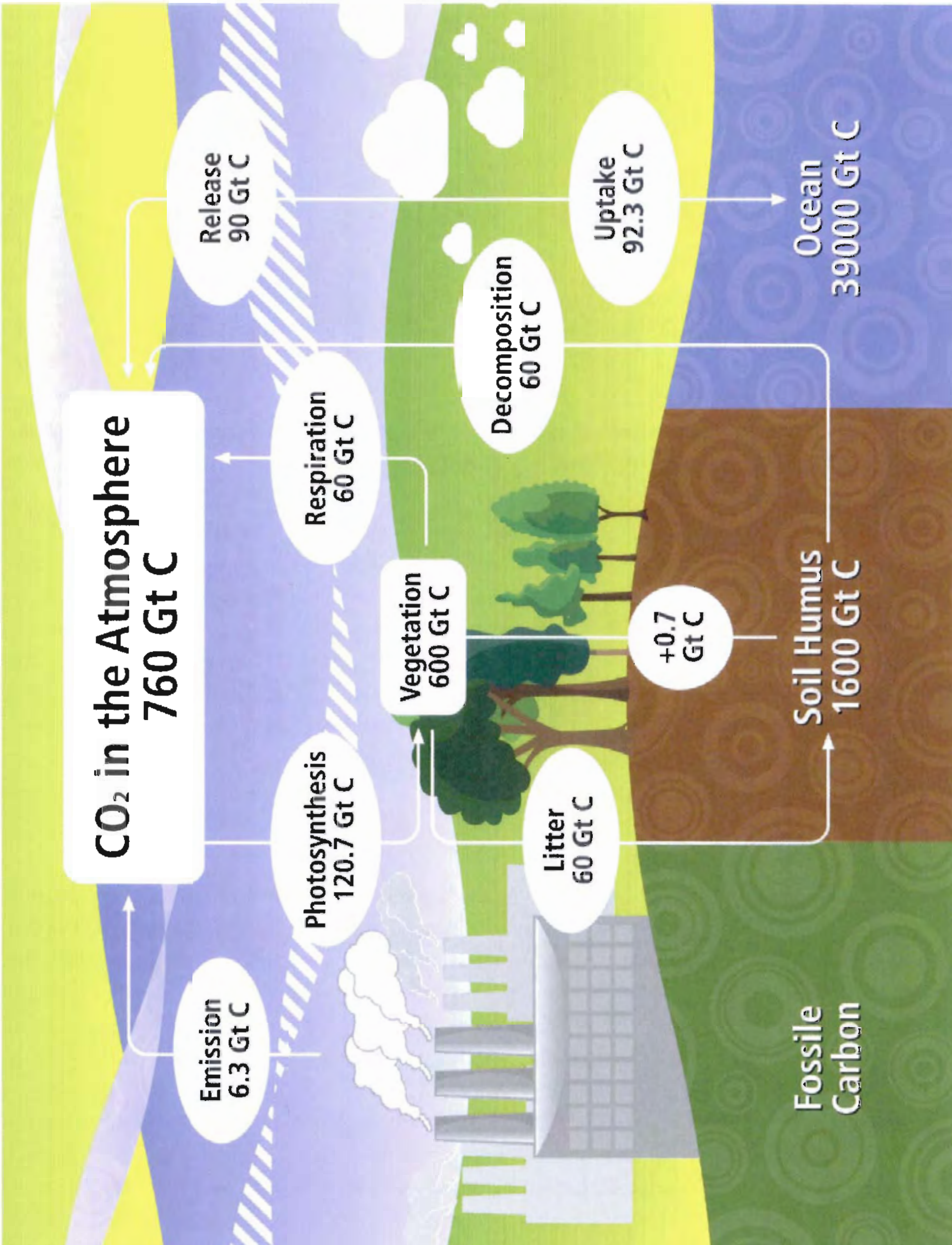

Figure 2. Carbon cycle (reprinted with permission from the Rodale Institute).

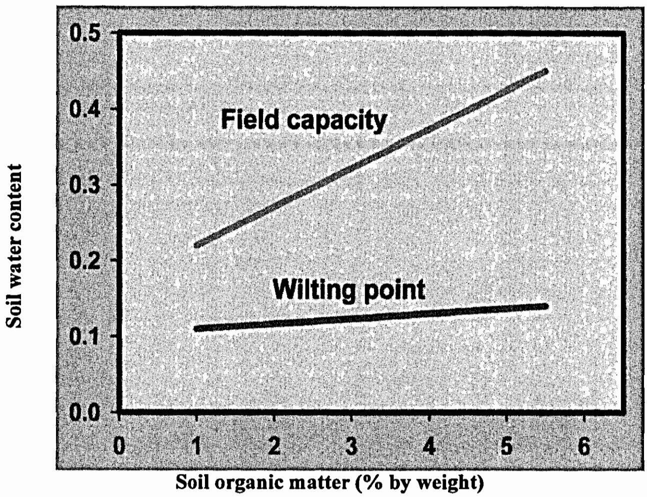

Figure 3. Effect of organic matter on available soil water (adapted from Brady and Weil 2002, reprinted with permission from the Rodale Institute).

The processes that occur at the field level serve both to maintain the system itself and to mediate the cycling of carbon, nutrients, and water on a global scale. The linkages among field system components created by these processes mean that no action within a field happens in isolation. In other words, management targeted at water conservation may also affect soil, living organisms, and energy in the field. This principle also applies to the linkages these cycles create between the field and higher system levels. A field system is not isolated but is nested within a larger complex adaptive system. Activity within the field, therefore, has repercussions in other systems. This concept will be explored more thoroughly below.

Field System Management for Resilience

Human management of a field system is driven by the desire to produce or extract tangible products that benefit human existence, such as food, fiber, medicines, or raw materials. The extent to which a field system meets this demand is often referred to as *productivity*. Historically, the primary concern of the individual field manager who serves as the decision maker in a field system has been the management of internal and external resources to increase output. Such increases in productivity can lead to improvements in family and societal economic conditions and quality of life.

Equally important to these economically tangible products of a field, however, are the economically intangible outcomes of human management of that field. Of primary concern is the impact of management on natural resources, which are fundamental to providing ecosystem services. Ecosystem services are processes by which the natural environment provides resources useful to people, such as clean water, air and a functional soil system. Many of these processes are essential to the function and resilience of the ecosystem itself. Management designed to build resilience—the capacity of the system to absorb and change in response to disturbance while retaining its function, structure, and essential identity—is paramount to maintaining both productivity and ecosystem services from which human communities benefit. Though field-level processes are fun-

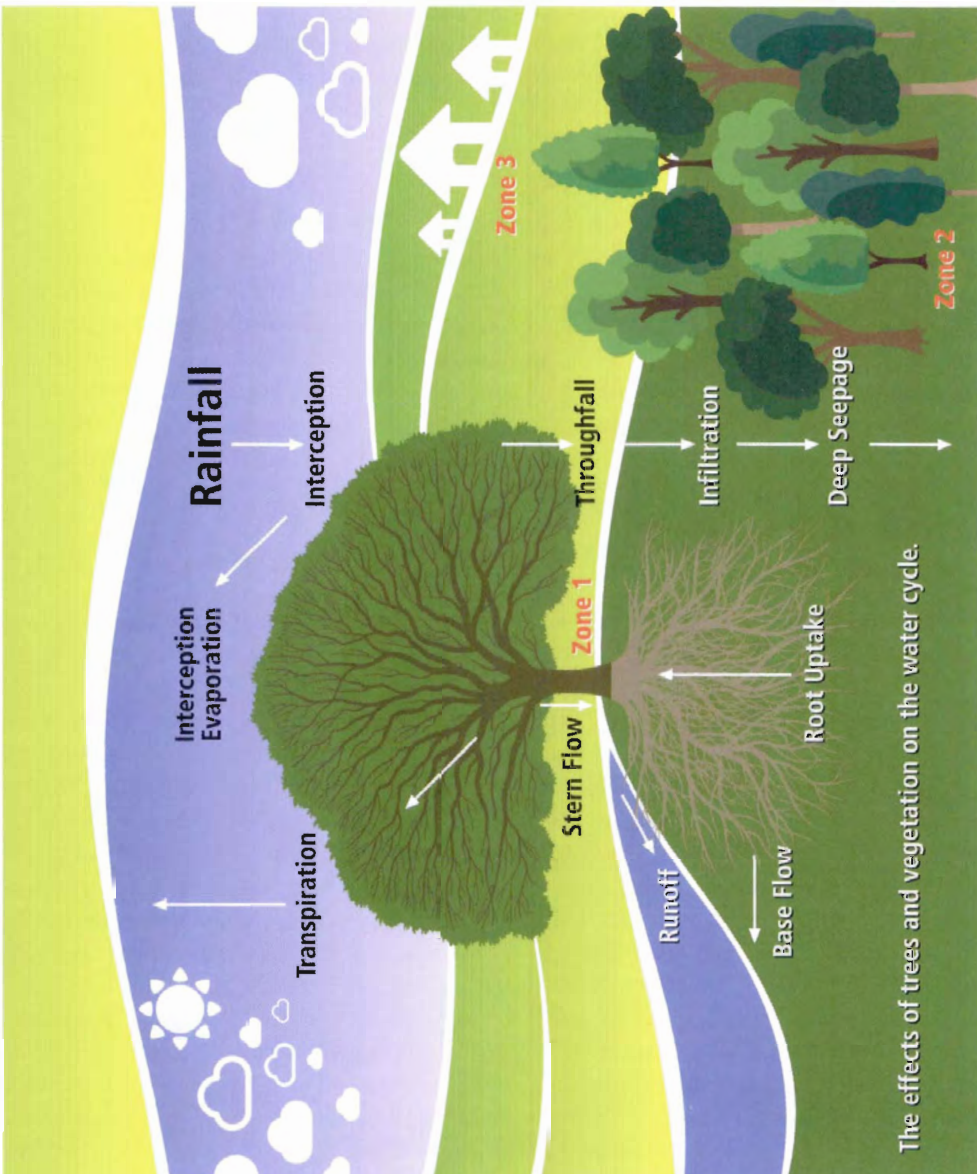

Figure 4. Cycling of water through the field system (reprinted with permission from the Rodale Institute).

damental to the overall resilience of a complex ecosystem, these processes are also influenced by and have an effect on other systems. Several examples help to illustrate these connections.

Soil erosion is an issue of global concern. Within an agricultural field system, erosion results in the loss of nutrient-rich topsoil and decreased agricultural yields (a loss of productivity). Externally, erosion contributes to sedimentation of local and regional water reservoirs, a significant negative influence of field system management on external systems. See the textbox below.

Soil erosion and the water supply: An example from Africa

Northern Ethopia offers an example of the impact of soil erosion on regional water supplies (Tamene et al. 2006). Numerous micro-dams and reservoirs were constructed across the region from 1996 to 2001, which led to increases in food production, improved access to drinking water for people and livestock, rise in the groundwater level, and issuance of new springs (Tamene et al.). By 1999, rapid loss of water storage capacity due to sedimentation was reported by local management agencies (Gebre-Hawariat and Haile 1999, cited in Tamene et al.). Reduced storage capacity has resulted in the loss of services provided by the micro-dams, including the provision of hydroelectric power. In this region, like many others around the globe, excessive sedimentation has been attributed to topography of the land as well as human management of field systems.

Field system management also plays an important role in global biodiversity. Biodiversity at the field level contributes directly to biodiversity at other system levels. For example, diversity within agricultural fields and field borders contributes to greater diversity at the farm level, providing options for stable yield, increased income, variety in diet, and minimization of risk. Diversity at the field level also contributes to a mosaic structure at higher ecosystem levels that can lead to the creation of multiple habitats for beneficial insect species, wildlife and game populations, and native crop species (Altieri 1994). Field systems often contain important ecological niches for mobile species. Removal of such niches may have significant repercussions at a regional or global level. For example, the conversion of mangrove ecosystems (a field system) to shrimp farms in Southeast Asia and South America has resulted in the removal of spawning and nursery habitat for fish and shellfish. The repercussions are felt by fisherman in other regions and often other countries as reduced or lost adult fish yields (Barbier et al. 1994, cited in Folke et al. 1996).

To view a field system as part of a complex adaptive system is to acknowledge that management practices at the field level can have both positive and negative effects on ecosystem resilience and the capacity of interrelated systems to provide ecosystem services. Promotion of sustainable agriculture and natural resource management must therefore meet the short-term needs of the field manager—productivity—while at the same time addressing long-term considerations for the building of resilience and provision of ecosystem services within the field and beyond. With regard to the latter, natural resource managers such as farmers increasingly have no real isolation from the larger society. In fact, informed communities are exercising a greater stakeholder function and demanding that farmers use methods that will maintain and even improve the overall environment while meeting certain social, labor, energy, and environmental standards for their products.

Adaptive Management of Field Systems for Sustainability

Managing a field system to enhance productivity, integrity and resilience is integral to sustainable community development. Change is a reliable and ubiquitous factor that field managers face in this effort. Adaptive management seeks to develop practices that interpret and respond to feedback within the system brought about by disturbance (Berkes and Folke 1998). Successful adaptive management applies knowledge of ecosystem processes and dynamics to modify and adopt practices appropriate to local environmental and cultural conditions. Adaptive practices also seek to regenerate internal system resources, a key to building system resilience.

Goal: Regenerate Internal Resources

Sustainable management of the field system emphasizes the utilization of its internal resources and strategically uses external inputs to meet the needs of the individual field manager, human communities, the ecological functioning of the field system, and the biosphere as a whole. The term *regenerative* is often used to describe practices that fit these criteria. *Regeneration* is the improvement of the resource base while the base is being used productively. Regenerative practices strengthen the natural resources on which production is based and enable field managers to efficiently use readily available internal resources and reduce reliance on external inputs. In developing countries the latter is critical to promoting subsistence and market agriculture among limited resource agriculturalists due to the lack of access to external inputs.

Each of the principal components of a field system represents an internal resource of the system. In the example of an agricultural plot, soil, water, living organisms, and energy are the internal resources necessary to support productivity and ecosystem services. Regenerating each of these may focus on a particular aspect of a given component. For example, regeneration of soil is largely achieved through management of its organic matter. The latter portion of this chapter focuses on objectives and practices relevant to the regeneration of internal resources in an agricultural field system. The principles of regenerative management of field resources in agroecosystems are a matter of good stewardship practices that enhance soil organic matter, assure clean and abundant water supplies, protect biodiversity, and reduce dependence on external energy inputs.

Enhancing Soil Organic Matter

The rise of high-input agriculture following World War II has promulgated the perception that soil is "a dead substrate holding nutrients for agricultural production" (Martius et al. 2001). This view rationalized reliance on chemical fertilizers and intensive land preparation methods that accelerate soil degradation (Hillel 1991). At the same time that input-intensive agriculture has increased, global soil organic matter levels have been declining, largely due to the conversion of natural areas to agricultural production (Wood et al. 2000). Recent surges in research on management of soil organic matter in developing countries highlight a renewed interest in the potential of SOM to mediate soil degradation, enhance production among limited-resource farmers, and reduce a number of negative effects of agricultural production on associated resources. Research suggests that smallholders in developing countries are also aware of the link the between soil organic matter and soil fertility (Murage et al. 2000; Hossain 2001; Quansah 2001). The textbox below provides a summary of the contributions of SOM to field system function. Table 3 (later in this chapter) provides strategies to increase soil organic matter.

Soil organic matter: A key factor in field system health

Soil organic matter makes a number of significant contributions to agroecosystem function, including the following:

- increased capacity of soil to hold water
- enhanced water infiltration
- improved soil aggregation and structure
- increased cation exchange capacity
- enhanced biological cycling of nutrients
- increased heat absorption
- pH buffer capacity
- enhanced chelation
- enhanced adsorption capacity
- reduced damage by soil pathogens

The centrality of functions carried out by SOM in agroecosystems warrants a special focus on practices that increase organic matter in agricultural soils. Because of the influence of SOM on other system components, most practices that aim to increase it will indirectly benefit soil water conservation, nutrient availability, and soil biodiversity, an important concept that will be addressed later in this chapter. A number of these practices also offer direct benefits to secondary aspects of the field system and are considered good tools for adaptive management.

Mulch

A common practice to add soil organic matter is the application of mulch. Mulch may be derived from material imported to the field, cover crops grown in the field, or crop residues left on the soil surface (Erenstein 2003). In humid to sub-humid areas, crop residue biomass is typically sufficient to provide adequate coverage of the soil surface (Erenstein). In arid and semiarid regions, however, crop residue production is generally not sufficient for mulching, and residues are often diverted to other uses such as animal fodder (Erenstein; Tiscareno-Lopez et al. 1999). In these areas, cover cropping may provide an alternative mulch production strategy. Regardless of the composition or origin of mulch, organic material added to the field system provides the substrate on which soil microorganisms act to create humus, as described previously, thus increasing SOM content.

Mulch also contributes to water conservation through two major actions: by adding to organic matter that improves soil aggregation and porosity (Pieri 1989); and as a physical layer covering soil to reduce surface runoff and evaporation (Erenstein 2002). The work of Greb (1983) in the American Great Plains demonstrated that mulch mass was directly related to water availability in semiarid environments. Compared with no mulch, 6,600 kilograms per hectare of dry stubble was sufficient to increase water in the field system by 50% in four sites tested. Gupta and Gupta (1986) reported that on an Indian aridisol, interrow placement of weed mulch at the rate of 6 tons per hectare significantly increased the mean moisture status of the 15 centimeter soil depth by 1.4% and significantly decreased the mean maximum temperature of the 10 cm depth (measured at 2 p.m.) by 3.9°C, resulting in increased plant biomass production. In cases where water availability is a primary constraint to crop yield, mulch application can lead to an immediate increase in water infiltration and, subsequently, crop yield. Measurable impacts of increased SOM provided by mulch may be observable only in the long run, for consistent mulching tends to stabilize and enhance crop yield (Erenstein 2003).

Short- and long-term effects of residue cover are demonstrated by a soil conservation program first adopted in Guaymango, El Salvador, in 1973. Though burning crop residues had been a common practice in the region, growers reported that they were motivated to end this practice because of the erosion control they observed when surface residues were left intact. After more than 20 years, the El Niño phenomenon provided evidence of the long-term impact of residue conservation on soil moisture. In 1997, farmers in Guaymango who had continuously practiced recommended soil conservation strategies reported achieving near-average yields despite drought conditions (Shaxson and Barber 2003).

Mulch also serves as a means of suppressing weed growth. Mulches limit germination and growth of weed seedlings by altering light, soil moisture, and soil temperature (Teasdale and Mohler 1993). The amount of mulch required for effective weed suppression varies with the type of mulch used. In general, weed suppression improves with increasing mulch thickness and uniformity of distribution. Ligneau and Watt (1995) demonstrated sufficient suppression of annual weed emergence with 3 centimeters of composted materials. For growers using cover crops as mulch, the question of how much biomass is needed for effective weed management is still being studied. Finding the optimal level of cover crop residue may involve on-farm trials of various cover crops to find the mulch system that is most reliable and effective in a particular locality.

Cover Crops

Cover cropping is a beneficial practice applicable to most agroecosystems. The benefits of cover crops include the following:

- protection against soil erosion
- addition of organic matter to the soil
- provision of nutrients (for example, legumes that host nitrogen-fixing bacteria)
- provision of habitat for beneficial insects and other organisms
- moderation of soil temperatures
- conservation of soil water
- biological nitrogen fixation (legume cover crops)

Cover crops may be planted in a field in rotation with food and fiber crops (see "Crop Rotation") as a living mulch under food and fiber crops, or in fallow fields. As listed in table 1, various species are suitable cover crops that may be used by smallholders in a range of environments. Mulching with cover crops may be possible in dry regions, though mulch production is limited by the short duration of the growing season and extraction of biomass for alternative uses such as fodder for livestock. In general, smallholders in semiarid to arid regions may need to pursue alternative strategies such as intercropping, reduced tillage, compost application, and crop rotation to reduce erosion and enhance SOM (FAO 2004).

Hedgerows

More permanent sources of organic material are available from the planting of trees, shrubs, and grasses as living fences or hedgerows. Such plantings can be cut regularly to provide mulch for cropping areas. It is common to use nitrogen-fixing leguminous trees for this purpose, as many

Table 1. Commonly used cover crops.

Scientific name	Common name(s)	Use	Recommended elevation	Recommended climate*
Avena sativa	Oat	Cereal		Ar, Aw, Bs, Bw, Cf, Cs, Cw, D
Brassica oleracea var. *Acephala*	Forage kale	Vegetable	Up to 3,000 m	Ar, Aw, Bs, Cf, Cs, Cw, D, E
Cajanus cajan	Pigeon pea	Herbaceous legume (shrubby)	Up to 3,000 m	Ar, Aw, Bs, Cf, Cs, Cw
Canavalia ensiformis	Jack bean Coffee bean	Herbaceous legume	Up to 1,800 m	Ar, Aw, Cf, Cs, Cw, D
Canavalia gladiata	Sword bean	Herbaceous legume	Up to 1,500 m	Ar, Aw
Canavalia maritime	Beach bean Bay bean	Herbaceous legume		Ar, Aw, Bs
Centrosema pubescens	Centro	Herbaceous legume	Up to 1,600 m	Ar, Aw
Clitoria ternatea	Butterfly pea	Herbaceous legume	Up to 1,800 m	Aw, Bs, Cw
Crotalaria juncea	Sunn hemp	Herbaceous legume	Up to 1,500 m	Ar, Aw, Bs, Cf, Cs, Cw
Eleusine coracana var. *coracana*	Finger millet African millet	Cereal	Up to 2,500 m	Aw, Bs, Bw, Cf, Cs, Cw
Fagopyrum esculentum	Buckwheat	Cereal	Up to 2,000 m	Aw, Bs, Cf, Cs, Cw, D
Glycine max	Soybean	Herbaceous legume	Up to 3,000 m	Aw, Bs, Cs
Glycine wightii	Perennial soybean Glycine	Herbaceous legume	Up to 2,450 m	Ar, Aw, Cf
Indigofera hirsute	Hairy indigo	Herbaceous legume	Up to 1,350 m	Ar, Aw, Cf, Cs, Cw
Lablab purpureus	Lablab bean Hyacinth bean	Herbaceous legume	Up to 2,100 m	Ar, Aw, Bs, Bw, Cf, Cs, Cw, D
Lupinus albus	Sweet lupine White lupine	Herbaceous legume	Up to 740 m	Bs, Cs, D
Lupinus mutabilis	Tarwi Andean lupin	Herbaceous legume	Up to 4,000 m	Aw, Bs, Cf, Cs, Cw, D
Medicago sativa	Alfalfa Lucerne	Herbaceous legume	Up to 4,000 m	Bs, Cf, Cs, Cw, D
Mucuna pruriens var. *utilis*	Velvet bean	Herbaceous legume	Up to 2,100 m	Ar, Aw, Cf, Cs
Panicum miliaceum	Proso millet Hog millet	Cereal	Up to 3,500 m	Aw, Bs, Bw, Cf, Cs, Cw
Pennisetum glaucum syn. *P. americanum*	Pearl millet	Cereal	Up to 1,800 m	Ar, Aw, Bs, Bw, Cf, Cs, Cw
Psophocarpus tetragonolobus	Winged bean Goa bean	Vining legume	Up to 2,000 m	Ar, Aw, Cf, Cs, Cw
Pueraria phaseoloides	Tropical kudzu	Herbaceous legume	Up to 2,000 m	Ar, Aw
Setaria italica	Foxtail millet Italian millet	Cereal	Up to 2,000 m	Aw, Bs, Cs
Stylosanthes guianensis var. *guianensis*	Common stylo Tropical lucerne	Herbaceous legume	Up to 2,200 m	Ar, Aw, Bs, Cf, Cw
Trifolium ssp.	Clover	Herbaceous legume	Varies by species	Varies by species
Vigna umbellata	rice bean	Herbaceous legume	Up to 2,000 m	Ar, Aw, Bs, Cs
Vigna unguiculata	Cowpea Yardlong bean	Herbaceous legume	Up to 2,000 m	Ar, Aw, Bs, Cf, Cs, Cw

Sources: Educational Concerns for Hunger Organization, North Fort Myers, Florida (www.echotech.org), and Ecocrop, a program of the United Nations Food and Agriculture Organization (ecocrop.fao.org).
* Key to climate type: Ar = tropical wet (rainforest, tropical lowlands); Aw = tropical wet and dry (monsoon, savannah); Bs = semiarid; Bw = desert; Cf = subtropical humid; Cs = subtropical dry summer; Cw = subtropical dry winter; D = temperate (all subgroups); E = boreal.

species also contribute to soil fertility and serve as animal fodder (Shaxson 1999). Table 2 provides information on commonly used leguminous trees.

In steep lands, cross-slope planting of trees, grasses, and shrubs is a common tool to mediate soil erosion. In a field system, this type of green hedgerow helps to stabilize soil, slows water run-off, and provides soil cover to minimize erosion (Shaxson 1999). In Vietnam, for instance, hedgerows of *Vetiver* sp. and *Tephrosia* sp. have been shown to reduce dry soil loss in cassava by 83% and 57%, respectively (Dang and Klinnert 2001). Farmer participatory research in the Philippines has demonstrated that high-value contour hedgerows such as asparagus, lemon grass, and pigeon peas can also reduce annual soil loss compared with loss under conventional farmer management. In this experiment, vegetable crops were planted on a 42% slope, and the average amount of soil lost when contour hedgerows were in place was 30% lower than the farmer-managed system without hedgerows (Poudel et al. 2000). Other high-value hedgerows may include fruit and nut trees. These examples demonstrate that sustainable management to both enhance productivity and provide ecosystem services (in this case the prevention of soil erosion) is possible even in marginal areas.

Table 2. Leguminous trees and shrubs commonly used as hedgerows.

Scientific name	Common name(s)	Growth habit	Recommended elevation	Recommended climate*
Albizia lebbeck	Women's tongue East Indian walnut	Tree	Up to 1,600 m	Aw, Bs, Cw
Calliandra calothyrus	Calliandra	Tree	Up to 1,800 m	Ar, Aw
Desmanthus virgatus	Wild tantan Dwarf koa Slender mimosa Bundleflower	Shrub	Up to 2,000 m	Aw, Bs, Bw, Cf, Cw
Desmodium intortum	Greenleaf desmodium	Tree	Up to 2 500 m	Ar, Cf
Erythrina poeppigiana	Coral tree	Tree	Up to 2,000 m	Ar, Aw
Flemingia macrophylla	Wild hops flemingia	Shrub	Up to 2,000 m	Ar, Aw
Gliricidia sepium	Gliricidia Madre de cacao	Tree	Up to 1 600 m	Ar, Aw
Leucaena ssp.	Leucaena	Tree	Varies by species	Ar, Aw, Bs, Cf, Cs, Cw (varies by species)
Robinia pseudoacacia	Black locust False acacia	Tree	Up to 3,300 m	Bs, Cf, Cs, D
Sesbania ssp.	Sesbania	Tree	Varies by species	Ar, Aw, Bs, Cf, Cs (varies by species)
Tephrosia vogelii	Tephrosia Fish bean Fish poison bean	Tree	Up to 2,100 m	Ar, Aw, Cf, Cs, Cw

Sources: Educational Concerns for Hunger Organization, North Fort Myers, Florida (www.echotech.org), and Agroforestry Net, Holualoa, Hawaii (www.agroforestry.net).

* Key to climate type: Ar = tropical wet (rainforest, tropical lowlands); Aw = tropical wet and dry (monsoon, savannah); Bs = semiarid; Bw = desert; Cf = subtropical humid; Cs = subtropical dry summer; Cw = subtropical dry winter; D = temperate (all subgroups).

Compost and Other Organic Amendments

In many areas of the world, field managers rely on synthetic fertilizers to sustain crop production. Though the application of synthetic fertilizers can support crop growth in the short term, this practice can also erode soil carbon content. Over the long term, this results in depletion SOM, compromising both the productive capacity and resilience of a field system. The use of organic amendments, particularly compost, to enhance soil fertility offers a means to increase organic matter and promote sustained soil quality.

The impact of organic amendments on soil microbial activity, increases in which are generally associated with higher rates of decomposition and nutrient transformation, and nitrogen retention in a temperate climate have been demonstrated by research at the Rodale Institute. Studies using tagged nitrogen (N_{15}) to compare nitrogen movement in organic and conventional cropping systems found that application of organic amendments led to higher rates of soil respiration (an indicator of soil microbial activity), increased quantities of nitrogen in soil microbial biomass, and reduced losses of nitrogen (as illustrated in figure 5).

These outcomes underscore the importance of building up quantities of SOM in agricultural field systems. Alternative agriculturists have called this concept "feeding the soil" an important concept in regenerative and sustainable field management.

Composting is a key practice with demonstrated ability to reverse loss of SOM in areas such as the endangered Sahel region that borders the Sahara Desert (Diop, personal communication, 2005). Among organic inputs, research suggests that application of composted, as opposed to raw, manure is an efficient means of increasing soil organic matter. In Senegal, West Africa, McClintock and Diop (2005) reported that field soils amended with compost or manure produced increased growth of millet and corn, and elevated cation exchange capacity and nutrients (potassium, magnesium) compared with non-amended soils. The authors recommended that farmers concentrate on refining the management of conventional compost piles rather than on more labor-intensive methods of composting. In the Rodale farming systems trial in the temperate United States, base SOM levels of 2.0% changed to 2.5%, 2.1%, and 1.9% in systems using composted manure, raw dairy manure, and synthetic chemical fertilizer, respectively, over nine years. Figure 6 provides a graphical representation of these results. Compost may also be derived from crop and household waste. In a study comparing yield response of cabbage with the application of composted crop waste, uncomposted crop waste, and conventional NPK fertilizers, researchers in Uganda observed that yields were highest in the composted crop waste system in two out of three growing seasons (Karungi et al. 2006). See Misra et al. (2003) for further information on composting techniques.

Increasing SOM through compost application provides the opportunity to reduce energy requirements derived from the use and application of conventional fertilizers. This technology not only reduces energy required for crop production through enhanced soil properties, it also reduces the energy required to apply organic materials such as manure. Composting reduces original masses and volumes by 80% to 90%. Through the composting process, potential pests and pathogens can also be eliminated from a field system, further reducing production and energy costs derived from pest management with conventional pesticides. When composting, the labor input can be minimized by using static pile methods and enhanced African pit compost methods. Simple animal draft equipment that can be cheaply constructed by locals is another mechanism for increasing efficiency of organic material use for societal gain.

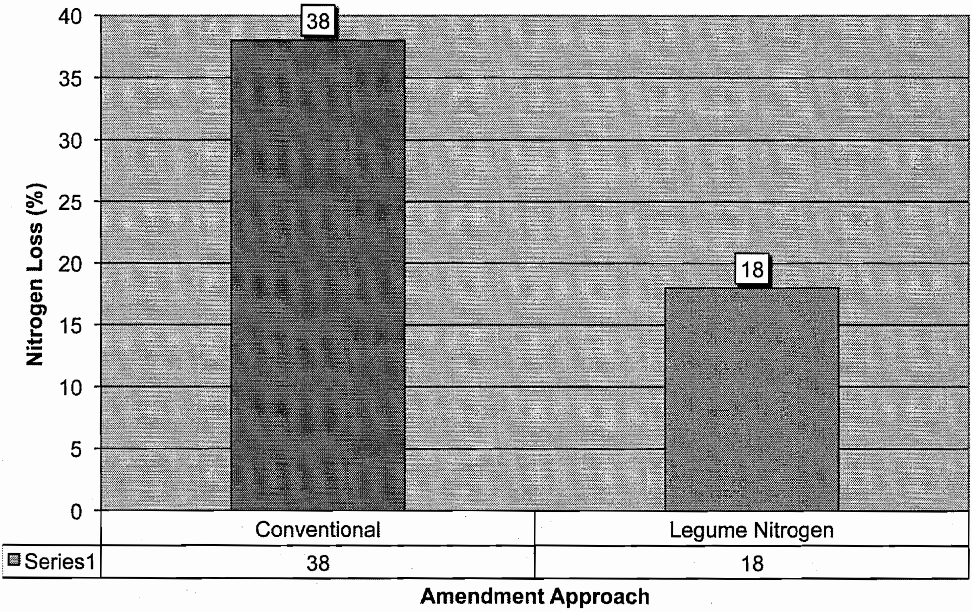

Figure 5. Nitrogen losses measured in Rodale Farming Systems Trial using N_{15} isotope (reprinted with permission from the Rodale Institute; see Harris et al. 1994 for details).

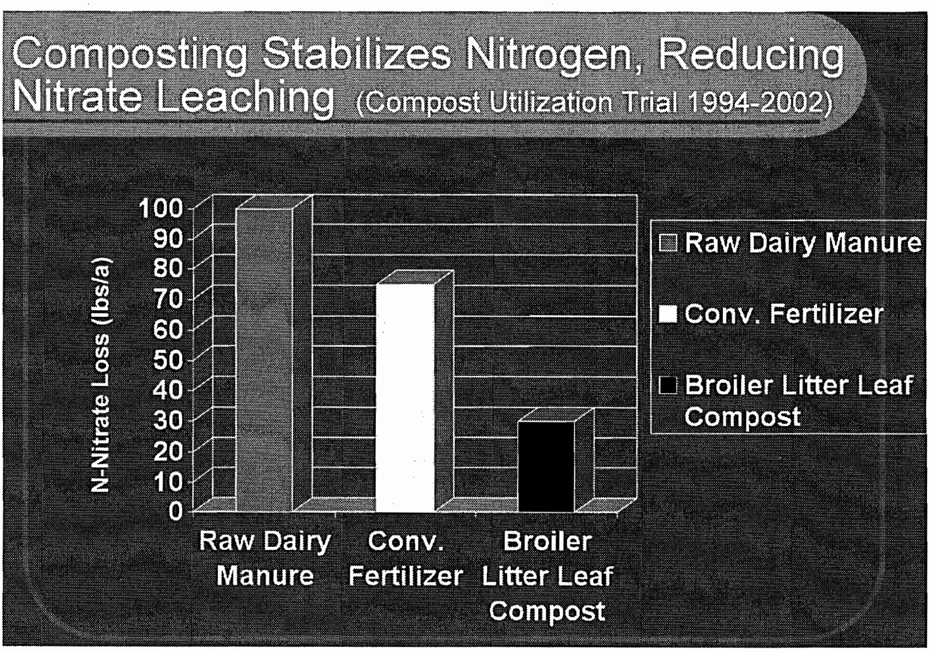

Figure 6. Effect of compost utilization on nitrogen leaching (reprinted with permission from the Rodale Institute; Hepperly et al. 2009).

It should be noted that sustainable management does not require the elimination of synthetic fertility amendments. In cases where synthetic fertilizers are deemed a necessity to support plant growth, proper placement of small amounts are recommended. These should be applied at key stages. Extensive starter fertilizer research shows that 80% of the fertilizer response can be achieved with 20% of the fertilizer effectively placed as a starter. For example, the placement of relatively small amounts of fertilizer at the side and below the seed is critical to avoiding salt toxicity while stimulating optimized nutrient use and early crop stimulation.

Reducing Tillage

Tillage has been employed historically in field systems to facilitate proper placement of seed and to control weeds. Nevertheless, tillage is highly disruptive to field system processes. One of the key processes affected by tillage is the carbon cycle. By turning and mixing organic residues into soil, tillage increases contact between organic materials and soil organisms. This, in turn, speeds the process of decomposition, generating less stable forms of soil humus and releasing higher quantities of carbon dioxide. The net result is decreased soil organic matter. As previously discussed, this can lead to reduction of soil's capacity to hold water. Other negative effects of tillage include loss of habitat for soil organisms, increased susceptibility to erosion, and higher external energy requirements. Because of the link between tillage and poor soil quality, many development organizations promote the adoption of practices that replace or reduce the need for tillage in soil preparation and weeding. These practices are often combined in a production system called conservation agriculture.

Conservation Agriculture

The term *conservation agriculture* is used to describe any farm production strategy that reduces or eliminates the use of tillage. The benefits of reduced or no-tillage include reduced risk of erosion, conservation and augmentation of SOM content, and conservation of soil water.

In many areas of the world, conservation agriculture is promoted as a strategy to replace management systems that contribute to human-induced soil erosion in field systems: excessive tillage, inadequate soil cover, utilization of hillsides and sloped lands for production without proper conservation practices, overgrazing, and slash-and-burn systems. Conservation agriculture is a sustainable field management strategy that can provide immediate and direct reduction of soil losses as well as promote long-term soil quality.

Conservation agriculture is based on three principles: minimal soil disturbance, permanent soil cover, and crop rotations. Management practices utilized in conservation agriculture include reduced or zero tillage, use of mulch (retaining crop residues, no burning), and cover cropping.

The principal biological concept on which conservation agriculture is based is the capacity of organic matter to stabilize and enhance soil structure and function. Tillage disrupts not only the soil's physical structure but also the habitat of soil organisms critical to decomposition, nutrient cycling, and organic matter formation. Therefore, strategies within conservation agriculture aim not only to provide short-term protection of soil structure (for example, by minimizing soil disturbance and covering exposed soil) but also to support the living organisms that promote soil health (FAO 2000). Associated ecosystem services offered by conservation agriculture include improved soil water properties, increased biodiversity, and enhanced carbon cycling. By reducing or eliminating the need for tillage machinery, conservation agriculture also provides a means by which smallholders can reduce external energy inputs.

Although conservation agriculture is prevalent in areas such as Latin America, the practice is lagging on other continents, especially in Africa. Conservation agriculture is still in its infancy in Africa, where it needs to be taught and demonstrated under African environments. It is important to acknowledge that many reduced-tillage systems, particularly those used in industrialized countries, are based on intensive fertilizer and pesticide use. Chemical-intensive conservation agriculture is a one step forward in relation to tillage but several steps back with regard to the known negative effects on natural resources and health from increased use of pesticides and chemical fertilizers. For this reason, it is important that conservation agriculture is recommended and promoted only within a package of sustainable management practices that emphasize both production and natural resource conservation and improvement.

More information on conservation agriculture is available from the Food and Agriculture Organization (FAO) Web site (www.fao.org). FAO Land and Water Bulletin No. 8 (2000) provides a comprehensive review of conservation agriculture practices.

Fallowing

Fallowing represents another tool to increase SOM. Natural fallow periods of sufficient duration (10 to 50 years) such as those used in shifting cultivation systems can restore soil biological, chemical, and physical properties (Greenland and Nye 1959). In any period during which a field is not used for economic crop production, the field can be managed as an improved fallow to restore or enhance soil quality. Herbaceous legumes and trees, also often leguminous, may be planted or encouraged to regenerate in a fallow field to contribute to soil fertility, provide soil cover, augment soil organic matter, and provide other benefits associated with temporal crop diversity (Ganry et al. 2001; Roose and Barthes 2001; Quansah et al. 2001). See "Hedgerows" for additional information on leguminous tree species.

Strategies to Increase Soil Organic Matter

Climate is a key factor determining the optimal strategies for adding organic matter to the field system. For example, in humid to sub-humid regions where biomass production capacity is not limiting, adding crop residues, cover crops, and weed residues to soil are the primary tools used by smallholders to augment soil carbon (Quansah et al. 2001; Hossain 2001; Dang and Klinnert 2001; Manna et al. 2003; Roldan et al. 2003). In semiarid to arid regions, where crop production is limited, farmyard manure and compost application are the most common and effective organic matter additions for soils (Quansah et al. 2001; Ganry et al. 2001; Manna et al. 2003; Bayu et al. 2004). It is important to consider environmental conditions and limitations when selecting practices to enhance soil organic matter. Table 3 provides examples of strategies used to increase soil organic matter in various climates.

Water Conservation

Field system environments are diverse, creating a wide variety of water management priorities. In this section we examine biological principles that govern water conservation and efficient water use in agricultural fields. Water management strategies based on these principles provide smallholders with a number of tools that both enhance field productivity and steward water resources transferred to higher system levels.

Water represents a key link between the field and other systems in the global biosphere. All systems share a limited supply of safe and clean water to meet human needs and support living

Table 3. Strategies to increase soil organic matter.

Strategy	Applications	Examples	References
Compost and manure	• Applicable in all climates • 8-10 tons of manure per hectare per season recommended [Bui Dinh Dinh 1995 (Vietnam)] • Prominent in areas where livestock production is prevalent, particularly arid and semiarid savannas	• Farmyard manure (most often a composted mix of animal dung, animal bedding and household wastes) • Raw manure • Improved manure (composted with crop residues) • Quick compost (oil cake, rice bran, and chicken, duck, and/or cow manure) • Pen manure (may be dry, moist, or straw) • Application of leftover excrement slurry following production of biogas from livestock and human excrement	Hossain 2001 (Bangladesh); Reported in Ganry et al. 2001 (semiarid Africa); Nyombi and Esser 2005 (Uganda); Tamang, 1992 (Nepal); Quasnah et al. 2001 (Ghana); Katyal et al. 2001 (India)
Plant residues: residues of crops and/or weeds left in a field or applied to a field as mulch	• Most applicable in humid to sub-humid climates • Residue production may be insufficient in arid and semiarid climates • In many locations, residues often diverted to fuel or livestock fodder	• Rice stubble left in field • Rice straw, sugarcane bagasse applied to crop fields • Corn residue left in field (not tilled) • Weeds slashed and left on fields • Guinea corn and millet stalks used as mulch	Hossain 2001 (Bangladesh);Whitbread et al. 1999 (Thailand); Taja and van de Zaag 1991 (Philippines); Roldan et al. 2003 (Mexico); Qunsah et al. 2001 (Ghana)
Living fences or hedgerows: trees or grasses pruned and cuttings used as mulch	• Applicable in all climates • Recommended in sloped areas to combat erosion	• *Calliandra, Flemingia, Gliricidia, Leucaena, Tephrosia* ssp. trees as living fences and/or hedgerows • Napiergrass (*Pennisetum purpureum*), *Setaria, Vetiver* ssp. grass hedgerows • *Erythrina, Gliricidia, Leucaena, Mimosa, Robinia, Sesbania* ssp. planted between alleys for crop production (alley-cropping)	Hossain 2001 (Bangladesh); Konig 1992 (Rwanda); reported in Dang & Klinnert 2001 (Thailand); reported in Dang & Klinnert 2001 (Vietnam); Ganry et al. 2001 (semiarid Africa)
Cover crops	• Most applicable in humid to sub-humid climates • Cover crop production be may limited in arid and semiarid climates	• Dhaincha (*Sesbania aculeate*), sunn hemp (*Crotolaria juncea*), soybean, mung bean, peanut, winter legume • vetch (*Vicia* sp.) or ayocote bean (*Phaselous vulgaris*) not tilled before corn planting • velvet bean (*Mucuna pruriens*) cut or uprooted and left on the surface before planting annual crops or in perennial crops such as banana	Hossain 2001 (Bangladesh); Dang & Klinnert 2001; Roldan et al. 2003 (Mexico); Ganry et al. 2001 (Benin, Ghana, Togo); Nyombi & Esser 2005 (Uganda)
Living mulch: cover crop species grown at the same time as crop species	• Most applicable in humid to sub-humid climates	• Grass pea (*Lathyrus sativus*) planted under taller winter crops such as eggplant	Hossain 2001 (Bangladesh)
Intercropping: two food crops grown at the same time	• Most applicable in humid to sub-humid climates	• Cassava and peanut • Maize and peanut • Litchi and peanut • Coffee and peanut • Tea and peanut	Reported in Dang & Klinnert 2001 (Vietnam)
Relay cropping: food or cover crops planted when food crop is near harvest	• Most applicable in humid to sub-humid climates	• Grass pea planted when aman rice reaches maturity and tilled in after harvest; boro rice then planted	Hossain 2001 (Bangladesh)
Azolla: nitrogen-fixing aquatic fern used as animal feed	• Applicable in flooded rice systems	• Intercropped in flooded rice	Hossain 2001 (Bangladesh); Dang & Klinnert 2001 (China, India, Vietnam)
Improved fallow	• Recommended in semiarid and arid areas • Recommended in livestock areas	• Planting legumes such as Stylosanthes hamata, Dolichos lablab, and Mucuna pruriens in fallow areas • Controlled grazing • Creating plantations of nitrogen-fixing leguminous trees such as *Acacia* ssp., *Albizia lebbeck*, and *Leucaena* ssp. during fallow periods (forest fallow)	Ganry et al. 2001 (semiarid Africa); Quansah et al. 2001 (Ghana); Bosma et al. 1993 (Mali); reported in Ganry et al. 2001 (semiarid Africa)

organisms that carry out critical ecosystems services such as the recycling of organic matter and redistribution of matter and energy (Danielopol et al. 2003). Human agents in all systems must practice judicious use of water to ensure adequate quantity and quality for the future. Within the field system, soil and crop management can have negative ramifications on the quality of water available to other systems through the diversion of feedback to underground aquifers and the introduction of contaminants such as excess nutrients, organic and inorganic compounds, and sediment.

Conserving Water through Soil Management

Soil physical and biological properties are the primary mediators of water conservation in an agricultural field. In addition to physical systems such as bunds, terraces, contour planting, and planting pits that can be used to conserve water in the field (Shaxson and Barber 2003), soil management strategies can be used as low-input, effective means of increasing water infiltration and reducing surface evaporation to conserve soil water. Rainwater harvesting that diverts farm runoff to temporary storage in tanks or small ponds, or increases in field storage through structures that slow and spread surface water movement, permitting infiltration, is also a valuable tool.

Increasing soil organic matter from 1% to 5% can lead to a fourfold increase in the ability of topsoil to hold water. In other words, 100 kg of dry soil that contains 1% organic matter can hold 30 kg of water, whereas soil with 5% organic matter can hold 195 kg of water (Brady and Weil 2002). Long-term studies at the Rodale Institute in Kutztown, Pennsylvania, provide evidence that practices that increase soil organic matter content improve water use efficiency in agricultural field systems. These studies demonstrated that increasing soil organic carbon from 2% to 2.5% increased corn and soybean yields by 28% to 36% in summer drought years under rain-fed conditions. "Drought-proofing" provided by increased soil organic matter was associated with an increase of 25% to 50% in percolation, or water movement, through the soil profile. As soil organic matter is increased and greater amounts of water infiltrate the soil, water return to underground aquifers and surface water may also increase.

Conserving Water through Crop Management

Water conservation strategies are also linked to crop selection and management. Through appropriate crop selection and management, field managers can reduce water losses through transpiration by crops and weeds, and assure sufficient water availability in the root zone for plant uptake. Strategies to conserve water through crop management should consider two critical aspects of plant physiology: plant species and varieties vary in their ability to use scarce water supplies, and water needs vary by stage of crop development.

Crop selection should be governed by knowledge of local growing conditions such as temperature ranges, water availability, and crop efficiency. In rain-fed systems, there is opportunity to improve water-use efficiency through plant variety selection and breeding. Unfortunately, large breeding programs have historically sought high yield at the expense of dryland adaptation. Local cultivars in particular may exhibit adaptations that support water conservation, such as a waxy cuticle to prevent plant water loss. These genetic resources should be protected and utilized to develop cultivars with a range of desirable qualities. Using a mixture of crops and varieties can also distribute risk posed by limited water availability and provide opportunities for increased productivity under optimal moisture conditions. One example of this is the intercropping of corn, sorghum, and millet.

The first critical stage of plant growth is seed germination. In most situations, delaying planting until rainfall is sufficient for crop germination is optimal to assure sufficient water to support seedling development. Planting should also be timed to so that rainfall periods coincide with critical stages of plant development, such as reproductive stages when water loss through evapotranspiration is often higher than the rate observed at other stages of growth. This phenomenon of terminal water deficit during flowering and pod-filling stages has been observed in many crops, including soybean (*Glycine max* L.) and pigeon pea (*Cajanus cajan* [L.] Millsp.) (DeBruyn et al. 1995; Patel et al. 2001). Other critical periods for yield determination are the first 30 days of growth and the periods just before and after pollination.

Irrigation Options for Smallholders

Around the globe, consumption of groundwater is rapidly increasing due to diversion of surface runoff to agriculture and alteration of landscapes for human use (Danielopol et al. 2003). Improved irrigation efficiency is considered a key strategy to slow and possibly reverse this process. Only about 17% of the world's available cropland is irrigated, yet this area produces roughly 40% of the world's food (Postel 1999). The increase in productivity from irrigation has already prevented the conversion of a significant area of natural vegetation, though diversion of water for irrigation has also contributed to regional water shortages. It is estimated that less than 3% of the world's water supply is fresh and suitable for irrigation. Collecting and transporting water to a field is often costly for smallholders. Appropriate timing of irrigation, with regard to both plant development and time of day, can reduce water loss through evaporation and transpiration, and promote optimal plant growth. Monitoring soil moisture with tensiometers, electronic resistance blocks, or with less sophisticated devices can promote more accurate use of limited water supplies without over- or under-irrigating. In this strategy, water is applied only when soil is reaching critical levels of dryness to less than full field capacity to prevent excessive losses and inefficient usage.

By delivering water directly to the plant root zone, micro-irrigation, or localized, systems maximize plant uptake efficiency and reduce water losses to runoff, soil evaporation, deep percolation, and transpiration from weeds (Sijala 2001). Micro-irrigation can reduce the quantity of water needed to meet crop demand, as demonstrated in table 4, and increase crop productivity (Namara et al. 2005). Drip irrigation systems have demonstrated reductions in water use by 30% to 70% and increases of 20% to 90% in crop yields (Postal 1999). Recent development of four kinds of low-pressure gravity drip systems specifically targeted to small farmers has improved prospects for increased implementation of these systems (Postel et al. 2001). They include the following:

Table 4. Comparison of irrigation requirements under well designed and managed drip, sprinkler, and furrow irrigation systems (modified from Sijala 2001).

Crop water demand	Quantity of water required for irrigation (mm/day)		
(mm/day)	Drip method	Sprinkler method	Furrow method
3.0	3.3	4.3	5.0
4.0	4.4	5.7	6.7
5.0	5.6	7.1	8.3
6.0	6.7	8.6	10.0

- bucket systems (20 liter) costing about $5 and covering an area of 25 square meters
- drum systems (200 liter) costing about $25 and covering 125 square meters, capable of expansion in 125 square meter increments at about $14 per increment
- shiftable drip systems costing about $50 and covering 1,200 square meter (similar to conventional drip systems but with reduced capital costs because they can be shifted)
- stationary microtube systems costing about $250 and covering 4,000 square meter (these systems consist of plastic lateral lines equipped with micro-tubes and cost about two-thirds less than conventional drip systems)

Despite advantages and availability of low-cost micro-irrigation, a 2005 survey in the Indian states of Mharashtra and Gujarat indicates that the technology has not been widely adopted by poor smallholders, primarily due to cost and educational barriers (Namara et al. 2005). Nevertheless, it has been suggested by Upadhyay (2004) that offering mortgage-free loans to poor landless farmers, usually women, coupled with local micro-finance plans, would allow them to lease land and implement micro-irrigation technologies resulting in cash income and improvement of household nutrition and food security. Micro-irrigation has mobility, and most equipment has multiple-use potential and is transportable.

The treadle pump for manual irrigation is a good example of a low-cost device developed specifically for smallholders. Costing $12 to $15, the treadle pump has a benefit-cost ratio of 5, an internal rate of return of 100%, and a payback period of one year (Shah et al. 2000). The pump enables a farmer to irrigate up to 0.3 hectare of crops. More than 1 million of them have been purchased in Bangladesh alone (Frausto 2000).

Reducing Contaminants

The World Commission on Water estimates that more than half of the world's rivers are "seriously depleted and polluted, degrading and poisoning the surrounding ecosystems, threatening the health and livelihoods of the people who depend on them" (United Nations Environment Program 2002). Many of the pollutants found in surface and groundwater supplies originate in managed field systems. As previously discussed, sediment due to erosion is a critical threat to the water supply. Other contaminants include nitrogen and phosphorus from synthetic fertilizers, pesticides, heavy metals, organic pollutants such as nutrients and pathogens from livestock, and pharmaceuticals such as steroids, antibiotics, and other drugs used in animal production. Decisions regarding the use of these materials often fall to the human managers of individual field systems. These managers determine if, when, and how much of an external input will added to the system or, in the case of livestock, what areas livestock will be restricted to.

Management strategies that reduce fertilizer and pesticide applications will reduce the quantity of pollutants that reach ground and surface water. These strategies may include increasing soil organic matter, as previously discussed, and initiating integrated pest management (IPM). Sustainable management may also include continued use of synthetic fertilizers and pesticides under certain conditions. For this reason, it is critical that adaptive management and local learning on crop nutritional requirements and methods to determine organic and synthetic fertilizer application rates that are neither too high nor too low. Training in IPM practices such as scouting will also promote appropriate safety practices, and timing and application rates of pesticides.

Protecting Biodiversity

The diversity of biological life on Earth has been exploited by humans for thousands of years for the purpose of survival. Biodiversity in agroecosystems is part of the complete range of biodiversity that humans depend on for food and fiber. Though often considered only in higher system levels, biodiversity is an important aspect of regenerative and sustainable management of field systems (see text box below). Figure 7 illustrates primary components and functions of biodiversity in field systems.

Biodiversity and plant breeding: Maintaining genetic resources

An important aspect of biodiversity conservation is the maintenance of local crop and animal genetic resources. Field managers play a central role in this activity as the primary decision makers regarding which crops and animals should be introduced to a field system and which individuals should be used to provide seed or stock for future generations. A necessary step in promoting sustainable management of genetic resources is the creation of institutions that strive to connect field managers to international research centers, catalog local knowledge and genetic resources, and engage field managers in the process of cultivar selection, multiplication, and distribution.

In recent years, international agricultural research centers and other research institutions have established participatory planting breeding programs aimed at improving smallholder adoption of improved varieties and maintaining beneficial cultivar diversity (Probst 2004). The aim of such programs is to ensure that the needs of farmers are met by research programs while promoting development and biodiversity (Vernooy and Stanley 2003). Participatory planting breeding combines farmer training based on local knowledge and environmental conditions with plant breeding programs targeted at overcoming local challenges to production. This approach gives farmers greater input into their own livelihoods and offers scientists access to new sources of knowledge and genetic material that can be utilized globally. The involvement of farmers in seed multiplication and distribution also encourages adoption by their peers, a key to widespread, successful scaling out of new innovations and technologies.

Conserving Crop and Animal Genetic Resources

The genetic diversity of crops and livestock represents an important component of biodiversity in managed field systems. Genes that control the physiological adaptation of plants and animals are the primary source of an organism's ability to respond to diverse abiotic and biotic stresses in the field environment. The potential yield of a specific crop variety, for example, is determined by its genetic makeup, as is its ability to reach this potential in a specific field system environment. Similarly, genes determine an animal's tolerance to insects and pathogens, ultimately dictating whether the animal thrives in the presence of these pests.

Crops and animals selected for certain environment and management conditions are likely to possess genes that allow them to reach optimum growth potential in that environment and develop internal protection mechanisms against common pests. For this reason, local crop cultivars and animal breeds are a good choice for a field system, for natural adaptations favor yield stability without requiring a high level of external inputs. Also, protection of local genetic resources

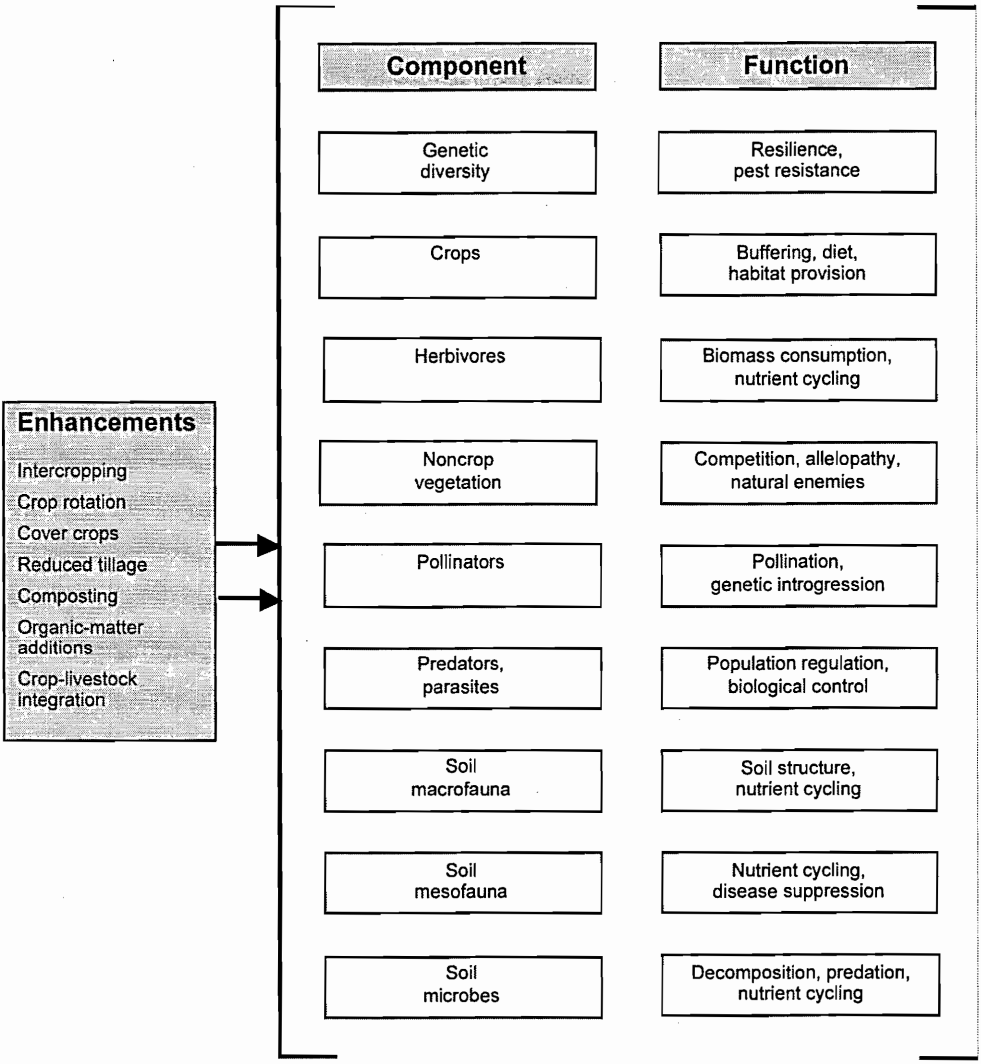

Figure 7. Agroecosystem biodiversity (adapted from Altieri 1999).

maintains the stock of potentially beneficial cultivars that field managers and breeders may use to improve production, confer protection against a specific pest in other locations, and exploit beneficial relationships among various components of a field system.

Enhancing Crop Diversity

Increased crop diversity represents a central strategy in sustainable management of an agricultural field. Introducing crop diversity will enhance diversity of other living organisms within the system and lead to secondary benefits such as improved nutrient availability (as contributed by soil biodiversity), pollination (by animal populations), and pest management (provided by soil biota and insect predators). Crop diversity also provides a buffer against crop failure or changes in agricultural markets. Though increased yield is cited most often as the primary indicator of improved production, increased crop diversity should also be considered a central objective of sustainable management. Finally, crop diversity can provide benefits to human agents interacting with the field system by offering a broad range of nutritional options for subsistence farmers. Tropical American indigenous civilizations, for example, used corn, beans, peppers, and squash as their principal field mixture both to benefit the ecological processes of the system and to create a rich and balanced diet.

From an agronomic standpoint, crop diversity confers biotic and abiotic stress avoidance, ultimately contributing to enhanced crop production (Clergue et al. 2005). The biotic stresses mediated by crop diversity include insects, weeds, diseases, and nematodes. Potato late blight (the disease that led to the Great Irish Famine of the 1840s) and Southern corn leaf blight (which threatened US crops in the 1970s) are good examples of how reliance on a single species can result in catastrophic epidemics that may have been avoided through diversity. Crop diversity can also provide a buffer against yield losses in a single crop due to environmental stresses such as extreme variation in temperature and rainfall. Diverse cropping systems exploit the broad range of ecological niches in a field during a specific growing season, enabling field managers to maintain yield stability and achieve other production goals from year to year.

Species and cultivars are the cropping system components that define crop diversity in a field system. Crop diversity has both temporal and spatial components. Different crops existing within the same field at the same time are an expression of spatial diversity. Polycultures—mixed stands of species and cultivars—are an important component of cropping systems used historically by smallholders (Altieri 1999; Haugeraud and Collinson 1991). Land equivalent ratio comparisons frequently reveal the increased efficiency of polycultures over monocultures (Schulthess et al. 2004; Hiebsch and McCollum 1987). Temporal diversity is represented by different crop species existing in the same field at different times (seasons or years). This is commonly the case with crop rotation.

Crop diversity supports biodiversity among field inhabitants critical for pollination and crop protection from pests, functions essential to field-level productivity. An estimated 75% of the world's major crops depend on pollination by bees, other insects, hummingbirds, and bats (Cassman and Wood 2005). Diversity of food sources and habitats supported by crop and soil organism diversity attracts pollinators that drive sexual reproduction. Pollination rate has a direct impact on the yield of numerous crops and helps maintain genetic diversity of crop plants (Clergue et al. 2005). Crop diversity also supports large, diverse populations of insects, arthropods, and bird predators that hold insect pest populations in check (Clergue et al. 2005) and promote stability in insect populations to minimize severe yield losses to a single pest outbreak (Altieri 1999). Research also suggests that greater diversity within a community confers resistance to, but does not always prevent, invasion by alien species (Shea and Chesson 2002).

Intercropping

Intercropping—combining two or more rows of crops in the same field—is widely practiced in Africa, Asia, and Latin America as a management strategy to introduce diversity and reduce risk. Increased diversity, in turn, performs several functions. Olasantan (2001) found that intercropping cassava with a high-density planting of okra (50,000 plants per hectare) reduced weed growth by 25% to 45% due to increased shading. Legumes planted with a cash crop can provide nitrogen needed by the cash crop, resulting in a reduced need for external nitrogen addition (Borin and Frankow-Lindberg 2005). Intercropped systems may also be composed of mixed cultivars of a single species. In East Africa, farmers report planting both early and late maturing maize cultivars to manage potential environmental stresses as well as meet different end use needs, such as home consumption and commercial sale (Haugeraud and Collinson 1990).

Crop Rotation

Crop rotation is a means of introducing temporal diversity that promotes crop protection and benefits soil nutrient cycling, water conservation, and output. On the same piece of land, growing a crop following one of a different species can also disrupt the life and reproductive cycles of pests such as weeds, insects, pathogens, and nematodes. There are two crop rotation strategies. In a *seasonal rotation*, a sequence of two or more crops is grown in a field in a single year; this same sequence is often repeated the following year. Farmers in Ethiopia, for example, grow potatoes or a cereal such as wheat during the period of long rains and, in the same year, grow another cereal such as maize during the period of short rains.

In an *annual rotation*, the crop grown in a field varies from year to year; an annual rotation may be as simple as yearly alternating between two crops or involve multiple crops grown in sequence over several years. Many farmers in Africa use an annual rotation in fields where millet is grown:

- year 1—millet
- year 2—cowpea
- year 3—millet
- year 4—cowpea

In this example, both millet and cowpea are important crops for home consumption and sale. Inclusion of a nitrogen-fixing legume such as cowpea in rotation with other cash crops can also boost overall productivity of the crop system.

Crop rotations including a legume are used in many rice production systems across Asia. A recent study in India demonstrated that including the legume mung bean (*Vigna mungo* L.) in the traditional Asian rice-wheat cropping system resulted in higher productivity, gross income, and net return than rice-wheat alone (Sharma and Sharma 2005). The sequence of this rotation is as follows:

- spring—mung bean
- summer—rice
- winter—wheat

Other rotations commonly used in Asia include the following:

- spring rice–summer rice–winter soybean (or other winter legume)
- spring mung bean (or soybean)–summer rice–winter maize
- spring peanut–summer rice–winter sweet potato

In these examples, the legume can be used for human consumption; however, it is not necessary that all crops in a rotation have a direct human benefit.

Though used for human consumption only on a limited basis, mucuna or velvet bean [*Mucuna pruriens* (L.) DC. var. Utilis (Wright) Bruck] is used worldwide in rotation with cash crops. In Central America the velvet bean is referred to "frijol de abono" (fertilizer bean), for it can fix more than 200 kg N per hectare annually, well over the quantity needed by corn. In western Kenya, mucuna grown following an intercrop of maize (*Zea mays* L.) and common bean (*Phaseolus vulgaris* L.) can lead to an increase in the yield of the subsequent maize crop as well as provide herbage for animal fodder (Nyambati et al., 2006). Also, *Mucuna* ssp and other legume species such as *Canavalia* ssp. can inhibit weed growth and suppress some species of plant parasitic nematodes (Camaal-Moldonado et al. 2001; Arim et al. 2006). Intercropping of grains and legumes is a regenerative practice with the potential to increase both the organic matter of soil and grain yields.

Promoting Soil Biodiversity

Soil supports a variety of living organisms that play an important role in field system function, resilience, and regeneration. For example, soil bacteria such as *Rhizobium* and *Azotobacter* and blue-green algae are responsible for the fixation of atmospheric nitrogen. Exploitation of free-living nitrogen fixers and those associated with leguminous crops is a key strategy to reduce reliance on costly external sources of N to support crop growth. Other bacteria in soil serve to mediate the impact of pests such as insects, non-beneficial nematodes, weeds, and diseases on field systems by serving as biological control agents (Kennedy 1999). Another class of microflora, mycorrhizae, is a fungal species symbiotically associated with plant root systems. These combinations can enhance nutrient uptake and water use efficiency of crop plants.

Macrofauna such as earthworms, termites, centipedes, and millipedes directly and indirectly affect decomposition and nutrient cycling through activities that mix, transport, and break apart litter; initial decomposition of resistant materials such as cellulose and chitin polymers; and provision of a food source for microbial populations in the form of castings. Soil arthropods play an important role in the regulation of agricultural pests such as insect and seed predators. Soil organisms also include antagonists that inhibit soil pathogens. Suppression of disease in environments favorable to the growth of certain pathogens is often observed in fertile soils with high levels of organic matter. These soils support diverse and large microbial populations such as actinomycetes and bacteria that may confer disease suppression (Altieri 1999). The critical functions carried out by soil organisms, summarized in table 5, underscore the necessity of management practices that enhance soil biodiversity.

Field management has a significant impact on soil biodiversity and activity. Practices that lead to increases in soil organic matter, such as mulching, cover cropping, and composting, all of which have been discussed in this chapter, support diverse soil populations. In contrast, tillage can significantly reduce soil microbial diversity (Lupwayi et al. 1998; Wander et al. 1995; Hassink et al.

Table 5. Functions carried out by soil organisms (biota) (adapted from Bot and Beites 2005).

Function	Organisms involved
Maintenance of soil structure	Macroorganisms (invertebrates) that turn soil; mycorrhizae, other microorganisms
Gas exchange, carbon sequestration	Soil microorganisms
Soil detoxification	Soil microorganisms
Nutrient cycling	Soil microorganisms; some litter- and soil-feeding invertebrates
Decomposition of organic matter	Litter-feeding invertebrates, fungi, bacteria, actinomycetes and other microorganisms
Suppression of pests, parasites, diseases	Mycorrhizae and other fungi, nematodes, bacteria and other microorganisms, earthworms, various invertebrate predators
Sources of food and medicines	Various insects, earthworms, vertebrates, microorganisms and their byproducts
Symbiotic and asymbiotic relationships with plants and their roots	Rhizobia, mycorrhizae, actinomycetes, diazotrophic bacteria, other rhizosphere microorganisms, ants
Plant growth regulation (positive and negative)	Rhizobia, mycorrhizae, actinomycetes, pathogens, phytoparasitic nematodes, rhizophagus insects, biocontrol

1991). Zhang et al. (2006) reported that fungal contribution to the microbial community increased with a decrease in tillage and that reducing human disturbance may facilitate the development of microbial communities that favor carbon retention in agricultural soils. By creating a homogenous soil environment, tillage eliminates habitats formed through the natural process of soil stratification and, therefore, the soil microorganisms exploiting these niches (Altieri 1999). Plowing can also physically break up fungal mycelium, resulting in reduced populations and activity. Reduced tillage practices that leave mulch or residues avoid or eliminate physical disruption and provide a variety of habitat and food sources that support diverse populations. These surface mulches also provide organic materials that are broken down by soil micro- and macro-organisms, adding to the organic matter pool.

Reducing Dependence on External Energy Inputs

Many field managers now rely on nonrenewable fossil fuels to meet external energy requirements in managed fields. Such reliance on a finite resource can limit the sustainable development of agricultural and natural resources. As fossil fuels become more expensive, field managers, particularly smallholders, must utilize alternative management strategies to reduce external energy demand. Regenerative practices are those that reduce external energy demand by efficient use of internal resources to provide ecosystem services. The term *low-input agriculture* is often used to refer to production systems that use combination of internal resources to replace and/or eliminate the need for external energy resources.

Energy Dynamics in Low-Input Agriculture

David Pimentel of Cornell University and co-workers have conducted several studies of energy-use efficiency in low- and high-input agricultural systems. In Mexico, for example, low-input corn production resulted in a low yield level of about 2,000 kg per hectare but had an energy output to energy input ratio of 12:1. In contrast, a high-input system in Minnesota resulted in a yield of 6,500 kg per hectare but had an energy output to energy input ratio of 2.9:1 (Pimentel et al. 1973). This comparison indicates that low-input systems can be more energy efficient than conventional high-input systems. More recently, Pimentel and Pimentel (2005) have estimated output to input ratios of an "industrialized" and an "improved sustainability" intensive maize system at 2.8:1 and 4.8:1, respectively. They suggest that these energy efficiency improvements of intensive production systems favored for higher yields and lower land area demands are the result of integration of low-input strategies such as crop rotation, livestock integration, cover cropping, and reduced tillage.

Alternative Sources of Fertility to Enhance Energy Efficiency

Of all agricultural practices, nitrogen fertilization with ammoniated fertilizer is the most energy intensive, representing up to 30% of the fossil fuel requirement for conventional maize production (Pimentel et al. 1973). Alternative strategies to meet nitrogen requirements include the application of manure (see "Compost and Other Organic Amendments" for more information) and integration of nitrogen-fixing legumes through crop rotation, intercropping, and cover cropping. Legumes provide several cost-saving strategies by reducing the external energy required to generate plant-available nitrogen and reducing or eliminating the need to purchase external sources of nitrogen such as chemical fertilizers. In the Rodale Institute's farming systems trial in the temperate United States, the fossil fuel requirement for legume-based organic production of corn and soybeans is 33% lower than the requirement for conventionally produced corn and soybeans. The legume-based systems have demonstrated equivalent yield and quality for both crops.

Integrating Crops and Livestock

Although the numbers of large specialized livestock farms have increased dramatically in developed countries since World War II, mixed crop-livestock farms still predominate in developing countries. These systems occupy about 2.5 billion hectares and globally account for 54% of meat and 90% of milk supply (CAST 1999). Crop-livestock systems employ a diversity of complementary resources, including crop residues, forage grasses and legumes, and manure. If managed properly, the system may substantially increase the efficiency of nutrient recycling. In the case of limited-resource smallholders, the integration of livestock in cropping systems is highly desirable because it adds flexibility and stability, both financial and physical, by buffering the system against climatic stresses and market fluctuations. Furthermore, livestock are easily marketable and provide a relatively high level of return per labor unit as well as manure, a valuable byproduct that can be used as fertilizer.

From a field-level perspective, ruminant livestock can take advantage of crop residues in the utilization and conversion of these fibrous, human-inedible materials to food, fiber, and other useful products as well as through their digestion and redistribution as manure. As mentioned by Latham (1997), management of crop residues is one of the most important issues of crop-livestock systems in the semiarid tropics; however it is not an issue with a simple technical solution. It requires that the farm household consider the risks and tradeoffs involved.

Many of the attributes of crops and livestock that are considered complimentary are crucial to the economic and ecological stability of the field system. Manure is probably the most obvious because of its role as a source of organic fertilizer. Because a large proportion (60% to 90%) of the nutrients that ruminant animals consume at the field level from pasture and crop residues is recycled in the dung and urine, the management of grazing patterns and the collection and redistribution of excreta is critical to crop production in many areas.

Furthermore, ruminant excreta can be a source for biogas generation for household use. Biogas generation for cooking and lighting can be a valuable resource in areas where water is not a limiting factor and temperatures remain between 20°C and 40°C most of the time. The excreta from a few cows collected and sealed in a digester could produce 2 to 3 cubic meters of methane daily, enough for a family of six to use in lieu of firewood or kerosene (FAO 2001). Moreover, the spent slurry from the digester remains a valuable fertilizer material for crop or pasture production. A variety of mixed crop-livestock systems have proved successful in many different environments. They may involve ruminants such as cattle, sheep, and goats; monogastrics such as pigs, chickens, and turkeys; and various combinations of crops and trees, depending on climate and available resources. Crop production also may be heavily dependent on animal traction for land preparation and cultivation and transport for market access. Economically, livestock also represent an additional source of income beyond crop production. It is imperative that farmers involved in integrated crop-livestock systems think holistically about the system, realizing that maximization of an individual system component such as crop yield may not result in the optimization of the system as a whole (figure 8).

As mentioned previously, there are many potential benefits from an integrated crop-livestock system at the field level. Nevertheless, tradeoffs are necessary to implement the system (table 6). For example, the field manager must have expertise in both crop and animal husbandry, and achieving economies of scale is difficult in this situation (Van Keulen and Schiere 2004).

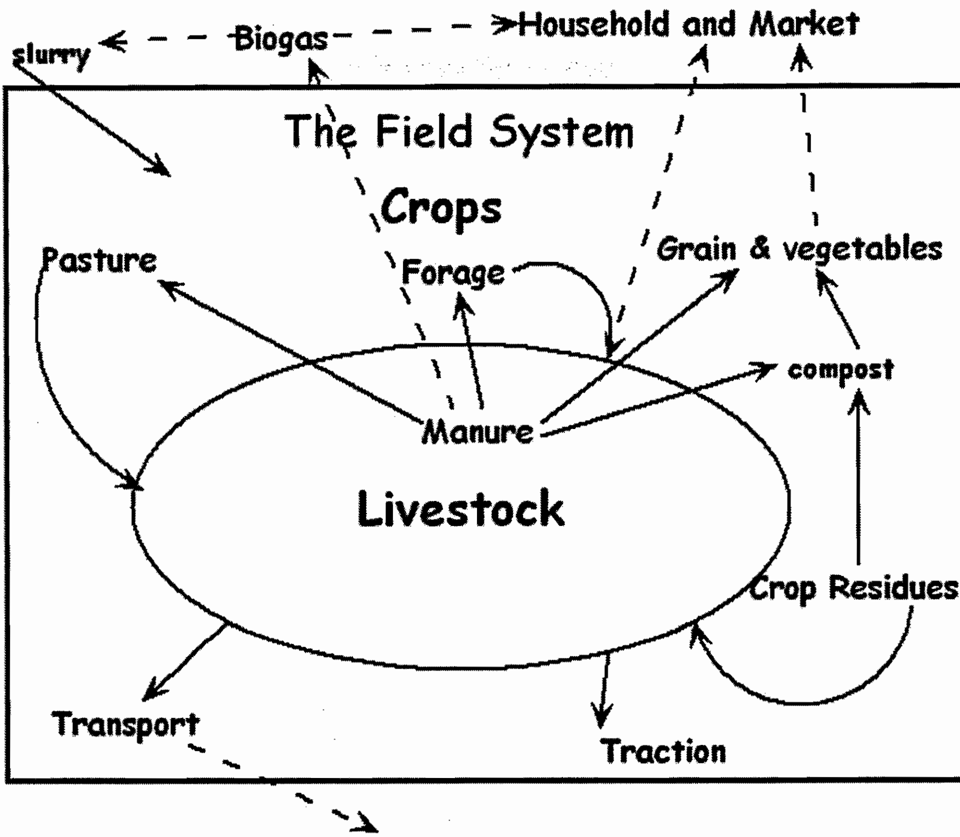

Figure 8. Crop-livestock integration in the field system.

Table 6. Benefits and challenges of crop-livestock systems (Van Keulen and Schiere 2004).

Benefits	Challenges
Buffered against fluctuations in trade and price	Requires double expertise
Buffered against climate fluctuation	Fewer economies of scale
Erosion control through perennial forages	Erosion hazard due to overgrazing
Higher nutrient recycling due to more direct soil-crop-animal manure relations	Nutrient losses through competitive uses for residues
Diversified income source	Continual labor requirement
Draught power allowing larger cultivated area, more flexible residue management	Capital required
Source of security and savings	Social function, potential cause of conflict

Note: Some of these issues could occur both in the left and right hand columns due to local context.

Overgrazing could cause compaction and erosion. Competition for crop residues by other uses such as fuel, building materials, or off-farm sales could diminish or eliminate nutrient recycling.

Management of pests such as diseases, insects, nematodes, and weeds that interrupt farm systems' function and production relies on the integration of practices that exploit complementary interactions of field system components. This approach is referred to as integrated pest management or IPM. Due to the number of resource materials available on IPM, this book will not provide an exhaustive discussion of this concept. It will, however, highlight several key practices used in IPM systems that provide cross-cutting benefits and enhance field system resilience. As with all adaptive management strategies, IPM is most effective when the practices employed are adapted for local environmental and cultural conditions.

Cultivar selection is a cornerstone of IPM. Using the rich diversity of plant and animal genetic resources available in the biosphere, both scientists and smallholders have identified plant cultivars that demonstrate resistance to specific pests. For example, use of resistant cultivars has been identified as a key strategy for effective integrated management of diseases in major crops such as wheat, potato, peanut, sorghum, and maize (Mehta et al. 1992; Pande et al. 2001; Ellis-Jones et al. 2004; Marley et al. 2004; Nyankanga et al. 2004). Similarly, the exploitation of host plants resistant to specific insect pests has been a central component of IPM programs for numerous world crops, including sorghum, rice, and cowpea. Introducing resistance to insects and diseases is a focus of many international breeding programs.

Crop cultivars vary in their abilities to compete with and adapt to weeds. There are several characteristics that a cultivar may exhibit that enhance competitive ability with weeds. For many row and horticultural crops, rapid growth and early canopy closure can result in the suppression of weeds. For this reason, using transplants when possible for horticultural crop production is advantageous. Use of transplants will increase production costs, so the economic benefit of using transplants must be weighed against cost. The physical structure of a cultivar may also affect competitive ability. Tall grain crops, for example, are generally more competitive with weeds because they intercept light. A large leaf area index and high biomass production can also contribute to a cultivar's competitive abilities. Local varieties often have these desirable traits that may not be prioritized for commercial seed varieties from centralized breeding programs.

IPM also relies on knowledge of the targeted pest. An organism cannot survive in an ecological system without resources for food and habitat provision, including locations for reproduction. When field managers eliminate these basic necessities from the system, the targeted pest population will be reduced. Strategies to deprive pest populations include delayed planting to avoid pest emergence, cultivation, and crop rotation. IPM may also include exploitation of pest antagonists such as soil pathogens, natural enemies, and biofumigants. Strategies to enhance these beneficial populations are those that promote biodiversity within the system, the direct and indirect benefits of which were discussed previously.

Another consideration in IPM is the extent to which management of pest populations is essential to eliminate interference with production goals. For example, the goal of eradicating weeds is unrealistic and unneeded. Most crops have a "critical weed-free period" during which competition from weeds is yield-limiting; the presence of weeds during growth phases outside this critical period is not detrimental to yield. In most situations, the critical period is in the first one-third of the crop growth cycle. With crops such as beans and corn, this means that controlling weeds for the first 40 days is sufficient to prevent severe losses. Weeding is not necessary through the entire period of crop growth. Similarly, field managers may use thresholds to determine the critical population size at which control of weed and insect populations is essential to avoid crop damage. The threshold concept recognizes that the presence of some weeds and insects can be tolerated with little negative effect on crop output.

Another system component to consider in developing an IPM plan is soil fertility. Recent research and reviews of past studies indicate a link between soil fertility management strategies and insect pest populations, for soil fertility management can influence the resistance of crops to insect pests (Altieri and Nicholls 2003). For example, numerous studies have documented increased damage and/or growth of insect pests on crops that receive synthetic nitrogen fertilizer (Scriber 1984). This increase is thought to be caused by high concentrations of foliar N, particularly following fertilizer application. In contrast, use of organic N does not lead to high foliar N concentrations or N pulses and has been cited as a factor leading to lower abundance of insect species in organically managed crops (Lampkin 1990). Though the relationship between soil fertility and insect pests is not well understood, current available knowledge suggests that strategies to enhance soil quality and organic matter will have positive impact on insect pest management.

In addition to benefiting ecological components of the field system, IPM can also have a positive impact on the human agents in the field system. Smallholders in developing countries commonly devote more than 50% of their labor time to weeding, a task often done by women (Ellis-Jones et al. 1993; Akobundu 1996). IPM empowers field managers to optimize use of limited labor resources and reallocate labor to other critical field and household tasks.

Conclusions

The field system represents the fundamental unit nested in farms, landscapes, watersheds, and ecosystems. Agricultural fields are governed by the ecological processes of photosynthesis and respiration that transform solar energy and regulate nutrient and mineral cycles. Field systems contain biotic and abiotic elements that are necessary to convert solar energy into plant tissue and subsequently to animal products. Guided by human interventions, field systems produce food, forage, fiber, fuel, and building materials. The production efficiency of these commodities drives human economies and to a large extent determines quality of life for human populations. The capability of field systems to conserve natural resources and provide ecosystem services is dependent on the knowledge and skill of field managers, land tenure issues, and wise governance. These issues and more will be explored in the chapters that follow.

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Chapter 3

Sustainable Agriculture and Natural Resource Management in Farm Enterprise Systems

Peter Wyeth

Farm enterprises, especially those in developing countries, take on a large variety of activities. They may grow a number of rain-fed and irrigated crops for both home consumption and sale, raise two or three kinds of livestock on their own land or on common pasture, and gather wood for fuel and construction—and those are only the on-farm operations. Family members may also be engaged in education or employment off the farm. Among these various possibilities, household members must decide which activities to undertake and how, and they do not make their decisions in isolation. They are guided, sometimes forced, to one decision or another by considerations arising from aspects in their wider context, such as cultural norms, market conditions, technological possibilities, and land and water rights. It is because of the interconnectedness of farming activities and their links with off-farm environments that a farm is a system and not simply a bundle of operations collected together. Viewing a farm as a system is not new, and over the years the system has been presented in many different ways. As in the other chapters in this book, the focus is on decision making for adaptive management as it bears on agricultural livelihoods using natural resource management practices and improving sustainability through innovations in farming practices.

Overview of the Farm Enterprise as a System

Figure 1 illustrates the farm enterprise system as it will be discussed here. This way of depicting the farm enterprise characterizes the system as a set of interacting components and influences on farm decisions. Also like other, similar diagrams, it is a less-than-perfect representation because it simplifies to bring out key points. It would be easy to complicate this one by, for example, adding arrows to show that output markets (box on the right) influence production possibilities and risk (oval on the left), but too much detail can be distracting. There are several features that this diagram aims to highlight in particular:

- ***The core elements of the farm enterprise make up a circular system, or feedback loop.*** Clearly farm level resources—most broadly its land, labor, and capital—are crucial in determining what a farm can produce, or its production possibilities. Furthermore, these resources can be augmented or diminished depending on how good farmers' management decisions are in raising the level of farm production and allocating it between household consumption, direct reinvestment back into farm resources (e.g., as seed or animal feed),

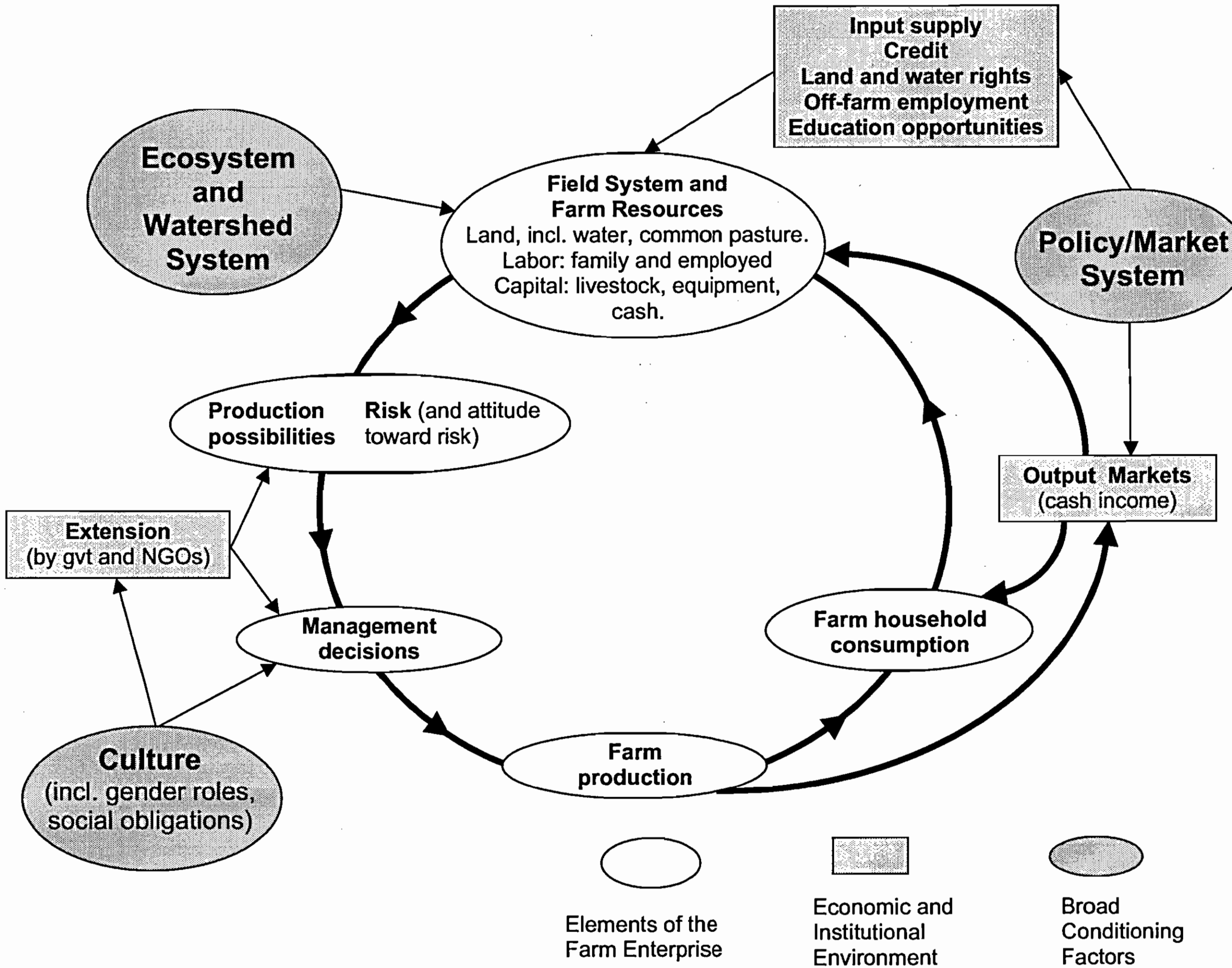

Figure 1. Factors affecting farm enterprise decisions.

and sales for cash to purchase more resources. Farmers will naturally be inclined to adopt innovations that they see as likely to have a positive effect on current livelihoods and future farm resources.

- ***There is an economic and institutional environment that is external to farms but has a very large effect on farmers' ability and incentive to make good use of their resources.*** The quality of advice that extension services provide influences the range of choices that farmers face and their ability to make wise decisions regarding them. Output markets and other aspects of the economic and institutional environment (input supply, credit) condition farmers' ability and incentive to convert production into cash income and shape farmers' choices of what, when, and how to produce. They also condition what farming innovations are appropriate or inappropriate to promote.
- ***Risk, and how it affects farmers' assessments of their production possibilities, emanate in large part from objective conditions, especially the nature of farm resources at their disposal and the farm's economic and institutional environment.*** Writers on technical change in agriculture have often put farmers into categories depending on their readiness to adopt new practices, attaching labels to them such as innovator, follower, or laggard. These terms allude to the psychological makeup of the people concerned, implying that they were somehow born with a greater or lesser eagerness to adopt change. However, while some farmers may be innately more or less timid than others in welcoming new possibilities, the resources they have available and the context in which they operate make for circumstances that can be objectively more or less risky. Recognizing this will help extension agents and implementers of projects determine what innovations they should or should not suggest.

  (Economic literature commonly makes a distinction between risk and uncertainty. Risk applies where a probability can be attached to the occurrence of an event, and uncertainty arises where no such probability can be assigned. For example, past experience may have told farmers that rainfall reaches 500 mm four out of every five years, so (if the year-to-year distribution is random) there is a 20% probability that in any given year rainfall will be less than 500 mm. Now, with climate change, farmers may observe that this pattern is less reliable; that is, uncertainty is creeping in where before they could calculate risk. This chapter only refers to risk, effectively presuming that farmers can assign probabilities, either objective or subjective, to different outcomes that are possible in their future.)
- ***Cultural influences are inherent in how farm households perceive and organize themselves and how extension services advise them.*** They are also the most difficult for communities themselves to take into account. It has been said that trying to be aware of one's own culture is like trying to smell one's own breath. Each person's culture seems to be the natural way to perceive the world until he or she notices that other people have different perceptions. Promoters of innovations commonly come from outside the regions where they are working (even extension agents are often from other areas of the country) and must not presume that what seems natural to them will seem natural to local farmers.

It is also easy to show in this diagram how the inner and outer nested systems impinge on the farm enterprise. Field systems are clearly part of the farm, influencing the nature of resources at its disposal. Farm resources are also affected by the watershed system and ecosystem within which the farm is located, while the policy-market system determines the structure and functioning of the output and input markets and other components of the economic and institutional environment.

The following sections in this chapter look more closely at how the nature of the farm enterprise system, the economic and institutional environment, risk, and culture affect management decisions and resource use. As smallholders are so often lumped together as if they were a homogeneous group, data will be presented that illustrate the considerable variability among them. Generally the facts and figures refer to differences among countries, but similar variability also exists within countries and, as extension workers well know, within most villages.

Farm-Level Resources and Decisions on Natural Resource Management Practices

Arable Land

While smallholders by definition own only modest amounts of land, there are differences in the size of landholdings among them that are important. Table 1 illustrates this, using figures from Africa. In the left-hand column, average land per household is less than 3 hectares for all countries but varies from 2.76 hectares in Zambia to about one-fourth of that, 0.71 hectares, in Rwanda. Looking at the amount of land per capita (i.e., per household member), the variations within each country are even greater, and the smallest farms have very little land at all. Malawi has the least uneven distribution, with the area per person in the top quartile being only seven and a half times that of the area in the lowest quartile. In Rwanda, which like Malawi is very small and densely populated, and in Ethiopia, people in the highest quartile have about 20 times more land than people in the lowest.

The amount of land plays a role in determining what resource management decisions are appropriate to farmers, and appropriate innovations cannot necessarily be uniform at even the most local level. For one thing, farmers with just enough land to subsist on in a good year are likely to perceive any modification in farm practices as much riskier than farmers who probably will not starve if they suffer some crop failure. Farmers at risk will want to be more certain of a favorable outcome to any change they make. Risks also vary with different forms of land tenure, as a later section of this chapter will show.

Another point is that what kind of innovation is appropriate will vary with the size of a farm's landholding. For example, interplanting maize with beans or other leguminous crops is a common practice that increases yields per hectare. This is a particularly valuable practice where land is

Table 1. Variations in household access to land in Africa.

Country	Avg. land per household (ha)	Household land access per capita by quartile (ha)					Highest/ lowest raio
		Avg.	Lowest 25%	Low-mid 25%	High- mid 25%	Highest 25%	
Ethiopia	1.17	0.24	0.03	0.12	0.22	0.58	19.3
Kenya	2.65	0.41	0.08	0.17	0.31	1.10	13.8
Malawi	0.99	0.22	0.08	0.15	0.25	0.60	7.5
Mozambique	2.10	0.48	0.10	0.26	0.40	1.16	11.6
Rwanda	0.71	0.16	0.02	0.06	0.13	0.43	21.5
Zambia	2.76	0.56	0.12	0.12	0.26	1.36	11.3

Source: Extracted from table 3.1 in Economic Commission for Africa, 2004. Original data from Jayne et al. (2001).

scarce, and it is no accident that there is special interest in testing and extending variations of this technique in countries such as Malawi where the average amount of land per household is less than a hectare. Where farmers have more land at their disposal, they are likely to be more interested in improved fallows—for example, covering their land in seasons between food crops with a leguminous shrub such as *Tephrosia vogelii.*

Pasture and Livestock

Farms in some countries have at their disposal only the land to which members of the household have private title, but in many countries they also have access to common pastureland. Table 2 shows that the amount of pasture available relative to arable land varies immensely. How much pasture a country has depends partly on the density of population, for people plow up pastureland to plant crops when population expands. It also depends on the quality of land. When land is poor in fertility or rainfall is low, the best way to turn the land to economic benefit is to run livestock on it. In Mali the pasture is mainly in the Sahel—the area just south of the Sahara desert where rainfall is uncertain and the land poor. There are similar dry areas where pasture is important in Bolivia (the Altiplano), China (Tibet and Inner Mongolia), and southern Africa (around the Kalahari and Namib deserts).

Pasture gives rise to possibilities beyond simply adding livestock raising, for with animals comes the potential for fertilizing with manure. A number of field trials applying manure to millet were run in the Sahel under Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program Phase II, and a computer model was also developed to simulate the experiment (Badini et al. 2005; Wyeth et al. 2005). According to the latter, applying two tons of cattle manure per hectare could raise millet yield from 505 metric tons (mt) obtainable on an unfertilized field to 991 mt. The impact of manure from sheep and goats was slightly greater. A variation of this practice is to corral animals on fields for several nights after harvest, allowing them to graze on crop residues and, in return, contribute both their manure and their nitrogen-rich urine to the land. It is easy for livestock owners to adopt these practices, and farmers who have no

Table 2. Availability of pasture and arable land (FAO Statistical Yearbook 2004).

Country	Pasture (1,000 ha)	Arable (1,000 ha)	Ratio
Malawi	1,850	2,100	0.88
Mali	30,000	4,634	6.47
Rwanda	520	900	0.58
Zambia	30,000	5,260	5.70
Bolivia	33,831	2,928	11.55
Ecuador	5,087	1,616	3.15
El Salvador	794	640	1.24
Guatemala	2,602	1,360	1.91
Cambodia	1,500	3,700	0.41
China	400,001	137,124	2.92
India	11,040	161,785	0.07
Indonesia	11,177	20,500	0.55
Pakistan	5,000	21,302	0.23

livestock can come to arrangements with others in the area who do. In the corralling experiment in Mali, the animals came from herders with whom the crop farmers had earlier been in active dispute over access to land and water. In this case researchers and extension workers helped the two groups to see that they could manage their different resources to bring mutual benefit rather than conflict.

Water and Irrigation

The enormous variation in access to water for irrigation between countries (table 3) is seen also within countries and even villages, depending on proximity to rivers and streams and the depth of the water table. These factors also determine what irrigation methods can be used. Where water can be diverted from rivers or streams that run during the dry season, farmers can irrigate substantial areas to produce relatively low-value staple crops. Paddy rice across all continents is a classic example, and wheat in Afghanistan is another. Where fields are above streams or there is water in shallow wells, farmers can use treadle pumps (small foot pumps) to move it to where they need it.

As the textbox on the following page shows, whether to invest in a piece of equipment even as apparently modest as a treadle pump requires consideration of a number of factors. Further, while the view that irrigation reduces risk is generally true, it is not always so. Risk reduction is sometimes the specific justification for investment in irrigation: to water staple crops when rainfall is below normal, for example, or to reduce dependence on rainfed crops by making it possible to grow other crops during the dry season. However, if the aim is to make money by growing crops for market, as the case in the box indicates, the buyers must be there, and this is not always the case. Irrigation almost inevitably involves some kind of investment, at least in labor time and usually in cash for seed, fertilizer, and other variable inputs in addition to paying for the equipment. This increases the farmer's vulnerability to loss.

Table 3. Irrigated land as a percentage of arable land (FAO Statistical Yearbook 2004).

Country	Irrigated as % of arable land
Malawi	1%
Mali	3%
Rwanda	<1%
Zambia	1%
Bolivia	4%
Ecuador	29%
El Salvador	5%
Guatemala	7%
Cambodia	7%
China	37%
India	34%
Indonesia	14%
Pakistan	82%

A decision to use a treadle pump depends on more than water

Factors other than the presence and nature of a water source affect ability to profit from a treadle pump. To begin with, $70 to $120 of capital is needed, an amount only some farmers can afford out of household funds. Others will need access to credit, which depends on the governance and policy context; or a gift of a pump from government agencies or nongovernmental organizations.

Farmers also need to be assured of the substantial amount of labor needed to operate the pumps. Clearly this varies according to the nature of the crops to be grown and how well drained the soil is, but one rule of thumb is that about five hours of labor are needed to irrigate 3,000 square meters of land if it is well laid out (Hayes et al. 2002, p. 15), and this is necessary up to three times a week, again depending on the crop, how mature it is, and the soil. Many or most farm households face labor constraints and will find it necessary to make a tradeoff between adopting this technique and taking an opportunity to earn money off the farm or, where the treadle pump can be operated by children (some can, some cannot), sending their children to school.

When deciding whether to irrigate, farers should also take into account how well they understand the technique they want to use, and this turns on the availability of extension advice from government and nongovernmental agencies or other farmers. Where treadle pumps have been distributed without ensuring that farmers learn how to manage them, fields have been unevenly watered, water and labor wasted, stream banks damaged, and yields and profits poor, discouraging their further spread. Similar considerations apply to the drip irrigation systems that are increasingly the irrigation technique of choice for smallholders.

Output markets are also important here. Even when optimally managed, the capital outlay and sheer effort that treadle pumps and drip irrigation require represent a substantial cost to farmers. Consequently, they grow high-value crops to earn a good return, often vegetables to be sold fresh in local markets. Farmers who adopt treadle pumps early and are among the first to produce during the dry season make good profits, but as others in the area follow their example and increase supply, margins decline. At this stage, farmers begin to want advice not only on production but also on marketing. Extension agents typically have no training themselves in how to spot market opportunities and take advantage of them, or even how to calculate profits from crops grown for cash. This is a good example of how progress in developing one part of a farming system can produce a bottleneck in another part of it, and marketing is receiving increasing attention from donors and organizations engaged in agricultural development.

Livestock and Equipment

Part of how livestock enters into the farm-level system was covered above when pasture was considered. Here, among farm resources, animals are classed with equipment and buildings as capital items. In general, the more diverse or plentiful the capital, the less risky the enterprise. A farm with livestock as well as arable land will be less vulnerable to any particular crop or livestock disease than one with only animals or crops, though diversity will be less protection against serious floods or drought. A farm that has more equipment and buildings of an appropriate kind and in reasonable condition can produce more than one with less. For example, a farm with good granaries can store its staple crops for later sale or its own use, and a farm with a plow and draft animals can cultivate more land than one without. On the other hand, the other side of a capital asset is debt. When farmers take on a heavy amount to buy capital items, their increased obligations to off-farm creditors place them in a risky situation, for bad weather or an epidemic could leave them unable to pay their creditors.

Labor and Family Dependents

The household comprises males and females of different ages with varying levels of education and skill. In the context of a farm enterprise, household members can scarcely be considered without bringing in cultural considerations and the influence they have on the roles that men, women, and children are expected to play. More will be said on the age and gender division of labor in the section on culture. Here, the focus is on essentially quantitative considerations: the amount of labor available to the farm and the number of consumers in the household.

The dependency ratio (most generally, the number of people who have to be cared for in a household divided by the number of workers in it) is a good summary statistic that is probably as important to a farm as the amount of land it has available. This figure is bound to vary greatly from household to household, depending especially on the age (and vigor) of household members. Table 4 shows that dependency ratios vary substantially from one country to another, though most are between 1 and 2. Further, in 7 out of the 10 cases in the table the dependency ratio is larger for households headed by females than for those headed by males. Dependency ratios can be significant to extension agents and project implementers for at least two reasons. One is that a higher ratio will generally mean greater vulnerability to crop loss due to adverse weather or innovations that turn out badly. A farm family comprising a recently widowed mother and five young children will not be the best to experiment with an innovation where the outcome is uncertain, such as intercropping millet with a legume in an area where annual rainfall is variable. The second point is that labor is likely to be in shorter supply in a female-headed household. Even if the household has considerable livestock, a

Table 4. Dependency ratios in male-headed households (MHH) and female-headed households (FHH) (extracted from tables 1 and 2 in Quisumbing et al. 2001).

Country	Year of survey	Dependency ratio		% FHH
		MHH	FHH	
Botswana	1993	1.57	2.00	58.1
Côte d'Ivoire	1986-1987	1.19	1.28	8.1
Ethiopia	1989-1990	1.66	2.03	9.4
Ghana	1987-1988	1.10	1.63	29.3
Madagascar	1992	1.27	1.58	10.1
Rwanda	1985-1986	1.30	1.21	11.1
Bangladesh	1991-1993	1.32	1.42	8.2
Indonesia	1991-1992	0.86	0.66	6.8
Nepal	1988-1989	1.01	0.90	8.3
Honduras	1988-1989	1.71	2.51	9.3

Note: Dependency ratio in this table is the number of people younger than 15 or older than 65, divided by those between 15 and 65 years.

single woman with young children will not have time to spread manure on fields at a rate of 2 mt per hectare or commit to the labor involved in alley cropping. To raise soil fertility, she is more likely to prefer a less labor-intensive practice, such as undersowing maize with *Tephrosia* or pigeon peas, or applying microdoses of chemical fertilizer. Such labor concerns will also be much more important in countries where HIV/AIDS is especially widespread. Currently this means southern Africa, where the rate among adults aged 15 to 49 ranges from 32.4% in Swaziland to 14.2% in Malawi (and rates in these countries are much higher among young women than young men).

Cash Income

Cash income can be from at least three sources: sales of farm produce, wages earned by household members, and remittances from relatives who have migrated elsewhere and send home some of their wages. Cash income can fund purchases of improved seed and fertilizer, additional livestock, or equipment such as better plows or irrigation equipment. It can also permit a farm to take on hired labor, releasing children to go to school. Regular income from off-farm sources is especially important. It can allow some farms to survive that would be too small to provide a living on their own, which must apply to a number of the smallest farms in table 3 above. Off-farm income can also can be an important buffer against the variability of crop and livestock production, for it allows the family another means to provide for its sustenance, reducing the risk of taking a chance on a farming practice that is new to the area.

While there are great disparities among households within any country or village in the amounts of off-farm income received, the statistics do not show as much variation between continents or countries as might be expected. In table 5, the region with the lowest percentage of off-farm income in total rural income is South Asia, at 29%, and the highest in East and Southern Africa, at 45%. The figures for individual countries in Latin America shown in table 6 are rather higher. The fact that the highest figure of 68% is for Haiti shows that a high proportion of income from off-farm sources can be due to low rural incomes rather than to good off-farm employment opportunities.

Table 5. Share of rural nonfarm income in total rural income (extracted from FAO, The State of Food and Agriculture 1998).

	Rural nonfarm income
Africa	42%
E. and S. Africa	45%
W. Africa	36%
Asia	32%
E. Asia	35%
S. Asia	29%
Latin America	40%

Table 6. Rural nonfarm income, Latin America (Reardon and Berdegué 1999).

Country	Year	Rural nonfarm income
Argentina	1997	51%
Brazil	1997	39%
Chile	1997	41%
Colombia	1997	50%
Costa Rica	1989	59%
Ecuador	1995	41%
El Salvador	1995	38%
Haiti	1996	68%
Honduras	1990	38%
Mexico	1994	37%
Nicaragua	1998	42%
Panama	1997	50%
Peru	1997	50%

Economic and Institutional Environment

The economic and institutional environment has as much bearing on decisions regarding what, when, and how to produce as the farm's physical resources discussed earlier.

Extension Services

Extension advice and training can not only increase the range of production possibilities by introducing farmers to products and techniques, they can also affect the quality of decision making by improving farmers' understanding of agricultural and market conditions and showing them how best to take advantage of these conditions. Government agencies, nongovernmental organizations, and private companies can all provide extension advice and training, and though the motivations of these entities may vary (private firms can be relied on to recommend their own products over any alternatives), the considerations brought up in this chapter and the conclusions at the end of it apply to all of them.

Output Markets

Market outlets available to farmers will determine what products they can raise for cash. While this seems an obvious point, it has not always been understood, and the implications are not always fully grasped even now, either by farmers or extension agents and project implementers. It is not simply a matter of ensuring that a market is there before production begins; it is also important to grow the varieties that consumers most like and to time harvest for those seasons when prices are most favorable. Difficulties increase where farmers want to produce for export markets; smallholders do not have the resources to learn much about these markets on their own, and buyers often want to purchase in larger quantities than producers have to sell. With help, however, farmers can adapt. A commonly effective approach is to help producers form associations, either formal cooperatives or informal groups, that permit them both to consolidate their production into bundles large enough to attract buyers and to negotiate good prices. Often donors are willing to support formation and training of such associations.

Input Supplies and Prices

These will certainly influence whether farmers can adopt practices that require certain inputs. While government policy can encourage or discourage the provision of supplies at good prices, as in the case of output markets, the matter is not entirely out of farmers' control because associations can access sources and negotiate prices that are out of reach for individuals.

Credit

Farmers often say they need credit. Commercial banks find small loans unprofitable, but a variety of institutional forms such as credit unions have developed that make it possible for rural people, organized in groups, to make loans to one another. Each group accepts collective responsibility for individual loans, and group pressure replaces conventional forms of collateral to encourage repayment. Where formal microcredit institutions do not already exist, it has been found that groups organized informally to receive loans for specific purposes also function well. Sometimes borrowers can repay in kind. A recipient of a cow might repay in the form of a calf that is passed on to another member of the same group. In fact, unless government regulation forbids any kind of rival to formal financial institutions, steps can usually be taken to make credit available to all but the most destitute.

Educational Opportunities

The existence of local schools clearly affects farm household decisions concerning which family members work. Furthermore, an important aim in many developing countries is to reduce child labor and increase school attendance. Even where there are effective programs to strengthen schools or build new ones, steps are necessary to reduce the incentive to keep children home to work in the fields. Extension services and projects promoting innovation have to be aware of the impact that farm practices might have on the demand for child labor. For example, working with farmers on growing irrigated crops during the dry season should take account of the fact that using watering cans takes a lot of work and could lead to keeping children out of school. This can be avoided by promoting the use of treadle pumps that can supply the needed water in much less time. Another aim is to encourage families to send their girls as well as their boys to school. In fact, there is a clear positive impact of female education on family nutrition and health (Klasen 1999; Summers 1994). Extension services may not feel that direct encouragement of female education is an appropriate role for them, but they may be able to promote it indirectly. For example, where females spend long hours collecting firewood, projects can increase supply close to home by supporting the planting of trees in woodlots or the borders between fields. They can also show households how to lower their demand for fuel by building simple brick-and-mud stoves that burn much less wood than open fires.

Off-Farm Employment

Opportunities for work off the farm are largely determined by the level of economic development of the country and how close farms are to urban areas. However, there is increasing emphasis on developing agricultural processing enterprises in rural areas. The aim is often to reach urban or export markets, but the fact is that local markets for items such as dried vegetables and fruit, jams, wines, and groundnut oil also provide worthwhile cash income. Frequently, successful processing enterprises have been cooperatives run by groups of women rather than operations run by an individual or single household.

Rights to Land and Water

Farmers' rights to land are often based on arrangements such as sharecropping, the local chief's allocation, or cash rent. Writers on development policy have commonly observed, though more so in the past than now, that anything less than the certainty of a clear ownership title reduces farmers' incentive to invest in their land. There is some truth to this, for without clear ownership farmers cannot be certain they will reap the benefits of their investments. However, the need can be exaggerated. Where customary law is important, as in most of Africa, it is frequently forbidden to arbitrarily terminate a farmer's right to use land that he or she has cultivated for years, and most farmers have an incentive to make investments that will pay off in their own lifetimes. In countries such as Afghanistan where land tenure arrangements include shareholding and cash rent agreements, owners have an incentive to see their land well managed and can pay part of the capital costs to encourage it.

(Rights to land in developing countries typically depend crucially on gender, with great variation from society to society. Where descent is matrilineal, women can often own land; but where descent is patrilineal, their rights are typically much less. In communities that adhere to Islamic *sharia* law, women inherit land that is a specified fraction of what males are entitled to—an inferior right but one that is at least clear and definite. This imbalance in land rights can lead to severe hardships and deserves more attention than it gets. However, its impact on natural resource management at the farm level is not clear.)

As already observed, some resources, in particular pastureland, forests and water, are common property. The difficulty with this is that the decisions that are sensible from the point of view of a single farm enterprise do not contribute to sustainable resource management when all farm enterprises act the same way. For example, an individual gains when he or she acquires more cattle and grazes them on common land, but when many individuals do the same in an unrestricted way, overgrazing and degradation result. Similarly, the more water each household takes from streams or aquifers, or the more trees each cuts from communal forests, the more rapidly the resource depletes.

This phenomenon is referred to as the "tragedy of the commons" after a 1968 article with that title by Garrett Hardin. For some observers the only way to resolve the problem is to divide the common pasture or woodland into private plots, though this would be difficult in the case of, say, river water. For others, the best solution is government-enforced regulation—issuing permits to livestock raisers, for example, up to the total number of cattle that the land can sustain. In some situations this kind of mechanism works, but because it would require individuals to cut back their usage of the commons to the number of permits they are given, it would be unpopular and, in the rural areas of many developing countries, difficult to enforce.

More recent research by Elinor Ostrom and others has noted that there are solutions that users of the commons can enforce themselves and often do. Livestock owners could keep all their animals but, perhaps with help from extension services and project implementers, organize themselves to move their herds in a coordinated way from one part of the pasture to another, establishing a system of rotational grazing that allows areas not being grazed to recuperate. Similarly, communities can agree to rotate tree cutting from section to section of a communal forest, replanting areas after cutting. Where downstream users of water are unhappy with the quantity or quality of water that upstream users allow to flow down to them, they can pay the upstream users in cash or in kind to reduce amounts used or their polluting behavior. The kind of cooperation needed to implement these solutions may not be easy or quick to organize, and a good deal of trial and error may be needed before the best approach is found for each case, but it offers a viable prospect for solving a very old problem.

Risk and Attitude toward Risk

The discussion of figure 1 made the point that risk should be seen as being determined by objective circumstances at least as much as by psychological factors. To take a simple example, a farm household with many dependents, little or no off-farm income, and limited land is highly vulnerable to drought and crop failure. A farmer in this situation should probably hesitate to try an innovation aimed at enriching the soil by replacing some of his millet with cowpeas if he knows cowpea crops fail 3 out of 10 years in his area because of poor rainfall. A neighbor with enough land to produce a substantial surplus over his family's food needs might or might not be braver, but he would certainly be much better placed to sustain a loss and take a chance on cowpeas.

Table 7 elaborates on this view, taking account of some of the points made in the sections above. The upper part of the table shows how farm-level resources affect risk. The more plentiful on-farm land and water are, the less risky the situation is for the farm enterprise, and so on. The second section of the table refers to the economic and institutional environment and the bottom section to two aspects of the broader watershed and ecological systems. Strong extension training and advice make for greater security because farmers are better informed about how to make the most of their resources under a variety of conditions. Better rainfall makes for better crops and pasture, and more food and income security.

An interesting point brought out by table 7 is that sometimes it is the level of an item that matters, while in other cases variability is more important. The higher the off-farm income, for example, the less risk a farm faces. In several instances, however, annual variation is at least as important as the absolute level of an item. In general, one might consider low rainfall and high levels of disease to make for high risk, and there is some truth in this. But suppose rainfall were consistently only 350 mm every year, and the same viruses attacked the same fields and same animals to the same degree annually. In this case, farm productivity would be low and costs high, but farmers would know what to do to make the best of these conditions and would see themselves as facing hardship rather than risk. It is because adverse factors come and go with varying intensity that it is difficult to choose which practices will pay off best in any given year.

A further conclusion is that the level of risk can be much affected by the level of training that farmers receive. Unlike the other factors, this is one that extension services and project implementers can do something about. Where farmers are trained inadequately or not at all, consequently adopting new practices poorly, their risk of running a loss and abandoning innovation is high. Governmental and nongovernmental agencies will have to devote more resources to conduct proper training, but the expense is essential to fostering innovation.

Table 7. On- and off-farm determinants of risks.

	Low-risk conditions	High-risk conditions
Farm-level resources		
Land and water on farm	Exceeds subsistence needs	Poor quality, small area
Dependency/labor ratio	Few dependents relative to farm workers	Many dependents relative to farm workers
Livestock, equipment, buildings	Plentiful, good quality	Limited, poor quality
Off-farm income	High and consistent	Low or inconsistent
Economic and institutiuonal environment		
Extension training and advice	Good training → good adaptation → known returns	Poor training → poor adaptation → unknown returns
Rights to land and water	Secure	Insecure
Output markets, prices	Competitive markets, steady prices	Low level of competition, highly variable prices
Input supplies and credit	Supplies assured, competitive prices or interest rates	Supplies unsure, uncompetitive prices or interest rates
Watershed and ecosystem		
Annual rainfall	Consistent	Highly variable
Crop and livestock diseases	Rare	Frequent

Culture and Natural Resource Management Decisions in a Farm Enterprise

When farmers make decisions about what to produce and who should do what in the production process, they are influenced, like all the rest of us, by notions of what is acceptable according to prevailing social and religious norms. Muslim farmers do not raise pigs, and Hindu farmers do not raise cattle for meat. When it comes to crops, what culture has to say is less obvious, and taste seems to come second to what growing conditions allow. For instance, there is an apparent tendency worldwide for farmers to grow maize where there is enough water and warmth, wheat where there is water but inadequate warmth, and sorghum and millet where there is warmth but not enough water. But when it comes to how to produce, in particular who does what and when, culture plays a critical role, especially where the division of labor and decision making within households are concerned.

Division of Labor

The most significant way in which culture has an impact on farming is through accepted attitudes regarding the proper roles of males and females. Typically, though not universally, men have worked in the fields, herded livestock, and taken farm produce to market. Women have been seen as having primary responsibility for domestic work within the home, feeding the family, cleaning, and caring for the sick. However, they have always done much more. They have worked in the fields when more hands have been needed to weed and harvest, raised kitchen gardens to supplement the family diet with vegetables, fruits, and herbs, and processed farm and garden produce, making bread and cheese and preserving vegetables. They have also raised poultry and dairy animals, and in many parts of Africa they have fattened small ruminants for market. In most developing countries today it also falls to women to collect firewood and water.

There are certainly variations on these themes. For example, while the general pattern just described holds in many communities in Afghanistan, others in that country do not think it proper for women to work outside the extended family's compound. Thus all fieldwork, other than in small gardens within the household compound, is left to men, even in the case of widows (common in that country) who have to rely on male relatives or sharecrop out their land. On the other hand, in African communities where the men have gone off to find work in the cities, women are left to do all the fieldwork.

Whatever the situation, it has been widespread and conventional practice for extension agents and most project implementers to be men and for them to deal with the males in households, though the many women's roles listed above indicate the importance of communicating with women too. There may be a few instances where the usual man-to-man interaction is enough to transfer technology such as building terraces to reduce soil erosion, but in others interaction with women is indispensable. For example, where the crops or livestock are women's particular responsibility, a cooking stove that uses less wood is to be introduced, or nutrition education is an issue. Indeed, it has been found that in some instances women extension agents succeed in circulating information within a village better than male extension agents (Moore et al. 2001).

Where most natural resource management practices are concerned, men and women will each have an interest. For instance, in discussions regarding tree planting for fuel wood, both will have opinions on what species they prefer and where the trees should be planted. When considering alternative practices to improve soil fertility, such as spreading animal manure, applying microdoses of chemical fertilizer, rotating traditional grains with legumes or interplanting them with legumes, both men and women will have legitimate considerations to bring to bear.

To interact effectively in these cases, extension agents and project implementers will sometimes have to broaden their own knowledge to take account of the food value of grains and pulses as well as their yields, for example. In many or most situations it will be necessary to hire qualified women to interact with female household members, either because men do not have the necessary expertise or because it is inappropriate for men to speak to women at all if they are not related to them.

Decision Making within Households

Decision making within the household is harder to investigate than the division of labor. Who does what is often open to observation, but decision making usually takes place in private discussions within families, and questions about these are commonly regarded as intrusive. One way out of dealing with this difficulty is to treat households as if they were single individuals, though very complicated ones. Those who have taken this approach have said that it does not necessarily amount to presuming that the husband makes decisions unilaterally without consulting other family members. Instead, they say, the household head can be presumed to value his or her relationship with other family members and to take account of their preferences when making decisions, so any decision will reflect what the family as a whole wants. This is a convenient formulation, but it is almost certainly more accurate—and effective—to consider that decisions are arrived at through a process of bargaining among family members and that the relative strength of their bargaining positions can vary with the circumstances. For example, women are known to have more bargaining power where they earn some cash income from activities such as selling vegetables, fruit preserves, or clothes that they produce.

Whatever view of household decision making is adopted, it is important that all family members who provide a significant amount of labor to the farm enterprise, especially spouses, be well informed about the relative payoffs and costs of alternative farm practices so they can contribute to informed decisions. How best to inform them and encourage their involvement in decisions will require considerable sensitivity on the part of extension agents and project implementers. The approach will vary from community to community and household to household. In some instances women can be expected to sit with the men in meetings and participate actively and without hesitation in discussions. In others, to insist on meetings that jointly involve men and women will be ineffective if either or both sexes refrain from speaking frankly for fear of upsetting the other. It can be counterproductive when joint meetings run so much against the cultural grain that even suggesting them can result in hostility among both men and women, toward the whole program. Again, the obvious solution is to hire or train enough qualified females to confer effectively with the women.

Conclusions: Promoting Innovations at the Farm Level

This chapter emphasizes several points:

- The farm enterprise can be represented as a circular system, with resources conditioning management decisions that determine this year's production and its allocation among consumption, sales, and investment in farm resources that will be available for next year.

- In the economic and institutional environment, output markets affect farmers' incentives and ability to convert farm production into cash income. Input markets, credit, land and water rights, and opportunities for off-farm employment and education also condition farmers' decisions regarding how to allocate resources and allow them to supplement resources produced on-farm with additional means acquired off-farm.
- Risk perceptions are not simply a matter of attitude but are also determined by on- and off-farm circumstances and resources.
- How resources are used and management decisions are made also depend on cultural influences.
- Circumstances vary immensely from country to country, district to district, and farm to farm. As a system, each farm is potentially unique. Even where land, crops grown, and livestock raised are the same, household makeup and availability of off-farm income can be different, leading to differences in production possibilities, views of risk, and decisions.

This view of the farming system has significant implications for the promotion of appropriate innovation in farm practices:

- ***Innovations should have a clear payoff to farmers within a fairly short time.*** Often innovations that make farming more ecologically sustainable are promoted without paying attention to how immediately profitable they are to farmers or whether they are profitable at all. Innovations are sustainable from the farmer's perspective if they result in a greater accumulation of resources as one production cycle succeeds another.
- ***Innovations will be viable if output markets, input suppliers, credit, and other aspects of the economic and institutional environment support them.*** In some instances, such as the law governing land rights, what government policy says is crucial, but sometimes institutional support can be created, as when producer groups are formed to funnel credit to farmers and to negotiate with traders in town.
- ***The promotion of innovations must accommodate risk and attitudes to it.*** If farmers are reluctant to think about innovating, it may be because the program proposed does not adequately take account of either the farm's own resources or the economic and institutional environment. In these cases it may be that project implementers and extension agents, rather than farmers, should adapt.
- ***Extension agents and project implementers should involve farm households in the choice of innovations.*** This is not the same as saying that farmers should not receive advice regarding what the innovations should be. They do not know all the technical possibilities that specialists are aware of. Because they know their own household preferences and constraints better than anyone, however, they are well qualified to collaborate in evaluating the relative importance of different alternatives. Going beyond the household and considering possible alternatives in neighborhood groups will raise the level of discussion and also encourage a wider appreciation of all the alternatives being offered.
- ***To involve farm households means to involve spouses. Not all innovations affect all household members, but most do.*** Consulting the head of household alone will result in only a partial appreciation of household preferences on the part of project implementers and extension agents. This will usually mean having to hire and train more females to work with the women of farm households.
- ***The benefits of innovations should be assessed collaboratively for the same reasons that the initial choice should be.*** Farm households understand their own circumstances better than anyone and so are generally better positioned to determine which innovations suit

them and which to reject. Furthermore, when innovations are tested or demonstrated in farmers' own fields with different farmers conducting different innovations, it is important that all farmers in a neighborhood be made aware as a group of all the results so that they have a chance to discuss the pros and cons of alternative practices.

- ***Patience and persistence are more important than expense.*** Experience shows that farms are most likely to innovate and increase their food security and incomes when researchers work with them over long periods of time, such as 10 years and more, which not all development projects permit. Large-scale efforts are less effective than long-term, flexible programs that pursue their own specific priorities as farm households respond to research results and new possibilities.

Acknowledgements

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Note

This chapter does not define and examine different categories of farming systems. For this approach see John Dixon and Aidan Gulliver with David Gibbon, *Farming Systems, and Poverty: Improving Farmers' Livelihoods in a Changing World*, FAO and World Bank, 2001.

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Chapter 4

Watershed-Based Systems

Sharyl Walker and Saied Mostaghimi

Agricultural and other human activities have the potential to impact the quantity and quality of water resources used by communities of various sizes. Successful development and protection of water resources require a technical understanding of watershed processes as well as development of a management plan for coordinating the actions of diverse people and organizations. This chapter defines watersheds, outlines basic hydrologic and erosion processes, and provides practical guidance for applying the adaptive management planning process to watershed-scale systems. The discussion concludes with outlining needs for further research.

This chapter cites case studies selected from focus regions of the United States Agency for International Development. The authors also draw from their own experiences in watershed management. While the principles governing runoff and erosion are the same around the world, empirical models designed for use in developed countries may need to be modified to address, for example, the severe slopes of Latin America or the monsoonal climate of Southeast Asia. Similarly, assumptions regarding how the "social catchment" (Ellis-Jones et al. 2001) should operate may have to be modified. For example, insidious waterborne diseases and HIV-AIDS take their toll in parts of Zimbabwe, making it difficult to hold regular planning meetings (Ellis-Jones 2004). Political unrest, organizational corruption, lack of established agencies, and economic crisis can also complicate data collection and coordination of efforts (Voinov et al. 1994).

The purpose of this chapter is to provide guidance in solving problems at the watershed scale, with the focus on quality and quantity of water supplies in developing countries. The chapter discusses both the technical and organizational aspects of solving water resources problems. It builds on the previous chapters because it is the strategic application of field and farm practices that ultimately affects downstream water supplies. This chapter sets the stage for the chapters that follow because policies and technology transfer methods influence how a water supply is used as well as the effective adoption of desirable practices for protecting or improving that water supply. Finally, this chapter provides a foundation for discussion of ecosystem-based management, for the same hydrologic and problem solving processes are applicable to larger scale systems.

Watershed System Processes

The fundamental unit of study in water resource management is the watershed or catchment, defined as the land that drains to a particular point of interest (figure 1). That point is the watershed outlet and may be the site of volumetric interest (how much water passes or collects here),

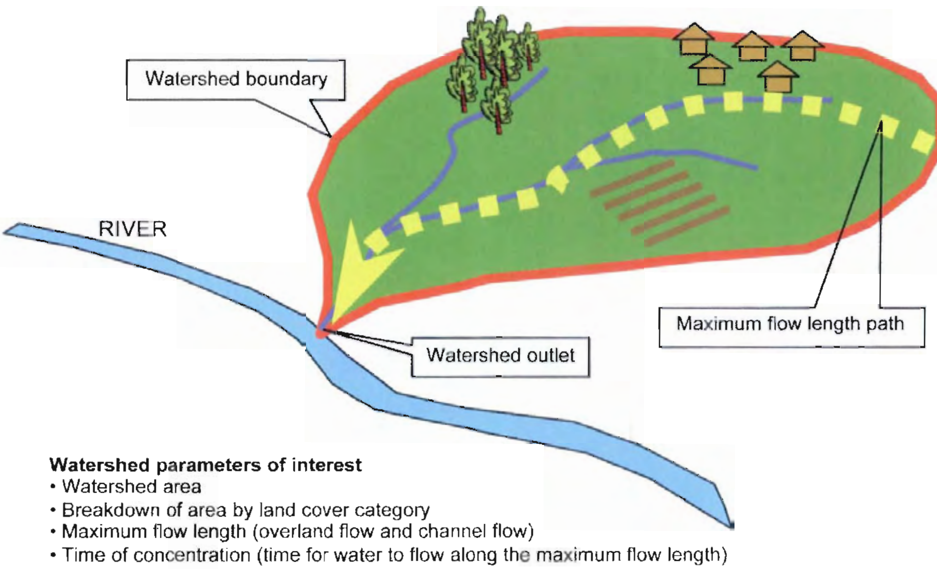

Figure 1. Parts of a watershed.

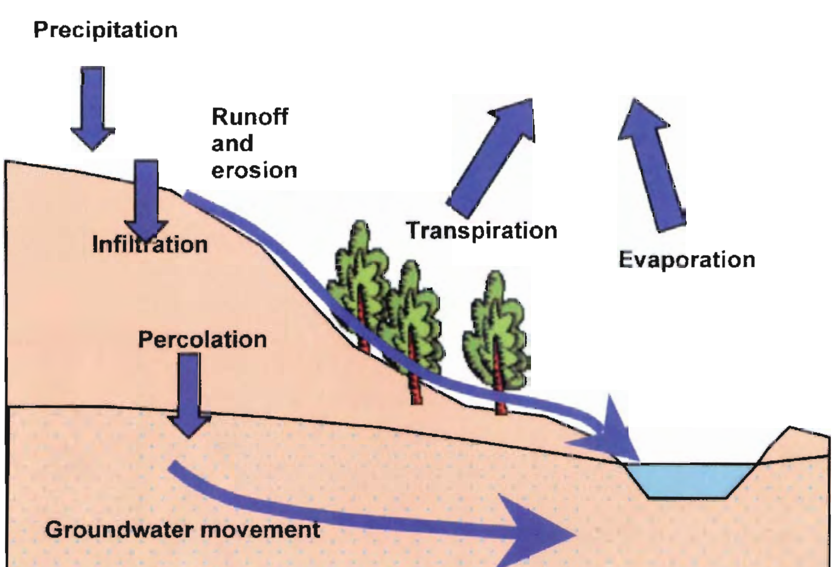

Figure 2. Basic watershed processes (adapted from Schwab et al. 1992).

such as a stream crossing, dam for a farm pond or local reservoir, or major hydroelectric facility. The outlet could also be a point of environmental interest, such as an entrance to a lake or estuary where impacts of upstream activity on water quality may be of concern. Topography governs the physical extent of the area that is included in the watershed draining to the chosen outlet. Weather, watershed size, land use, soil types, and other factors determine the quantity and quality of the water that is "shed" to the outlet. A watershed can be any size, but for water supply projects, watersheds will be typically on the order of 100 to 100,000 hectares. Time scales of interest for studying watershed processes can range from minutes to many years, depending on watershed size and the types of activities involved. Effects of human activities can be noticeable within a few hours, such as in the case of an accidental manure slurry release; or may take several years, as is frequently the case with conservation measures. Ellis-Jones et al. (2001) suggest that 10 to 20 years may pass between conservation implementation and reduction in sedimentation rates for reservoirs in Zimbabwe. Unfortunately, projects are rarely funded long enough for such results to be documented.

Physical processes essential to the understanding of watershed systems are identified in figure 2 and include precipitation, infiltration, percolation, runoff, evaporation, transpiration, and erosion. Many of these processes are discussed in chapter 2 in relation to the field scale landscape (see for example figures 1 and 2). At the watershed scale, we are concerned with the cumulative effects of these processes on water quantity and/or quality at the outlet of interest. Mathematical description of these cumulative processes is crucial to answering the "how big" questions of project design.

Some of the processes illustrated in figure 2 are briefly described below. The reader is directed to Morgan (2005) and Schwab et al. (1992) for more in-depth discussion and presentation of equations used to quantify the magnitude of these processes.

Precipitation

Precipitation in all forms contributes to the quantity of water available for infiltration and runoff. Also, precipitation can play a significant role in erosion and pollutant transport. Rainfall can cause unprotected soil particles to be dislodged from the surface, the first step in the erosion process (Schwab et al. 1992).

Rainfall can also transport airborne pollutants. Watersheds in the Black Triangle region of the Czech Republic are undergoing restoration from damage caused by acid rain resulting from upwind lignite coal-burning operations (Krecek and Horicka 2001). Deposition of sulfate by rainfall in the Jizera Mountains led to defoliation of spruce trees and low pH in reservoirs. Low pH, increased sedimentation, and increased levels of aluminum killed fish and other aquatic life. With decreased coal power production in central Europe, improved forestry methods, and liming of reservoirs, water quality has been improving since the late 1980s (Krecek and Horicka 2001).

Precipitation depth and duration of a storm event are important parameters for estimating the volume of water draining to the watershed outlet. Water depth divided by the time over which that depth fell is the intensity of the rainfall. A hyetograph is a plot of rainfall depth or intensity over time. A hypothetical storm is represented in figure 3. The block-like shape of the plot is due to the fact that rainfall is typically recorded at regular time intervals (such as hours) rather than as a continuous function.

In some developing areas, planners must consider the impact of long periods of drought, as in the West African Sahel, or very high intensity (large depth over a short duration) monsoonal storms, as in Bangladesh. Ideally, an agency will collect rainfall records over a long period so that regional statistics can be generated to estimate frequency of a given storm depth and duration. A

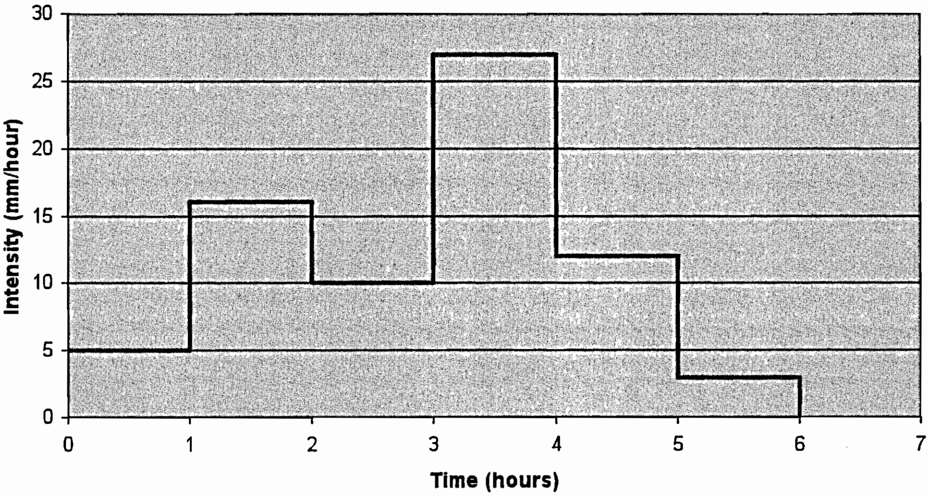

Figure 3. Hyetograph for a hypothetical six-hour storm.

Storm statistics
Total duration = 6 hours
Total storm depth = area under plot = 73 mm
Average storm intensity = depth/duration = 12 mm/hr
Maximum intensity = 27 mm/hr

storm that produces 75 mm of rain in one hour may only happen once every 10 years in a particular location. However, the same amount falling over a 24-hour period may be a more common event, perhaps happening once every two years. This statistical return period (for example, 10 years or two years) is one way of expressing storm frequency. Numerically, return period is the inverse of frequency (10 versus 0.1).

How much, how fast, and how often are key questions in determining the answer to the "how big" question in project design. Is it desirable to build a reservoir that can contain runoff from the largest conceivable storms (return period of 100 years or more)? Perhaps it is better to design for a storm occurring, for example, on average every 25 years, so that scant resources can be used to address other problems as well. The consequences of failure and its impact upstream and downstream of the project must be balanced against available resources. If local rainfall statistics are not available, statistics from another area having a similar climate combined with local memory of extreme events can provide a starting point for design. Perhaps a longtime resident can remember floodwaters reaching the base of particular landmark two times during the past 20 years and covering a second, lower landmark about every other year. Such information provides insight into the magnitude of the 10-year and two-year runoff events.

Infiltration and Percolation

Infiltration is the process by which precipitation enters the soil. The process may be limited by surface compaction, crusting, sealing, or by an impervious layer (such as bedrock or clay) beneath the surface. Soil properties, surface cover, rainfall intensity, and the degree to which the soil is already saturated influence how much rainfall enters the soil in a given period. Tillage influences the ability of the soil to absorb precipitation, both in terms of the spaces between soil aggregates and disruption of macropores formed by earthworms, insects, or roots. Conservation agriculture methods increase infiltration through minimal soil disturbance and maintenance of soil cover (see chapter 2 for discussion). Percolation is the downward movement of water to the aquifer. Water-soluble pollutants such as nitrate and some pesticides may be transported from the surface to the groundwater through percolation. More information on infiltration can be found in texts such as Schwab et al. (1992).

Evaporation and Transpiration

Liquid water returns to the atmosphere as vapor by means of evaporation from soil, water, or other surfaces or by transpiration from plant tissue. The two processes are often combined as evapotranspiration (ET) and can account for a large portion of the water cycling through the system. Estimates of ET are particularly important for designing irrigation systems and for crop growth models. Temperature, relative humidity, wind, vegetation type, soil cover, and other factors influence ET. A lysimeter—a device for measuring soil moisture—can be used to estimate ET losses in the field. Such measurements can be used to develop empirical relations with climatological data for use in predicting ET in other areas. See Schwab et al. (1992) or other texts for a discussion of the Blaney-Criddle and other empirical methods for predicting ET.

Runoff

Rainfall will initially infiltrate into the soil. When the rate of rainfall exceeds the rate at which water infiltrates into the soil, there may be some ponding and filling of surface depressions, then runoff will occur. Runoff rate plotted against time is called a hydrograph. A hypothetical hydrograph is shown in figure 4. Runoff volume (the area under a hydrograph curve) and peak runoff rate are two important parameters for the design of water resources management structures. Runoff volume is necessary for sizing storage structures such as reservoirs, as well as for estimating runoff-borne contaminant loads such as sediment. Runoff rate information is needed to size channels or pipes for conveying flow.

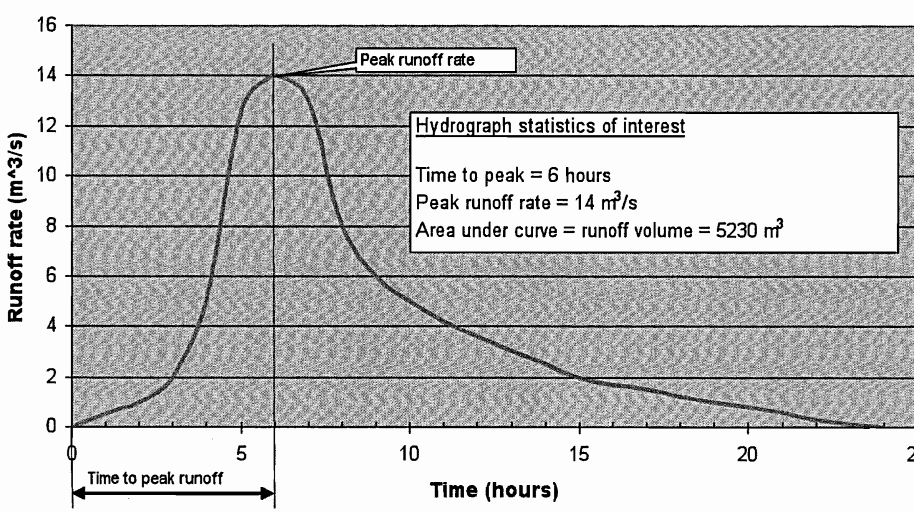

Figure 4. Hypothetical hydrograph.

Generally, it is neither practical nor necessary to measure the hydrograph for a particular watershed outlet resulting from a particular storm. Hydrologists devote much effort to the study of relationships between hyetographs (rainfall rate plotted against time) and hydrographs (runoff rate plotted against time) and the effects of land cover, soils, slope, degree of soil saturation at the time of the storm, watershed size and shape, and other factors. Simplified hydrograph shapes (triangles or curves) have been mathematically defined. Equations have been developed relating a watershed's time of concentration (time for water to travel from the most remote point of the watershed to the outlet) to the time to peak runoff and to the total time of runoff flow (base of the hydrograph) (Schwab et al. 1992). Other equations estimate total storm runoff volume and peak rate. Thus, a hydrograph can be constructed for design purposes for a storm of given depth and duration corresponding to the desired return period.

A simple relationship known as the Rational Method can be used to demonstrate some basic hydrologic principles. McCuen (1989) cites literature that traces the use of the method to the late 1800s. Suppose a small watershed is completely impervious—a metal roof, for example—and suppose that water flows from the roof to a gutter to collect in a cistern. When it first starts raining, nothing flows into the cistern because it takes a short time for water to flow down the roof and along the gutter. That time will be influenced by the slope of the roof and gutter and the roughness of those surfaces. Flow into the gutter starts out small, reaches a peak, then tapers off. According to the Rational Method, the maximum flow rate (peak runoff) will be observed when all parts of the roof are contributing flow. That is, peak flow will be observed once sufficient time has elapsed for raindrops from the most remote corner of the roof to flow down the roof and down the full length of the gutter—or time to peak = time of concentration. The magnitude of the peak flow rate is the rainfall intensity (depth/time) times the area of the roof. The method assumes a constant rainfall intensity and a storm duration equal to the time of concentration. If these assumptions are true, the hydrograph can be represented by an isosceles triangle such as shown in figure 5, which

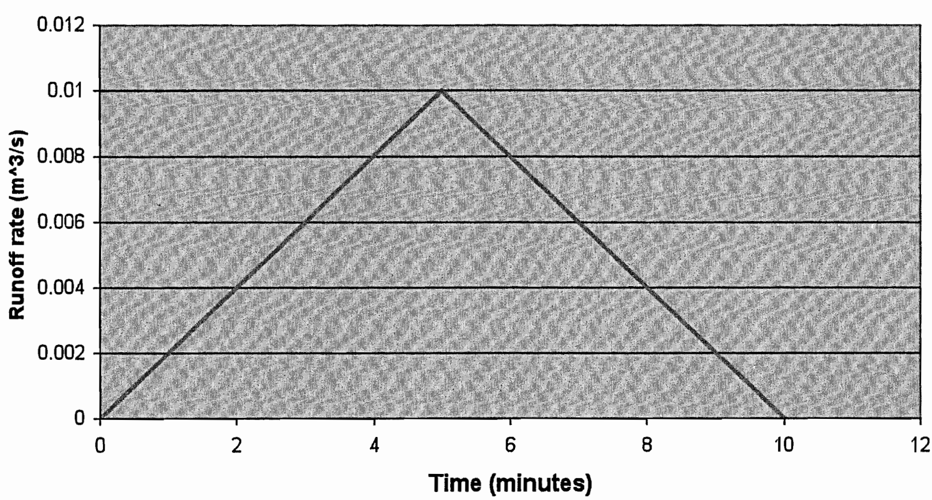

Figure 5. Hydrograph for Rational Method example.

Hydrograph statistics
Time to peak = 5 minutes
Peak runoff = 0.01 m^3/s
Runoff volume = area of triangle = 3 m^3

assumes a roof area, A, of 100 m^2, a time of concentration of 5 minutes, and a rainstorm lasting 5 minutes with intensity, I, of 360 mm/h (or 0.0001 m/s). Thus, peak runoff rate, $Q = IA = 0.01$ m^3/s, and the volume of water collected in the cistern is the area under the triangle or 3 m^3. If we analyze a design storm (depth and duration for a desired return period), the peak rate could be used to determine the size of a filtering device at the end of the gutter, and the runoff volume could be used to size a cistern to hold the water from the desired number of such storms.

Carrying the roof example a little further, suppose that instead of metal, the roof is made of vegetative material that absorbs some of the rainfall. We can still use the basic Rational Method to compute peak runoff rate and volume, but we need to add a "fudge factor" or runoff coefficient, C, to account for the fact that not all of the rainfall will reach the watershed outlet (cistern). Thus the Rational equation for peak runoff rate, Q, is often written as follows:

$$Q = CIA ,$$

where Q = peak runoff rate (volume/time), C = runoff coefficient that accounts for the degree of imperviousness of the watershed surface, I = rainfall intensity (depth/time), and A = area of watershed.

Units can be English or metric. If metric units are used, one either has to be consistent in expressing time and length, or apply a conversion factor. If English units are used (cfs, in/hr, and acres), the units happen to work out so that no unit conversion is needed. An impervious surface has a runoff coefficient (C) of 1; a fully absorbent surface has a coefficient of 0. Coefficients have been developed through field experiments for a variety of land cover conditions, and these are often tabulated in texts on hydrology such as McCuen (1989).

Watersheds on the natural landscape and their hydrographs get more complicated than the roof example. Additional equations for predicting peak flow, runoff volume, and hydrograph dimensions can be found in texts such as McCuen (1989), Schwab et al. (1992), and Morgan (2005). Equations that simplify complicated natural processes typically rely on empirical relationships with coefficients developed through extensive field tests. Caution should be exercised in using those formulas in areas where conditions (such as extreme terrain and high-intensity storms) may be outside the range of those originally tested.

Erosion

Movement of soil by water or by wind is of concern because it affects soil fertility, decreases downstream reservoir storage capacity, and can expose structural supports. Raindrops can start the erosion process by dislodging soil particles. Runoff then carries the dislodged particles and associated pollutants downhill and can dislodge more soil in the process.

Soil properties such as structure, texture, and organic matter affect a soil's vulnerability to erosion. As mentioned in the "Infiltration" section, maintaining a surface cover and practicing conservation tillage methods can help to reduce erosion. Slope severity and slope length influence the transport of eroded soil. Thus vegetated field borders, terraces, contour farming, and similar practices that interrupt the runoff flow path can help to reduce erosion.

All of these factors affecting erosion rate are captured in the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978). The equation is written as follows:

$$A = RKLSCP ,$$

where A = average annual soil loss per unit area, R = rainfall and runoff erosivity, K = soil erodibility factor, LS = length-slope or topographic factor, C = cropping-management factor (includes crop cover, rotation, tillage), and P = conservation practice factor.

The equation is presented here without units for simplicity in order to communicate the general concept of the method. Use of the equation involves in-depth considerations best left to the referenced texts for explanation. Empirical relationships for the factors were developed using data from the United States. Nevertheless, the tool has been used successfully in many parts of the world. Onyando et al. (2005) discuss USLE parameter determination for a watershed in Kenya. Stolpe (2005) discusses application of USLE and other erosion models to volcanic soils in Chile. Similar to the USLE is the Soil Loss Estimator for Southern Africa, developed using data from Zimbabwe (Morgan 2005).

Over the years, the USLE has been modified and revised. The Modified USLE (MUSLE) is a method for estimating soil loss for a given storm event rather than as an average annual quantity (Williams 1975). The Revised Universal Soil Loss Equation (RUSLE and now RUSLE2) provides an improvement in the methods used for selecting values for the USLE input factors (Foster et al. 2000). Millward and Mersey (1999) discuss adapting RUSLE to accommodate the mountainous terrain and tropical precipitation in the Sierra de Manantlán Biosphere Reserve in southwestern Mexico.

Watershed Resource Management Planning Process

Chapter 1 introduced the concept of adaptive management. These are the basic steps, applicable to any system scale:

- Identify the problems and stakeholders involved.
- Collect and analyze relevant data.
- Determine what needs to change and how to change it.
- Implement the solutions.
- Monitor results and evaluate the solutions.
- Repeat steps 1–5, refining the solutions as needed.

At the field and farm scale, one landholder and possibly the family will work through these steps. The process need not be formal, written, or consciously labeled as "adaptive management." However, at the watershed scale,

- many people may be involved in creating both the problems and solutions, both upstream and downstream of the point of interest;
- the complexity of the problem(s) will likely be greater (for example, how to increase food production on upland fields and reduce siltation in the downstream reservoir);
- data collection, organization, and analysis needs will increase; *and*
- multiple stakeholders will need to coordinate their actions.

Because the number of people, problems, and data needs can increase exponentially at the watershed scale, it may be necessary to formalize the adaptive management process to diffuse conflicts, provide a means of organization, provide a method for breaking down seemingly overwhelming problems into solvable parts, and encourage commitment in adoption of solutions. Several agencies have outlined formal procedures to aid groups involved in natural resource management. The United States Department of Agriculture Natural Resources Conservation Service advocates use of a three-phase, nine-step planning process involving stakeholders and technical experts to develop strategies for addressing the wise use of watershed resources. Similar concepts can be found in documents produced by the Australian Land Care organization (Roberts 1992). Participatory planning steps are outlined by Ellis-Jones et al. (2001) with respect to small dam projects in Zimbabwe, and in Pezzullo (1982) with respect to planning of development projects in Latin America. Murwira et al. (2000) do an excellent job of documenting the process used in addressing food security in Zimbabwe. They describe how government agencies had developed and promoted various conservation strategies (such as tied ridges for conserving soil moisture) with little success. However, when farmers went through a participatory planning process in which they were responsible for identifying their problems, and investigating and modifying their own solutions, the result was very positive, with widespread adoption of tied ridges and other practices. In other words, the planning process was absolutely critical to allow those in a position to solve the problems to take ownership of the solutions.

The number and names of steps used in a planning process are unimportant, and any written description of the process is at best a crude representation of what actually takes place when people come together to solve a common problem. For the sake of simplicity, the rest of this section will discuss the basic steps of data collection, analysis and decision support, and project evaluation as they apply to watershed-scale planning. Forming effective coordinating groups to carry out these steps is essential to project success and is addressed in chapters 5 and 8.

Data Collection

The stakeholder committee or its technical assistance group should gather basic information about the watershed as well as facts pertinent to the concerns identified. Basic information should include the following:

- Watershed boundary
- Hydrologic data
- Outlet flow hydraulics
- Soils
- Land-use capacity and current land use
- Other information

Watershed boundary

The boundary is important for determining what areas are involved in contributing runoff, sediment, and pollutants. Delineating the boundary is necessary for estimating parameters for hydrologic analysis such as watershed size and the length of the flow path to the outlet. Also, the location of the watershed boundary with respect to institutional boundaries is essential for identifying project stakeholders and authorities.

Topographic maps are valuable tools for delineating watershed boundaries. The elevation contours are used to reveal the watershed boundary by starting at the outlet location on the map and tracing a line perpendicular to the contours. Eventually the traced line will end back at the outlet, forming an enclosed polygon. The goal is to identify where the terrain "breaks" such that rain falling on one side of the break (watershed boundary) flows toward the identified outlet, and rain falling on the other side flows somewhere else. In determining which way water will flow, bear in mind that water will take the most direct path downhill, that is, perpendicular to the contours. Figure 6 illustrates the procedure.

If a digital elevation model of the area exists, geographic information system (GIS) software can be used to delineate the watershed boundary. However, use of such automated methods should not take the place of understanding the process of watershed delineation. A computer-generated watershed boundary should be checked carefully because digital elevation models can be flawed or too coarse in resolution for the application.

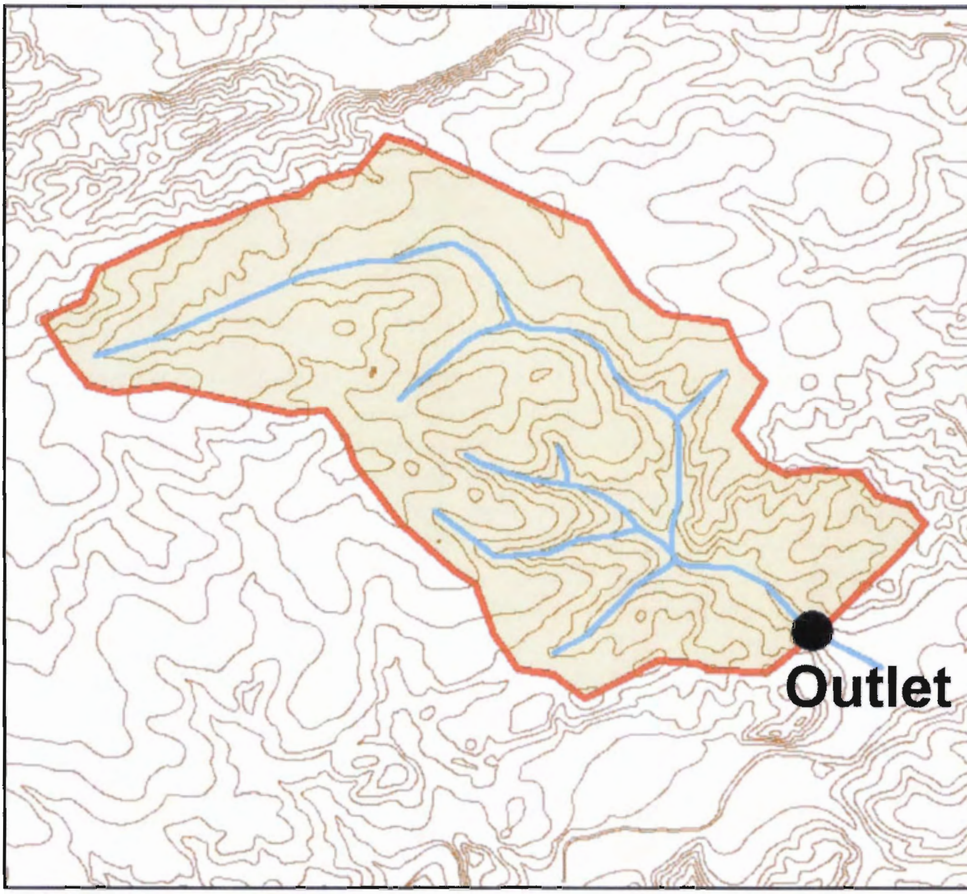

Figure 6. Watershed delineation process.

Dot = outlet.

Watershed delineation guidelines:

1. Identify watershed outlet.
2. Highlight stream channels and draws to get a general idea of the extent of the watershed. Remember that contour lines "point" upstream, hence toward the watershed boundary. The boundary will lie between where contours are pointing in different directions.
3. Start at the outlet and trace a line perpendicular to the contours.
4. Split ridge tops.
5. Continue to trace until the watershed boundary closes on itself at the outlet.
6. Check the boundary by choosing points on both sides and visualizing whether runoff from each point will flow towards or away from the outlet.

If topographic maps are not available, the area can be toured and the approximate boundary determined from observation of the terrain. Even if topographic maps are available, visual inspection of the area is useful for observing current watershed activities and land uses. Aerial photography can aid the visual inspection.

Hydrologic data

Rainfall statistics (depth, duration, frequency) will be needed for the locale to design structures to store or convey runoff from a particular size storm. Ideally, an agency or organization will have collected rainfall records over several decades at many locations across the country. The resulting statistics will be maintained in a database and conveniently tabulated or represented graphically on a map. Lacking such a record, estimates may need to be made using data from areas with similar climates and topography. A meteorologist may be able to assist in extrapolating the data to the location of interest. It may be a worthwhile investment to establish a rainfall recording station or network of stations in the watershed. Recording stations can range from very simple rain gauges with recording performed manually to complete weather stations with automatic data recording and wireless data transmittal. Rain gauges should be located in clear, level areas protected from wind. Equipment should also be secured against curious animals and humans.

Outlet flow hydraulics

In some applications, it may be desirable to relate water level at the watershed outlet to flow rate. Flow rate is equal to the velocity of the water times the cross-sectional area of the water flowing in the channel ($Q = VA$). Flow can be measured at bridge crossings to provide a convenient work platform. The cross-sectional area of the stream can be determined by measuring the distance to the bottom of the channel at different points along the bridge. Channel bottom elevations can also be determined with a surveyor's level and rod. The cross section can then be plotted and area computed based on geometry for different water levels. Depending on the precision needed, the channel cross-section can also be approximated as a triangle, trapezoid, or parabola.

Velocity can be measured with a current meter at various points along the cross-section as well as at different water depths. Velocities will tend to be slower close to the bottom and sides of the channel due to friction. Other means for estimating channel velocity include measuring the time it takes for visible, floatable objects such as oranges to travel a known distance downstream, and using Manning's equation (Schwab et al. 1992):

$$V = R^{2/3}\, S^{1/2}\, 1/n$$

where V = average flow velocity (m/s); R = hydraulic radius (m) cross-sectional area /wetted perimeter, where wetted perimeter is the bottom width plus the length of the channel side slopes that are wet (wetted perimeter can be approximated by the channel top width for most natural channels); S = channel slope (measured from riffle to riffle along the channel profile); and n = Manning's roughness coefficient, estimated from experience or the use of tables provided in many texts on channel hydraulics.

Once flow rate ($Q = VA$) has been determined for several water levels, flow rate can be plotted against water level, and a mathematical or graphical relationship can be derived to relate the two parameters. Such a graph is known as a stage-discharge curve. An example is shown in figure 7. Marked graduations can then be mounted against a bridge pier or other convenient place so that flow rate can be determined from observing water height (stage). Water stage can also be recorded continually using a float or pressure transducer system connected to a paper or digital recording unit.

Another way to measure flow is to install a weir or flume with known dimensions for which stage-discharge relationships have already been determined. These relationships can be found in hydraulics texts such as Brater et al. (1996). Water height is recorded as previously described.

Soils

Soil properties influence erodibility, how quickly water moves to the outlet, and the selection of management practices. In the absence of detailed soil maps, some general information can be

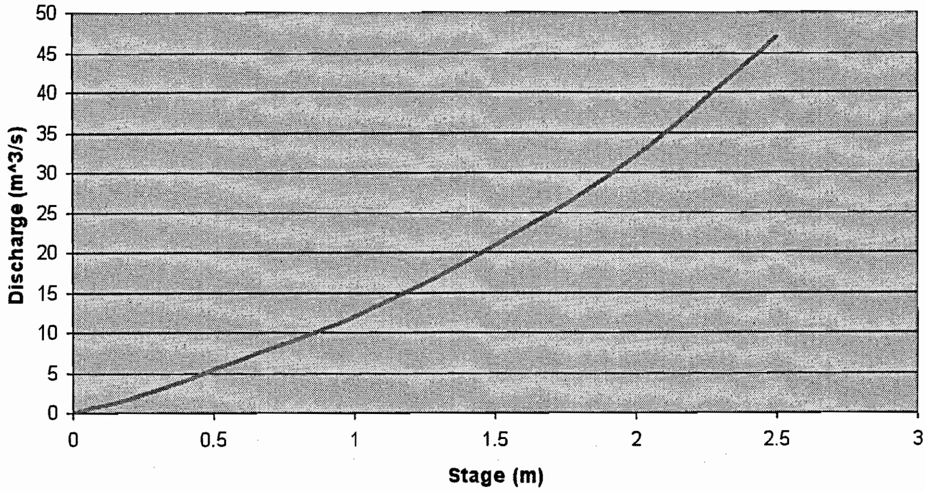

Figure 7. Stage-discharge curve for the outlet of a hypothetical watershed.

obtained from Web sites such as http://soils.usda.gov/use/worldsoils/index.html. Such information can then be coupled with local knowledge and sampling of soils from different parts of the landscape. Stocking and Murnaghan (2001) provide practical guidance for assessing local soil properties and identifying signs of soil erosion and degradation.

Of particular interest to watershed hydrology is the runoff potential of the soil. Sandy soils have a low runoff potential because they allow rain to infiltrate deeply into the soil profile. Clay soils, however, have a high runoff potential. Also, shallow soils on top of an impermeable layer would have a high runoff potential. Runoff potential influences selection of coefficients used in runoff estimations (see the "Runoff" section as well as McCuen [1989]). In the absence of soil maps and tabulated hydrologic soil groups, basic field knowledge of local soil texture can guide selection of coefficients.

Land-use capacity and current land use

Land-use capacity is closely tied to soil properties and indicates the most intense use a land unit can sustain without degradation from erosion and loss of fertility. For example, bottomland is generally more capable of supporting intense cropping than steeply sloping land. Steeply sloping land, however, may be capable of supporting grazing or some silvicultural practices. Morgan (2005) describes various classification systems. Perez and Tschinkel (2003) emphasize the importance of mapping this parameter before selecting practices. They state that it is important for local land users to determine their own criteria for identifying the most intensive use that a particular unit can handle. An example of a classification system from Guatemala includes seven categories ranging from annual cropland without limitations (most intense use) to forestland for protection (least intense use) (Perez and Tschinkel 2003).

Perez and Tschinkel (2003) conclude: "The bottom line is that projects should not promote practices that exceed the capacity of a site based on the local definition of land use potential. Where the land is already used beyond its capacity, projects should focus on the difficult task of promoting conversion to less intensive uses."

Thus, collecting data related to land-use capacity and current land use is essential to the planning process. Hand-sketched maps based on field visits and interviews with local residents can accomplish the purpose. In some cases, such an approach may be impractical. The use of satellites and aircraft can aid in collecting land-use and land degradation data in areas that are difficult to sample due to extreme terrain or human violence. Remote sensing can also reveal patterns from the bird's eye view that might not be detectable with ground-based mapping. Khawlie et al. (2005) discuss the use of remote sensing techniques for detecting human impacts on the environment for a watershed on the border of Lebanon and Syria. Ouattara et al. (2004) discuss the problems of interpreting satellite imagery of high relief areas in Bolivia as well as their solution of combining radar and optical data.

Other information

Demographics, cultural practices, water use statistics, wells, and native plants are examples of other types of data that may be worthy of inventory depending on the nature of the problem to be solved.

If computers are available, data can be organized into spreadsheets or GIS to facilitate analysis and presentation. Whether or not computers are available, the information described above should be compiled on hardcopy maps and graphs for use during discussions and on-site planning. Visually organized information will help in communicating with all involved in the planning process.

There will always be a desire for more data, no matter the location or the challenges to be overcome, thus the inventory steps are never fully complete. Nevertheless, the lack of data should not be allowed to prevent forward movement in the planning process. Varis and Lahtela (2002) express this theme in their discussion of the data-poor situation of the Senegal River basin. The authors used trends, rather than numerical data, in examining the interactions of 45 variables for assessing three approaches to water resource management. Motzafi-Haller (2005) laments "the urge to produce more and more data" as an excuse for not solving gender-related problems in rural development projects. Thus, the stakeholder committee and its technical assistance group must do what it can with the best available information and revise the strategy as experience cultivates the knowledgebase.

Analysis and Decision Support

Once data have been collected and organized, the planning group can analyze the information as well as alternative solutions. Perhaps it is desirable to estimate the combined effects of different upland erosion control practices on reservoir siltation. Or perhaps the best site for a reservoir must be chosen from six candidate sites. In some cases, the complexity of the data and alternatives involved will justify the use of computer-based tools. In other situations, simplifying assumptions and an intuitive understanding of the particular system will lead to the same management conclusions as results generated from a complicated model.

GIS allows multiple layers of spatial information such as satellite imagery, topography, soils, and land use to be viewed and analyzed. GIS is useful for visual presentation because maps of different scales and projections can be viewed simultaneously and, in some cases, in three dimensions. It is also useful as an analysis tool for selecting sites that meet multiple spatial criteria. GIS is often used in combination with erosion and runoff models for either generating model input values or displaying model results. Onyando et al. (2005) used GIS and satellite imagery in combination with the Universal Soil Loss Equation to identify priority areas for erosion control for the Perkerra River watershed in Kenya. Millward and Mersey (1999) conducted a similar erosion study in southwestern Mexico with the goal of modifying the RUSLE to take into account the rugged terrain and tropical precipitation pattern of the region. Luijten et al. (2001) used GIS with Landsat imagery and the CROPGRO irrigation model to study the effects of three development scenarios on water budget in the Cabuyal River watershed in Colombia.

Computer models can provide a useful structure for organizing resource inventory data and in some cases are useful for analyzing the complex interactions of alternative scenarios. Computer models become particularly useful in analyzing hydrology of large watersheds where hydrographs from subwatersheds must be combined and then routed to the outlet. Hydrograph routing uses an upstream hydrograph to predict a downstream hydrograph by considering the effects of water storage in the channel. The general result is that the hydrograph peak will decrease and the base will broaden as the hydrograph is routed downstream. A computer can alleviate the computational burden of channel routing. McCuen (1989) describes the mathematical methods involved.

Caution should be taken when considering use of a computer model, however. Much time can be wasted gathering input data to feed a computational monster created for research purposes and conditions inappropriate to the situation at hand. A computer model should be used to manage large amounts of data and to perform repetitive and intensive computations in cases where the model's underlying assumptions and equations match the modeler's understanding of the watershed system.

Project Evaluation

The resource management plan should include strategies for monitoring, evaluating, and refining the individual practices as well as for measuring the cumulative effects at the watershed outlet. Evaluation criteria should be determined by the stakeholder group. Murwira et al. (2000) emphasized this recommendation in their comparison of two evaluation systems for a sustainability project in the Chivi District of Zimbabwe. One system was designed by development staff, while the other was designed by project stakeholders. The first included 28 quantitative indicators of success. While useful to the project funding partners, these indicators were not meaningful to the community stakeholders who ultimately had to make decisions regarding project modification. Ellis-Jones et al. (2001) also expressed the importance of stakeholder-led evaluation as part of a resource management project in Masvingo, Zimbabwe. Very few case studies present the results of evaluating the overall effects of plan implementation on water quantity or quality at the watershed outlet. This is likely due to short-term funding cycles, participant turnover, and the time needed to see the effects of many conservation practices.

Depending on the chosen criteria, implementation of a watershed plan might be evaluated using before-and-after photographs of field or channel conditions, participation statistics (in terms of land area and number of people), and measurement of water quantity or quality at the watershed outlet (see Deutsch et al. 2001). Measurement of water quantity has already been discussed.

Water-quality parameters of interest may include bacteria, total suspended solids, pesticides, and nutrients (nitrate and phosphorus). These parameters should be monitored at the watershed outlet as well as at the outlets of subwatersheds, if of interest. Flow measurements will also be needed at these points to relate measured concentrations to pollutant loads (mass). Samples should be collected in containers free of contaminants that might interfere with the test. Samples can be collected by hand or with an automatic sampler. If a water quality laboratory is not available to process samples, field test kits can be purchased to measure some parameters. In Sustainable

Agriculture and Natural Resource Management Collaborative Research Support Program Phases I and II, water quality test kits for community monitoring were used in the Philippines and Ecuador (Deutsch et al. 2001; Ruiz-Córdova et al. 2005).

One simple test appropriate for reservoirs is Secchi depth. A disk, about 20 cm in diameter and painted with black and white markings, is lowered into the water with a rope. The depth at which the markings are just barely visible is the Secchi depth. This parameter is a measure of water clarity and is related to other parameters of interest such as total suspended solids, bacteria, and nutrients. Secchi depth should be measured each time by the same person and at the same time of day.

Whatever the means of evaluation, results should be documented and used to provide feedback for refining solutions as well as for providing encouragement among stakeholders. At the watershed scale, the large number of people involved can sometimes slow the planning and implementation process to the point that participants become discouraged. Documentation and communication of results can help maintain project interest.

Needs and Opportunities for Additional Study

The literature reviewed for this chapter reveals three main needs for future efforts:

- ***Development of a practical handbook of field measurement and estimation methods.*** Practical guidance on estimating hydrologic parameters, soil properties, and water quality parameters using inexpensive tools needs to be compiled for a large range of climatic and topographic conditions. Stocking and Murnaghan's *Handbook for the Field Assessment of Land Degradation* (2001) is an excellent start in meeting this need.
- ***Development and easy access of basic GIS layers suitable for analysis at 1:24,000 or better.*** Layers useful for most watershed resource applications include aerial photography, soils, land use, and topography. The United States Geological Survey and Cornell University are making progress in this area. Web sites of interest include http://www.agiweb.org/pubs/globalgis/ and http://atlas.geo.cornell.edu/ .
- ***Documentation of long-term results following implementation of watershed management plans.*** Few studies have been found reporting what happened to the water resource or to the planning committee after completing one full cycle of a formal adaptive management planning process. Murwira et al. (2000) do an excellent job of documenting a decade's worth of experience in promoting food security in Zimbabwe. Such a time span proved to be a rarity in the literature reviewed.

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Chapter 5

Governance of Landscape Systems: A Dinner Party Approach

Cornelia Butler Flora and Arion Thiboumery

Effective governance of natural resources requires that diverse stakeholders feel comfortable and positively engaged in a collaborative effort. In this chapter, etiquette is used as a metaphor for manufacturing these conditions of sustainable agriculture and natural resource management governance. Here we use the common experience of eating together, a dinner party, as a practical means to express that metaphor. This chapter draws heavily on etiquette manuals and aphorisms culturally adapted to early to mid-20th century English-speaking upper classes. Other societies and cultures have their own systems of etiquette that also provide for civil exchange—how to get along in discomfiting social situations. Many of these etiquettes have been handed down from generation to generation through written and oral traditions such as stories and sayings, and often still are. This is why we should be listening to our elders, even if their substantive knowledge may seem less relevant in today's globalizing society. Etiquette facilitates the creation of an atmosphere of safe expression, drawing forth good intentions. Once created, this atmosphere allows for dialogue and interaction to move beyond the confines of formal etiquette to deeper levels of expression about landscape system concerns and the identification of commonalities on which governance decisions can be based.

Etiquette is built on commonly accepted (i.e., socially constructed) terms, and there may be quite a variety of ways to behave properly with respect to others across, and even within, regions. Take for example the belch: While quite likely to offend the middle and upper classes of Europe and the United States, a round little belch after dinner in most of the Middle East is quite proper. While we offer many examples, ultimately finding the best etiquette for a particular landscape setting will probably require some research and reflection on that specific life scape (Honadle 1999). The diversity of interests and power relations in any community setting is likely to pose challenging governance problems. Hence, etiquette's function is, as Eleanor Roosevelt put it in her 1962 Book of Common Sense Etiquette, to "find some difficult moments made easier." We hope you will come to agree.

The Dinner Party

> An Albanian proverb goes, "Every guest hates the others, and the host hates them all." Too much entertaining is exactly like that, with no fun intended.... When guests are invited to break bread for other than purely friendly reasons the entertainment is too often a failure, unless it so happens that such business acquaintances turn out to be congenial. (Vanderbilt 1954, p. 260)

Congeniality is the essence of success for any social event. Congeniality produces a setting of mutual respect and trust –high social capital. If you cannot establish and maintain trust, nothing else will follow; your dinner party will fail to achieve the resource-sharing consensus you seek. Integration of the guests with each other and the purpose of the gathering is essential, and achieving that integration is the duty of the host. Further, the host cannot suppose this will happen automatically simply by proximity. The host must be ready to quickly change place settings or even prepare an additional entree in response to the emerging nature of the interactions and the participants.

If we have only people who like and agree with each other at the table as we discuss complicated issues of natural resource management, we are unlikely to bring about change in the landscape. Thus our guest list focuses on inclusion, rather than like-mindedness. Nevertheless, despite different definitions of sustainability, all the guests should share sustainability of the landscape as a goal. Thus it is important to set up an opportunity for informal interaction around the resource, such as transect walks, for everyone to get similar experiences, although they may interpret them differently.

Your invitation should be explicit about the purpose of the event (transparency), which will often mean that a written invitation should be preceded by a personal conversation and perhaps another follow-up before the party so that each guest knows that they will meet with no surprises. When the purpose is clear, the guests will not suffer the embarrassment of arriving in their best formal attire and then be expected to peel potatoes for dinner. Such conversations let those on your guest list ask questions and voice doubts about the gathering. In some countries, many poorer people will not attend meetings with people that they regard as their superiors, for they feel their own knowledge to be inferior to that of people coming from higher rungs of the socioeconomic ladder. It will be important to explain to them the importance of the knowledge that they have and how it is critical for success of the endeavor.

Collective learning and decision making require stakeholders or their representatives to come together socially and negotiate space congenially, much like a dinner party. Dinner parties and adaptive management are not scientific meetings. They require at least as much feeling as thinking; they defy systematic management, replication, and regression analysis. There is no general formula that says, if you play tango music and serve caviar, you will have a great dinner party. However, a successful dinner party is not random; being a social occasion, it can make great use of insights from those with experience. Ultimately, developing local governance is more like a series of dinner parties than just one. But the etiquette will not change much from dinner party to dinner party. The attention paid to organizing the first party must be repeated in the subsequent events as circumstances change and new guests are needed to make the adaptive process work.

The Party's Host

Dinner parties do not just *happen*. They need a third-party catalytic agent, an organizer, someone to create a welcoming space and foot the bill: the host. (We use the term "host" generically. A host may be male or female.) The responsibilities of the host should not be taken lightly. So, if you are going to be the host, thank you for taking on this honorable chore. You may want to have co-hosts to give the party the right feel. If you are part of a government agency, you might ask the heads of a local business and a respected nongovernmental organization also to sign the invitation. This helps establish the legitimacy of the gathering with the invited guests.

Often, if you do not know the invited guest well, that individual or group may be hesitant to attend a gathering that might be uncomfortable. Thus you and your co-hosts must go to special pains to make it easy for all those invited to attend, even if it means changing the date, place, or menu to accommodate the more hesitant participants. That could include offering childcare and transportation, as well as not holding the meeting when those invited are likely to be at work or out of town. It means attention to religious holidays.

Every culture we can think of has some conception of a host, almost always with associated responsibilities of graciousness and generosity. Whether you are in Central Africa, East Asia, or South America, a good host offers a guest the best of what he has to eat and drink, sees that they sleep well, and generally keeps them entertained. Whether the language being spoken is Chinese, Swahili, or Spanish, expressions abound that a good host can use to make a guest feel at home. Adaptability is required by the host to make this happen.

"A true gentleman places pauper and prince at equal ease," goes the English adage. In dealing with local or regional governance, being a good host is important beyond just goodwill and propriety. Making people feel comfortable is the key to having them express themselves among others. But first, you must feel at ease to help others get there. How can they feel comfortable if you are not? As Amy Vanderbilt (1954, p. 260) puts it, "If the host and hostess are smiling, the guests will feel at home and at ease."

T.E. Byers (personal communication, 2008) recounts the following story illustrating the effects of a host offering the best of what he has:

> At a breakfast party in Kadugli, Sudan, we were presented many different delicacies, all of which were interesting and some of which were exotic, and unknown. The host had made us feel quite comfortable and we all ate (the men all ate) the food with relish, some more than others. When we were finished, and after I as a good and willing guest had eaten several items that I had never eaten before, I asked my Sudanese colleague exactly what those delicacies were. He looked at me and said, "I don't know, I never eat those things." The host had made us comfortable, we had done things that we would never have done outside the breakfast party, we had developed a level of camaraderie that would not have existed without the experience and I think we agreed to utilize my Ford pickup to go hunting for guinea fowl ... an activity that later led to four flat tires. Breakfast parties can lead to ill-planned and poorly thought through immediate actions but the bonding can create a new stakeholder group that can then make a case known to those at other system levels.

Affability and trustworthiness are obvious characteristics of any good party host. A very good host can make perfect strangers feel welcome. Foreknowledge of guest interests and activities generally makes it easier to help guests mix with others. Multiple hosts can work well together if they know each other, for instance, the classic married couple as a host team. Host diversity is particularly important when there are traditions of separation between men and women. Integrating women into the party in a way that respects local customs and acknowledges women's special knowledge, access, and control of natural resources is critical. Thus a previous dinner for the women (or other less powerful group) might serve to make them more confident in working with men (or the more powerful) to define and address their common goals for landscape management.

If all stakeholders got along well with each other, there would probably be no need for a dinner party or a host. But most landscape conflicts arise among groups lacking social connection, with uneven political power and often ethnic, class, or gender differences. Getting everybody to sit at the same table can be a colossal chore indeed. Whatever the reason that groups culturally do not to sit together (e.g., a culture where women and men, or different castes, traditionally do not eat together), your job is to find a culturally appropriate way around this. This could include finding a removed location where traditions can be relaxed, finding group representatives who are willing to be more flexible, or holding parallel events with a high level of sharing of information between them.

You and your fellow hosts are on the ground, informed by your fieldwork and contacts. Your openness to recognize immediate problems of collaboration and ways that different groups can contribute to improving the landscape is critical. As host, you are responsible for keeping the discussion polite, encouraging comments from those who sit shyly, and making sure no one goes home hungry—that is, disappointed with the event's outcomes. You must show yourself as fair, transparent, and accountable to your guests. And if at first you don't succeed, try, try again a different way.

The Theme of the Party

So you want to have a dinner party. Every party has an implicit theme for being held, a cause that brings people together, even if it is just to reaffirm commitment (friendship or a community celebration). Your guests must be assured that you have no hidden agenda but are transparent in the goals and accountable for the process. The theme is your landscape management issue at hand. It should be concise enough to fit on an invitation, clear enough that guests will understand why they have been invited, and interesting enough that they will want to attend. Invitations in person can help to clarify but can put people on the spot to say they will come. You can write different personal invitations to different people, but the theme must be consistent; you are not planning a surprise party. If you are still somewhat uncertain about how best to approach or even flesh out your landscape use issues, this itself could be a party theme.

Make each guest feel special. Let each person invited know why his or her presence is essential. In a proactive way if possible, the theme of the party should empower those stakeholders least empowered. They are your honored guests. People go to dinner parties because they feel socially obligated and/or think the party will be fun. Those who feel socially obligated are usually the empowered ones who will come anyway. The party needs to be appealing and interesting for those least likely to come. By "interesting" we mean that people should feel that attendance will be a rewarding experience ("fun"). How will the subject of the conversation be relevant to them? What do you think they will be able to contribute so they will not feel left out? Does the party offer a forum where they can comfortably express themselves? Who else will be there?

Whom to Invite, How Many

Your carefully chosen guest list should include knowledge of the relation of each to others in the landscape; their concern for its state can help with the interaction and the planning. No guest should be there as the sole representative of the stakeholder group he or she is presumed to represent. Two or three such representatives allow for affirmation but not the opportunity to simply set up a group apart from the main party.

This constraint of human scale makes stakeholder representation necessary. Stakeholder groups are not always neatly organized with ready and waiting representatives. Often a meet-your-stakeholder-group-fellows dinner party will be in order first (more on this later). At any rate, you should be familiar with and have good rapport with all invitees before bringing them together.

Know Your Guests

It is good to know the intentions of people when planning any event. Your dinner party will be a bit like a group-prepared dinner in the sense that you will need to know who will bring what to the table. Participatory action researchers recommend, for the purposes of clarity, that there be something written down indicating who will do what and what each person might consider bringing to share with the group. For the important guests who do not write, preliminary discussion can help them in their preparation to contribute to complex adaptive landscape management. Such transparency as to theme and to negotiated expectations helps people remember their commitments to the hosts, each other, and the landscape.

At formal dinner parties of old, as at yours, being under the same roof was not sufficient introduction. That is, do not expect people to naturally introduce themselves to others simply because they are at the same party. Guests must be formally introduced to each other, though what constitutes an introduction can vary from place to place. If you work in your native society you should have some feel for local social graces, trust yourself, and recognize that they are appropriate for their adaptive management of complex adaptive landscape systems. If you are a non-native, you are probably developing a local etiquette feel from your fieldwork. Do not be afraid to ask those locals who seem to possess great social grace.

You might try to introduce guests in a way that shows commonalities with others at the party—"Luis, you're an avid soccer player, and so is Pedro. His village youth team just completed a fund-raising campaign to pay for participation in the tournament in Sao Paulo"—even if that is not how they would introduce themselves. If you are concerned about offending the person to be introduced, consult her or him beforehand and explain your reasoning. You are looking for common ground on which to found understanding among the group. Confiding in people, doing what you say, and representing them without surprises will help to build trust.

Location, Location, Location and Timing

If you want people to reach common ground around landscape management, you might as well start them off on common ground physically. Pick a location where everyone feels comfortable. If none exists, err on the side of making the least empowered more comfortable. Meeting time is also very important. Women are often excluded by meeting time, even in progressive communities. Local leaders explain, "We asked them, but they never come to our lunch meetings," not realizing that village women are busy preparing and serving lunch in their own extended households. They do not have the flexible work schedules and child care that men have.

Culturally, people may have different meeting styles. Passing around a Native American talking stick may well put off European-American ranchers. And handing out green hats to a group of Han Chinese as tokens of friendships will have the reverse effect (green hats are symbols of cuckolds in China). As the host, your job is to figure out what will make everybody physically and culturally the most comfortable.

The Menu: Who Might Be Offended?

Food, locality, and identity are highly interrelated, and your respect for multiple norms establishes you as a trustworthy and accountable host. A diverse group has diverse preferences, and often some among them may have different dietary restrictions. The host might provide a series of main dishes and beverages that honors dietary differences (pork and no pork, meat and no meat, alcohol and no alcohol) yet offer enough varied side dishes for most dietary restrictions to be met and preferences observed.

Beverages and Hors d'Oeuvres

People will arrive at different times, no matter what the invitation said. Beverages and hors d'oeuvres before the formal event gets under way give people a chance to interact informally and talk about the landscape in unstructured ways. The exchange of a few friendly words can have quite an impact on first impressions.

Depending on the scale of your project, the notion of having beverages and hors d'oeuvres can be interpreted on different levels. It could be as simple as explained above, or it could be as complicated as inviting each group to a separate get-to-know-your-fellow-stakeholders party at which you serve beverages only: tea, coffee, or special local concoctions. However, respect the differences of those you have invited. While the Austrian participants may feel right at home with beer and sausages, this is not a good option for your Muslim guests.

As you will not be able to invite more than one or two representatives from each stakeholder group due to the tendency of large groups to fragment, as explained earlier, the success of your dinner party will be greatly affected by the relationship between the representatives and their respective groups. For less organized groups this may be particularly tricky and will probably need one of these get-to-know-your-fellow-stakeholders beverage parties. If the group can elect someone it feels comfortable with but the individual lacks the social confidence to attend your dinner party comfortably, seriously consider coaching the person for the task.

While it might seem trivial, a gathering's beverage of choice should be well thought out with much cultural sensitivity. Alcohol may be usual in some cultures and taboo in others. In some countries, the Evangelicals do not drink and the Catholics do. If there are abstainers, better to avoid alcohol. If it is served, always have several nonalcoholic alternatives. In some cases, the selection of a universal beverage may be better suited to put all at ease with one another. Tea, for example, "has not the arrogance of wine, the self-consciousness of coffee, nor the simpering innocence of cocoa," art and cultural scholar Kakuzo Okakura wrote in 1906. Okakura, a native of Japan, found tea to be the curiously perfect beverage for which people the world over could come together:

> Strangely enough, humanity has so far met in the tea-cup. It is the only Asiatic ceremonial which commands universal esteem. The white man has scoffed at our religion and our morals, but has accepted the brown beverage without hesitation. The afternoon tea is now an important function in western society. In the delicate clatter of trays and saucers, in the soft rustle of feminine hospitality, in the common catechism about cream and sugar, we know the Worship of Tea is established beyond question.

Facilitating the Conversation

The French philosopher Voltaire, known for his keen and witty discussion, was known to often begin, "Before I discuss anything with you, you must define your terms." You can expect various stakeholders to come to the table with different conceptions of the world, its assets, and who should own them. You cannot expect anybody to readily see things from another's perspective. You can request that all guests be forthright with their opinions about a subject and that they take the time to explain why they think the way they do; being a good and inquisitive host means inviting them into a respectful discussion. The gaps, discrepancies, and resulting questions that emerge are your opportunities for social learning.

Supposing that everyone is on the same page just because the same language is spoken is sure folly. Truly understanding people requires an appreciation of their cultural background and a communications approach respecting it. British and Americans do speak the same language, but as playwright George Bernard Shaw famously said regarding this illusion of similarity, "England and America are two countries separated by a common language." Another case of miscommunication is from Edward T. Hall's *The Silent Language*, retold by Eleanor Roosevelt (1962, p. 204):

> [A]n American agriculturalist deeply offended a farmer in Egypt by a well meant question as to how much the man expected his field to yield that year. Nonplussed by the man's anger, the [American] farmer later made inquiries and found that the Arab had believed him to be crazy, since only God knows the future, and it is presumptuous even to talk about it.

As the host, do not undervalue your own input. Your perspective can help draw connections among such variant viewpoints. At the very least, you may try to make sure that the discussion does not stray too much into the same old static reductionist perspectives. Again, honest congenial communication will be of utmost importance to establishing a common vocabulary. A rapid rural reconnaissance is an excellent tool to help guests understand how others see the landscape and the problems, solutions, and opportunities that can serve as the basis for complex adaptive management.

As stated earlier, social learning by its nature is adaptive and develops according to the group's negotiation. Such negotiation may be best carried out experientially—through transect walks and sharing indicators of the condition of the ecosystem together in the field. The food, drink, and interactions at the dinner party allow the mindset of adaptive management of complex systems to be further developed as guests are surprised by and impressed with the different sorts of knowledge present at the table. The sense of shared discovery marks a truly successful event.

Seating and Honored Guests

> Ordinarily, among people who see each other frequently, the hostess places to the host's right any woman who has obvious seniority over the rest or, if none has, any woman guest who will bring out her husband conversationally if he needs special incentive. To her own right the hostess places the husband of the guest of honor, if there is one, the man who has come the greatest distance and is an infrequent visitor to the household or a man who may be a little shy or difficult conversationally. (Vanderbilt 1954, p. 273)

Classical formal dinner parties had the hostess and host seated at opposite ends of the table. The point of this was to better monitor the enjoyment of every guest, invite each to discuss a subject of interest should he or she have an air of disengagement, or offer a fresh bowl should a fly have inadvertently strayed into the soup. If you are working with someone else, consider sitting at opposite ends. And consider who has the best rapport with which guests. Do keep those "difficult conversationally" close to you so as to give them special encouragement and invitation to speak. As our colleague Andrew Hochstetler says, "One of the things an applied researcher does, and what I think is the most fun, is not showing how smart you are but helping [others] to show how smart they are."

Your job as host-coordinator is to help bridge the gaps among your guests. Paying particular attention to making those whose voices are seldom heard feel comfortable and share their knowledge is critical.

Toasting

Often it is good to talk up the actions of a marginalized group or player to a dominant one in the terms of success used by the dominant. However, in some cultures it is not seen as proper to raise some above the rest, and other forms of praise may need to be sought. Toasting could simply be making an open statement recognizing an individual or group's efforts. If someone is shy or if culture discourages him or her from claiming successes, it may be necessary for you to make others aware of the person's strengths by proposing a toast. This might be in front of the distinguished person or not. It could be to a small group or a whole party. Remember, the objective is not to embarrass but to empower. A little bit of pride is not always a sin; in fact, confidence without arrogance will help things fly better than pixie dust.

Where Are We Going? What Can Be Accomplished?

In your own locality, the idea of getting people to sit down at the same table, let alone "develop instinctive consideration for the feelings of others" may seem hopelessly optimistic. Some gaps are so large with prejudices running so deep that they may take the passing of a generation to be overcome. Regardless, we start from where we are and cannot be deterred from at least imagining. Consider the methodologies laid out in this chapter simply as a means of bringing people together around managing a shared landscape. Even if you can bring together stakeholders from only one group, nothing can be lost by listening, talking, and learning. In fact, we have often found this too opens up unseen avenues, even in the bleakest of situations. In the beginning, it may take multiple small dinner engagements before the formal dinner party.

Good Night and Good Luck: Moving from Dinner to Healthy Landscapes

It has been a lovely evening. Thank you very much for coming. There is much to hosting a dinner party, and we hope this will set you in the right direction. No book of etiquette can possibly imagine every situation; this chapter is meant merely to stir the pot, shake out the wrinkles, and remind you to not open the oven or the soufflé will fall.

We also recognize that dinner parties are not expected to resolve disputes or come up with plans. For Eleanor Roosevelt, it was enough that shouting matches did not break out. But in governance of natural resources, groups come together to identify the desired future conditions for a landscape—to see where there is agreement and to work first on those issues in determining how to reach the desired future conditions.

Your dinner party has been a process, not a single event. In that process, you established the legitimacy of the collective enterprise by ensuring transparency and accountability throughout the process. You worked hard to be inclusive, for a wide variety of stakeholders is necessary to manage complex adaptive landscape systems. You made sure not only that there is a diverse set of perspectives at the table but that those perspectives are integrated and that all the guests increased their capability to act together to improve the landscape. Your handling of the dinner party should result in an adaptable network of relationships to address a complex system.

Managing and coordinating the human elements in complex adaptive systems require complex adaptive governance to successfully link the household to the larger policy setting. Governance is quite different from government. Governance does not exclude governments, but it also involves actors from the market and civil society, composed of what local actors can best muster to address landscape issues with, or sometimes despite, each other and in alliance with or in opposition to outside actors. Governance is about people working, asking questions, learning, and making decisions together. A variety of scholars (Davidson 2008a, 2008b; Flora et al. 2004; Gasteyer et al. 2002; Flora 2000; Wycroft-Baird 2005) have found that collaborative landscape management requires a process aimed at developing legitimacy, fairness, transparency, accountability, inclusiveness, integration, capability, and adaptability.

We have seen how proper etiquette is integral to success in developing these characteristics. From successful invitations to providing the experience promised to adapting to changing circumstances, the good host embodies these virtues. We could not agree more with Eleanor Roosevelt (1962, p. ix):

> Etiquette, from my point of view, is not just a matter of knowing how a lunch or dinner should be served, or what the "proper" behavior is in this or that situation. There are many correct ways of behaving in any situation, and many proper ways of doing those things for which there precise rules in formal etiquette books. But the basis of all good human behavior is kindness. If you really act toward people in your home and out of it with kindness you will never go wrong.

Now go forth, invite guests, make dinner, and enjoy it.

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Chapter 6
Ecosystems and Ecosystem-Based Management

Carola A. Haas, Emmanuel A. Frimpong, and Sarah M. Karpanty

Within the complex adaptive systems (CAS) framework, working at the ecosystem level requires actions across large scales over time as well as space. Processes such as water and nutrient cycling, soil formation, and desertification take place over much more than a few years and across areas that can encompass an entire continent and surrounding oceans. Because most human actions occur at a certain time and place but with consequences occurring far beyond that moment and place, an effective adaptive management process requires us to continually look back and forth, from local to regional scales, and from short to long time frames. In this chapter, we will follow three basic principles for sustainable management:

- We focus on the long-term and regional scale.
- We value diversity in systems (biological and social/cultural).
- We believe that the more closely human activities resemble natural patterns and natural disturbance regimes (such as fire frequency) the more sustainable the system is likely to be.

In the earlier description of the scalar dimensions of the Sustainable Agriculture and Natural Resource Management landscape system (see chapter 1), we define the ecosystem as the system that encompasses the field, farm enterprise, and watershed systems and that operates on a similar scale with policy and markets most effectively for sustainable management. Before effectively working in a CAS framework, it is necessary that we understand the origins, varied definitions, and properties of this ecosystem-level concept.

The concept of the ecosystem arose early in the science of ecology as a logical extension of the debate at the time over how communities of organisms are structured and whether or not they operate as a self-contained system, as in the sense of closed physical systems. Tansley (1935) was the first to formally define an ecosystem as a holistic concept of the plants, the animals associated with them, and all the physical and chemical components of the immediate environment, which together form a recognizable self-contained entity. As a self-contained entity, the ecosystem is governed by several processes that form the basis of CAS management. First, an ecosystem must have an input of energy that is equal to the demand of the organisms within it, as energy is harvested from the abiotic solar environment by photosynthetic organisms and flows through the biotic environment. Energy is used by organisms in metabolic processes and lost as heat at each transfer through the food web, resulting in pyramids of energy and biomass with photosynthetic organisms predominant at the base and carnivores at the pinnacle. Odum (1969), in his pioneering work on ecosystem ecology, used energy as the currency to define an ecosystem, stating simply that an ecosystem is an area within which the energy flow is in balance. It is important to note that this classic definition of the ecosystem was developed with the concept of an autochthonous system in mind, in other words, a system that is unaltered by humans from its natural state. In reality, most ecosystems today are strongly impacted by human activities and highly managed, such as agricultural systems. These highly managed systems are generally sustained by energy subsidies of various forms.

Another unique process at the ecosystem level of CAS is that nutrients and water cycle throughout the system by the processes of photosynthesis, respiration, ingestion, digestion, excretion, and decomposition. Pools of chemical elements such as carbon, nitrogen, and phosphorous exist in the atmosphere, lithosphere, and hydrosphere and are naturally released into the ecosystem through processes such as weathering and carbonation of rocks and minerals, microbial conversion of atmospheric nitrogen to ammonium, and uptake of atmospheric carbon dioxide by plants. Other nutrients may enter systems from the atmosphere, either by dissolving in rain as it falls to the earth or being deposited directly from the air. Once nutrients such as carbon, nitrogen, and phosphorous enter an ecosystem, they are repeatedly converted between organic and inorganic forms and recycled through the system. One important outcome of these processes of recycling and decomposition is the formation of soils, which serve as the foundation for productivity in both natural and agricultural and agroforestry systems.

Human activities now dominate the input and output of nutrients to many ecosystems around the world. Large quantities of carbon, nitrogen, and phosphorous are released into the environment as byproducts of industrial and agricultural practices, such as the burning of fossil fuels and use of nitrogen and phosphorous fertilizers. Globally, agricultural and forestry practices play a significant role in the disruption of natural nutrient cycles because continuous harvesting depletes nutrients in one area and transports them to another. Farmers and foresters who want to maintain long-term productivity must fertilize their lands with nutrients and other soil amendments to maintain high levels of productivity. If the system becomes unbalanced (e.g., too few or excessive nutrients), as is the case in many agricultural systems, external inputs (e.g., fertilizer) or export of excess nutrients (e.g., transport of excess animal manure and wastewater treatment plant residuals to nutrient deficient areas) may be required to maintain ecosystem integrity. These fundamental processes of energy flow, nutrient and water cycling, decomposition, and soil formation must inform the decisions made by planners at the ecosystem level and are key to maintaining balance in the lower levels of CAS, specifically watersheds, farms and fields. When imbalance is suspected, the manager must ask two questions to diagnose the imbalance and to recommend mitigation. How is the abiotic environment affecting the organisms within it? How are the organisms affecting the abiotic and biotic environment? Imbalance can come from one or both directions.

As the science of ecology has progressed, ecosystem science has been refined to clarify that human beings are an integral biotic component and have significant impacts on the biotic and abiotic components of most ecosystems. This was explicitly stated in the Millennium Ecosystem Assessment (MEA 2005a): Humans are an integral part of ecosystems. (The MEA, conducted between 2001 and 2005, included more than 1,300 experts around the globe working to evaluate the effects of ecosystem change on human wellbeing.) As addressed throughout this book, there is no shortage of examples of the myriad ways that the human species alters ecosystems. The challenge for managers of CAS is to identify what abiotic and biotic components are being affected and then to develop adaptive management strategies to restore energy flow and nutrient and water cycling in the system.

One of the major challenges for managers at the ecosystem level of CAS is defining the boundaries, temporally and spatially. As succinctly stated in the MEA, "Ecosystems vary enormously in size; a temporary pond in a tree hollow and an ocean basin can both be ecosystems" (MEA 2005a.) While defining the limits of a terrestrial-based ecosystem by barriers such as high mountains or deep rivers may be possible, marine and large-aquatic systems can be especially difficult to define for policymakers and managers. From an energetic perspective, an ecosystem may be defined as the area in which the demand of predators is equal to the production of prey. In terms of behavioral ecology, an ecosystem boundary may be defined to include the foraging range of the organisms that live within it, at least for a large part of their life cycle. Ciannelli et al. (2004) tried to address this question of defining ecosystem boundaries in a challenging marine system, the Pribilof Archipelago in the Southeast Bering Sea, an area of particular importance to multinational fisheries' interests. They demonstrated that the foraging range of the breeding northern fur seals (*Callorhinus ursinus*), which are central-place foragers that depart from and return to a central breeding colony daily and are a dominant vertebrate species in this ecosystem, provided a good estimate of the ecosystem extent and the area needed to provide an energy balance in this oceanic system. Their work demonstrates that it is possible to draw boundaries on ecosystems that enable more coherent policy interventions.

For species with more complicated life histories, such as migratory salmon that spawn in inland streams and die after spawning while juveniles migrate back to the ocean to complete their life cycle, one may choose to define the entire area of their life cycle as one ecosystem or, more commonly, to refer to the inland waterways and ocean as different ecosystems used by these species at different stages of their life history. The challenge is for those in governance, policy, and markets to recognize that the ecosystem(s) required by a species of management concern, such as commercial fish species or migratory ungulates of Africa, may cover areas larger than a single national or regional government alone controls and thus require cross-border treaties or agreements for effective management (Valencia 1990; Smith et al. 2008; Sultanian and van Beukering 2008). In summary, the unique properties of the ecosystem level required by species of interest (because of economic, cultural, or biodiversity value) may serve as leverage for usually difficult negotiations between distinct scales of adaptive management.

Understanding what defines an ecosystem and its role as an organizing principle in ecology (as it encompasses the concepts of abiotic factors, organisms, populations, and communities) does not alone justify its importance as one of the highest levels of organization in CAS. The importance of the ecosystem level in the complex adaptive system paradigm comes from the fact that humans are but one of the many biotic components in an ecosystem and that humans stand to benefit from the properties and emergent effects of all the other abiotic and biotic components of these systems. These benefits are described as ecosystem services (MEA 2005a). The biotic and abiotic components, the process of water and nutrient cycling and energy flow, and the interaction of these abiotic and biotic components and the ecosystem processes create provisioning, regulating, and cultural services of extreme importance to human wellbeing at the field, farm, and watershed levels of the CAS. It is these ecosystem services, described in the following section, that are of primary interest to humans and markets.

Ecosystems: Features critical to the complex adaptive system paradigm

- Ecosystems are complex, and their unique processes operate at long-term and regional spatial scales.
- Energy flows through ecosystems while nutrients cycle within them. When energy or nutrients are out of balance, managers must identify the limiting factors and manage the system to alleviate the imbalance.
- Humans at the field, farm, and watershed levels of CAS cannot exist in the absence of the provisioning, regulating, and cultural services uniquely provided by ecosystems.

Ecosystem Services from Agricultural Landscapes

Agricultural lands provide a variety of ecosystem services. Ecosystem services have been classified in the Millennium Ecosystem Assessment (MEA 2005a) into four major groups: provisioning services (e.g., food, water, fiber/fuel), regulating services (e.g., air quality and water regulation, pollination, reduction of soil erosion and sedimentation), cultural services (e.g., spiritual values, aesthetic values), and supporting services (e.g., soil formation, nutrient cycling). In more recent formulations (e.g., Carpenter et al. 2006; Wallace 2007), the supporting services are now referred to as ecosystem processes rather than services, for their benefits to humans accrue indirectly only through subsequent links. Examples of services that are derived from agricultural land or are threatened by agricultural processes are detailed in the first two columns of table 1(a). As will be pointed out through various examples in this and other chapters, the effect of agricultural activities on ecosystem services, whether positive or negative, is not uniform across time and space. Understanding the scales at which services operate is essential to developing landscape-level management plans (Kremen 2005). Management decisions necessarily involve tradeoffs across services and between time periods (Foley et al. 2005; Farber et al. 2006). The International Assessment of Agricultural Science and Technology for Development described the need for improvements in delivery of science and technology information (Kiers et al. 2008). Environmental costs and unequal distribution of benefits in ecosystem service affect different players and levels in the CAS differently and may accrue immediately or over generations. Identifying the effects on ecosystem services of activities at multiple spatial and temporal scales is a critical step for planners and managers.

Ecosystem services

Three concepts are poorly understood by most people who are not familiar with ecosystem services:

- "Natural ecosystems provide services on which our economic, social, cultural, and political systems depend.
- "When these processes are altered, our quality of life declines.
- "When the processes fail, life becomes very difficult or impossible.

As a result [of this lack of understanding], ... conservation is seen by many as a minor amenity benefiting a small cadre of birdwatchers or backpackers that stands in the way of 'progress' that benefits all" (Brussard and Tull 2007).

The benefit or cost in ecosystem services resulting from farming activities may accrue to the farmers primarily or entirely to people who have no physical or economic ties with the agricultural land. Farmers benefit directly from services such as pollination and on-farm cycling of waste products into soil nutrients. They may also benefit from increased food or medicinal sources if their farmland provides habitat for wild plant and animal species that the farmer harvests and consumes directly. However, the economic benefits of cultural services such as wildlife habitat provided by forest reserves, sacred groves, or fallow farmland that may be important to ecotourism or regulation of water quantity and quality tend to accrue to off-farm users, sometimes to people who live hundreds of kilometers downstream.

Understanding who benefits from a particular activity and how much different parties benefit is critical to effectively managing an ecosystem under the CAS paradigm. Different communities and cultural groups are likely to value ecosystem services differently. For instance, farming activities that result in soil erosion cause water quality problems primarily for downstream water users. Thus, in the absence of appropriate incentives, people who live downstream of their farms and rely on river water supply would be naturally more interested in investing in farming techniques that prevent soil erosion than those who live upstream of their farms. Similarly, some cultures have more concern for posterity than others. A society's propensity to utilize, degrade, or conserve intergenerational resources is a reflection of the discount it attaches to postponed costs and benefits (i.e., those that would accrue only to future generations). Women, who tend to bear responsibility for attending to sick family members, may place more importance than men on a close supply of medicinal plants (Howard 2003). Because the cultural, temporal, and spatial context will determine who benefits from a particular ecosystem service, the willingness of different communities or groups to conserve a resource will vary as well. Arnold Pacey (1983), in his book *Culture of Technology*, emphasizes the importance of addressing cultural values in development programs. By operating at the interface among technical, organizational, and cultural aspects, projects are more likely to accomplish the goals of a local community (Pacey 1983).

Evaluating Ecosystem Services in the Complex Adaptive System Decision-Making Framework: An Example

In addition to the real examples provided in this chapter to illustrate complexities in the decision-making process at the ecosystem level using the CAS framework, it is instructive to have a model system to visualize the idea of the complex adaptive system and to reinforce the notion of unequal distribution of the costs and benefits of ecosystem services related to agricultural practices. Figure 1 shows a small ecosystem defined by a river basin containing three subwatersheds in which watershed 1 and watershed 2 drain into watershed 3. The native vegetation in this model is tropical forest, but it could be wet or dry forest, with or without seasonality in temperature or rainfall. By using watersheds and subwatersheds to delineate the ecosystem boundary in this example, and generally at the higher levels of the complex adaptive system landscape, we are recognizing the importance of the hydrological regime as one of the major processes for delineating scales and boundaries of ecosystems (Noss 1996). Two villages are located in the ecosystem, called Highlanders and Lowlanders. The two villages are only 10 km apart, and citizens of these villages may own land in any part of the ecosystem. In the development of these models we used the following three assumptions:

- ***Model assumption 1.*** The three possible land uses in this ecosystem are natural forest, shifting cultivation in short rotations (less than 10 years) and without use of agrochemi-

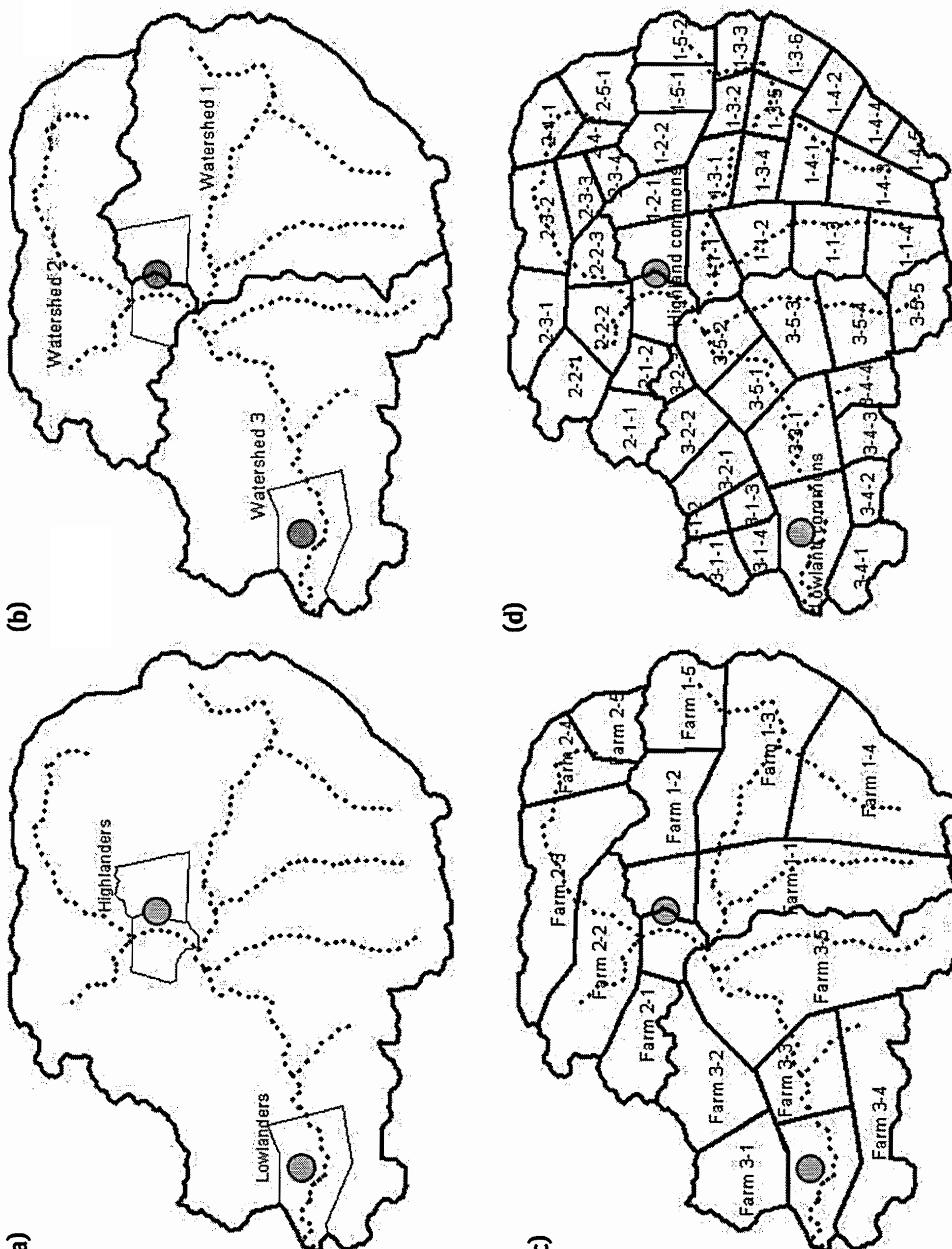

Figure 1. A model ecosystem shown sequentially (a) to (d), with two villages (Highlanders and Lowlanders), three watersheds (1-2-3), and hierarchically nested farms (farm 2-3 is farm 3 in watershed 2) and fields (field 2-3-2 is field 2 in farm 3 in watershed 2).

cals, and low intensity agroforestry without agrochemical use. By eliminating the use of agrochemicals (fertilizers), we are constraining the system to its natural nutrient cycling capabilities, which is typical in shifting cultivation and low intensity agroforestry systems. The main features defining shifting cultivation in this example are clearing of the field, burning of cleared vegetation in the field, growing crops, and abandoning the field for a new one in two to three years after soil fertility declines with successive crops (ThinkQuest 1999). We used short-rotation shifting cultivation to demonstrate an unsustainable system, although in some cases a farmer will not return to the abandoned field for 50 years or more (ThinkQuest), in which case soil fertility would return, woody vegetation will regrow, and shifting cultivation would represent a sustainable farming practice. However, in our example, the field is returned to cultivation when the fallow period has been too short to restore nutrients or regrow substantial woody vegetation.

In our model, we define agroforestry as the intentional co-planting of shade trees with agricultural crops (Bhagwat et al. 2008). The example agroforestry has extensive tree cover and diverse crops and, while structurally simpler, resembles the nearby forests in structure and function (Greenberg et al. 2008). We also presume that there is considerable homogeneity in the structure of agroforests across fields and the landscape, making their aggregated effect on the ecosystem more predictable. While functioning as farms, agroforests have the potential to provide wildlife habitat and serve as dispersal corridors connecting patches of natural forests (Bhagwat et al. 2008).

- ***Model assumption 2.*** In the long term, every field plot can change to another use, limited by what is feasible. For instance, it would not be possible for a field that was in short-rotation shifting cultivation for a long time to return to natural forest in the short term (e.g., less than 10 years). When farms contain some fields in short-rotation shifting cultivation, we presume that, in the long term, shifting cultivation will take over the entire farm, for degradation of the area managed through short rotations will force more intense farming activities to other areas of the farm. However, a farm that started out entirely in agroforestry could be maintained in the long term in agroforestry because this low-impact practice would continue to provide substantial benefits to the farmers. If a greater proportion of a farm/enterprise started in agroforestry or natural forest, any land in shifting cultivation would eventually be converted to a more sustainable practice as the long-term benefits become apparent. Forests will remain forest for a longer time, and some agroforest may rotate between secondary natural forest and agroforest over time.
- ***Model assumption 3.*** We purposely do not define the short, medium, and long time frames in terms of number of years but presume that the short time frame is equivalent to a few growing seasons and that the long time frame would occur over more than one generation.

Now consider the two land-use scenarios shown in figure 2. Tables 1(a) and 1(b) present ecosystem services that may be affected under these land-use scenarios (compared with the natural state of the watershed as tropical forest) and how these costs and benefits may accrue to the field, farm enterprise, watershed, and ecosystem under the two land-use scenarios. Note that the scale of service generation is not necessarily the same as the scale at which service accruing is being estimated. Freshwater supply and water purification, for example, are generated at the watershed and ecosystem scales, but the benefits of the services can be measured at any level in the CAS landscape. These tables focus on field 2-3-2, which is part of farm 2-3, which is in turn a part of watershed 2. The farmers of farm 2-3 live in the Highlanders village. Following the method of Farber et al. (2006), ecosystem services that are increased compared with native forest are indi-

(a)

(b)

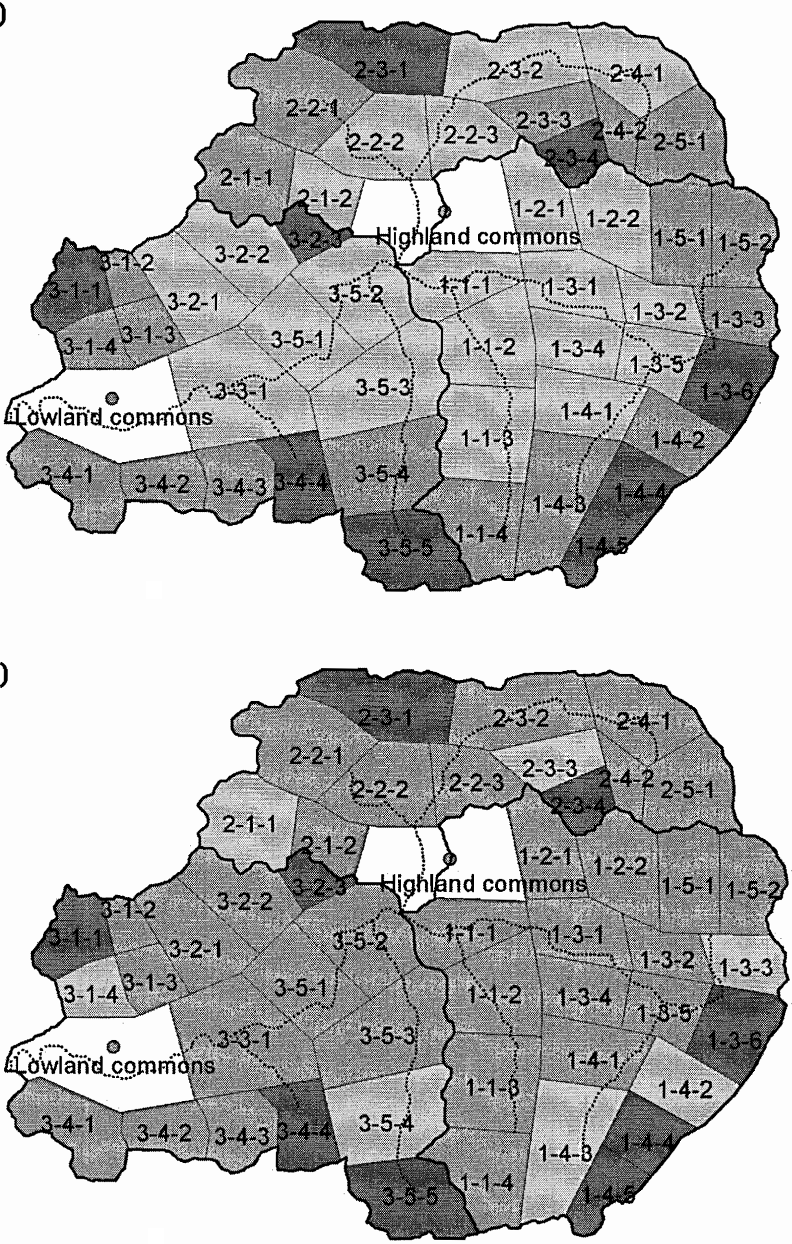

Figure 2. Alternative land-use scenarios in a model watershed (described in figure 1) with first scenario (a) depicting predominantly shifting cultivation near streams and in flood plains and agroforestry in highlands. The second scenario (b) depicts a watershed system dominated by agroforestry around streams and rivers. Dark gray = forest. Medium gray = agroforestry. Pale gray = shifting cultivation.

Table 1(a). Costs (-) and benefits (+) of ecosystem services related to the first land-use scenario depicted in Figure 2a: Owners of farm 2-3 live in the highland community and convert field 2-3-2 from natural forest to short-term shifting cultivation. Costs and benefits of ecosystem services are averaged for the stakeholders of the respective levels of the complex adaptive system landscape.

		Potential direction of change in service compared with natural ecosystem											
		Field 2-3-2			Farm enterprise 2-3			Watershed 2			Ecosystem		
Ecosystem service and category	Subcategory	Short-term	Medium-term	Long-term	Short-term	Medium-term	Long-term	Short-term	Medium-term	Long-term	Short-term	Medium-term	Long-term
Provisioning services													
Food	Domesticated crops, livestock	+3	+1	0	+2	+1	0	+1	+1	0	+1	+1	0
	Wild plant and animal food products	+3	-1	-3	+2	+2	-3	+1	+1	-3	+1	0	-3
Fiber/fuel	Timber	+3	-2	-3	+2	+1	-3	+1	0	-3	+1	-1	-3
	Wood fuel	+3	0	-3	+2	+1	-3	+1	0	-3	+1	0	-3
Biochemicals, natural medicines		-1	-2	-3	0	-1	-3	0	0	-3	-1	-2	-3
Fresh water		-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
Regulating services													
Water regulation/ purification		-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
Pest regulation		+2	-1	-3	0	0	-3	-1	-1	-3	-1	-1	-3
Pollination		+2	+1	-2	+1	0	-2	0	-1	-3	0	-1	-3
Cultural services													
Aesthetic values/ recreation and ecotourism		+1	-1	-3	+1	-1	-3	0	-1	-3	0	-1	-3
Sense of place/ cultural heritage values		+2	+1	-3	+2	-1	-3	0	+1	-3	0	-1	-3

Table 1(b). Ecosystem service accruals under second land-use scenario, depicted in figure 2b: Owners of farm 2-3 live in the highland community and convert field 2-3-2 from natural forest to agroforestry. Costs and benefits of ecosystem services are averaged for the stakeholders of the respective levels of the complex adaptive system landscape.

		Potential direction of change in service compared with natural ecosystem											
		Field 2-3-2			Farm enterprise 2-3			Watershed 2			Ecosystem		
Ecosystem service and category	Subcategory	Short-term	Medium-term	Long-term	Short-term	Medium-term	Long-term	Short-term	Medium-term	Long-term	Short-term	Medium-term	Long-term
Provisioning services													
Food	Domesticated crops, livestock	+1	+2	+3	+1	+2	+3	+2	+2	+3	+2	+2	+3
	Wild plant and animal food products	+1	0	0	0	0	0	0	0	0	0	0	0
Fiber/fuel	Timber	+1	0	-1	+1	+1	0	0	0	0	0	0	0
	Wood fuel	+2	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
Biochemicals, natural medicines		0	0	0	0	0	0	0	0	0	0	0	0
Fresh water		0	0	0	0	0	0	0	0	0	0	0	0
Regulating services													
Water regulation/ purification		0	0	0	0	0	0	0	0	0	0	0	0
Pest regulation		+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
Pollination		+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
Cultural services													
Aesthetic values/ recreation and ecotourism		-1	-1	-1	+2	+2	+2	0	0	0	0	0	0
Sense of place/ cultural heritage values		+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1

cated with a +, those that are neutral with a 0, and those that are decreased are indicated with a -, and the magnitude of change is ordered from 1 to 3. The numbers allow us to assign relative degrees of change. For instance, +1 under food provisioning services would indicate a minor increase above levels in native forest, whereas a +3 would indicate a large increase. The numbers in tables 1(a) and 1(b) represent the average value for all nested components for the complex adaptive system level being studied. For the purpose of this model exercise, the "averaging" was done heuristically with no mathematical rigor enforced.

The first scenario shown in figure 2 has field 2-3-2 in short-rotation shifting cultivation. At the beginning of this cycle, field 2-3-2 is cleared from native forest. In table 1(a), we can see the effects at the field scale in the short term by reading down the first column at each level of the CAS. Clearing native forest allows the farmer to harvest a substantial amount of wood for timber and fuel in the initial year of the cycle. At the same time, wild game is readily harvested from the plot both before it is burned and later as animals enter from adjacent stands of mature forest. However, field 2-3-2 is located along a stream. The activities of field 2-3-2 together with nearby fields (2-2-2, 2-2-3, 2-4-1), which are also practicing shifting cultivation in riparian zones, results in diminished hydrologic services (water supply and quality) to the downstream Highlander village. As forest quality declines over time with increasing amounts of shifting cultivation, hydrologic services continue to decline. Pest regulation services would be high in the short term with the surrounding forests protecting the isolated field from crop pests. In addition, the surrounding forest would provide suitable habitat for many beneficial insects and birds that could serve as pollinators. A recent review found that avian pollinators increase in low-intensity agricultural fields compared with native forest and that bee populations remain constant (Tscharntke et al. 2008). The aesthetic and recreational values of a cultivated field would decline relative to native forest, but the cultural values and sense of place might increase as farmers began to make their mark on the land and successfully grew crops to provide for their families.

The changing costs and benefits of ecosystem services in the medium and long term of this example are shown in columns 2 and 3 of each CAS level in tables 1(a) and 1(b). As the amount of forest declines, less timber and fuel wood are available, and more weedy vegetation begins to invade the fields. The insufficient fallow period results in more water runoff and the loss of topsoil and nutrients. Siltation of streams and rivers increases with the increase in shifting cultivation, and as more of the land shifts from late- or mid-succession to early-successional habitats, pollination services and pest regulation services decline. Once the fields become highly eroded and unproductive, there is little value for food production and no longer the benefit of pride in place or cultural heritage values.

As our focus shifts in spatial scale to the farm enterprise level (shown in columns 4 to 6 of table 1[a]), the patterns are similar to that at the field level, although because farm 2-3 incorporates a substantial amount of native forest and a small stand in agroforestry, more of the benefits of shifting cultivation persist into the midterm, while the overall farm is still relatively diverse. In the long term, however, the shifting cultivation spreads from the now-depleted fields into the native forest, causing an ultimate collapse. At the watershed and ecosystem levels (shown in columns 7 to 12 of table 1[a]), because many fields are in shifting cultivation, especially those that border stream corridors, there are fewer benefits even in the short term, and the decline in services happens faster at these larger scales.

The second scenario (figure 2, table 1[b]) shows a contrasting situation in which many of the farms start out with low-intensity agroforestry and no shifting cultivation. Based on model assumption 2, we expect shifting cultivation to remain limited or to change to agroforestry in the long term, with agroforestry fields remaining in agroforestry or transitioning between agroforestry and natural forest. While provisioning services may not accrue initially in quantities as high as the first scenario, these services are sustained over time. Most services are still provided at levels greater than or equal to that obtained from the natural forest, as indicated by the 0s, and services are rarely generated below natural levels. At the watershed and ecosystem levels, because almost all of the land surrounding stream corridors is native forest or agroforestry, high-value hydrologic provisioning and regulating services are provided. The long-term outcomes at these higher scales allow for a variety of sustainable ecosystem services. While there is greater individual immediate benefit in the form of most provisioning services in the first scenario, these are accompanied by shared societal costs in the form of diminishing regulating and cultural services, especially in the medium and long term. These regulating and cultural services mostly fall in the purview of common property and public goods, the preservation of which is often ignored or even subconsciously sabotaged by individual-level decision making (Hardin 1968; Odum 1982). In the second scenario, individual gains are not at the expense of large-scale and long-term deterioration in ecosystem services. Hein et al. (2006) analyzed the ecological scales (plant-plot, ecosystem) at which ecosystem services (provisioning of reed and fish, recreation, nature conservation) are generated and the institutional scales (individual, family, municipal, state/provincial, national, international) at which services accrue to stakeholders from a wetland. Not unlike CAS expectations, they concluded that stakeholders at different scales can have very different interests in ecosystem services, emphasizing that the consideration of scales is crucial in the formulation or implementation of management plans.

The previous scenarios are simplifications for illustrative purposes. For instance, there may be biophysical constraints (perhaps soil fertility is much higher in the floodplain, or upland slopes are too steep to permit cultivation) to the location of certain agricultural or land-use practices in the landscape. Two important inputs for projecting the trajectories of future land uses are past land-use transitions in the landscape (formally, a transition probability matrix) incorporating biophysical constraints, and the specific market and policy context (such as existence of credit, incentives, or technical support for adopting alternative practices) that are expected to influence current and future decisions.

Different individuals may make different decisions when presented with the same biophysical and market conditions. For example, the tendency of a farmer to adopt a particular practice may be a function of level of education (Abdulai and Binder 2006) among other socioeconomic factors. There is general supporting (Abdulai and Binder 2006) and contrary (Borggaard et al. 2003) evidence for increased use of chemical fertilizer as a consequence of short-rotation, slash-and-burn shifting cultivation. Fertilizers increase productivity by reducing nutrient losses from intensive cropping and erosion. When credit is available, farmers may purchase more inputs to improve productivity (Abdulai and Binder 2006). In the absence of credit, the cost of fertilization is prohibitive for subsistence farmers, who tend to compensate for declining production by increasing labor instead (Borggaard et al. 2003; Abdulai and Binder 2006).

A scenario that involves extensive use of fertilizer in shifting cultivation would present its own suite of new challenges in the CAS. Besides the upfront cost to farmers or to governments in the form of subsidies, efficient fertilizer-based shifting cultivation would require a different cropping system than the typical agro-diverse farms. In subsistence farming, fields are often planted to multiple crops, but different crops have different nutrient requirements. Fertilizing all with the same fertilizer will not be so effective, but there are cash and labor costs of trying to apply different chemical fertilizers on the same field. If fertilizer use encourages reduction of crop diversity, this has negative implications such as increased risk of disease, pests, crop failure, and dietary deficiencies; and increased plant-plant competition from reduced variation in plant architecture, water, and nutrient demands. External costs of intensive fertilizer use in shifting cultivation include water-quality problems from non-point source nitrogen and phosphorus exported to streams. Our analysis of costs and benefits at the hierarchical scales did not go beyond boundaries of the single ecosystem. However, it is convenient here to point out that investment in fertilizer may not accrue benefits to the local market, for fertilizers are typically imported. Purchasing non-local inputs has implications for other ecosystems in ways that our model is not designed to address (e.g., implications for global carbon budgets).

Clearly, the many factors that affect decisions and consequently projection of alternative futures for the CAS tend to be context-specific. However, as an illustration of decision making at the ecosystem level using the CAS framework, we hope the process is clarified and that users and decision makers can envision with this simple example what it would take to create realistic alternative futures to guide their decisions. In the following sections, we provide a variety of examples of real-life management dilemmas and solutions. We hope this example may serve as a template for understanding these real-life scenarios.

Managing for Ecosystem Services on the Ground: Examples from Real Complex Adaptive Systems

To ensure that appropriate incentives are in place to achieve environmental goals, practices that provide direct benefits to farmers without substantial cost to the larger society should be used. Alternatively, there should be financial incentives for farmers to provide such services to others. In some systems, penalties rather than rewards are used to encourage agricultural practices that reduce damage to ecosystem services. However, this approach often requires a significant infrastructure for enforcement of penalties, which often may not be feasible.

Development of sustainable and environmentally sound agricultural production systems requires multidisciplinary teams with knowledge of agricultural, cultural, economic, and ecological systems. A multidisciplinary approach allows solutions to be identified for what may seem like intractable problems. For example, grassland songbirds have shown serious declines across much of North America (Askins et al. 2007) and Europe (Krebs et al. 1999; Vickery et al. 2004). Many native prairie species now breed primarily in hayfields. When hayfields are mowed in the spring, bird nests are destroyed, and there is often complete reproductive failure for these species. Conservation biologists had hoped that farmers who had learned about the condition of the birds would delay mowing until after peak breeding season, but this did not occur. The problem was not that farmers did not care about grassland birds but that the conservation biologists failed to recognize the real economic costs of delaying haymaking. The forage value of a hay crop peaks at a particular time of year. For alfalfa, that point occurs just as the plant is beginning to flower. For most grass species, that point occurs before the plant sends up a flowering stalk. Cool-season grasses should be cut in early spring and, depending on environmental conditions, can often receive a second or third cutting before growth slows. If farmers delayed cutting a cool-season grass hay until mid- to late summer, the nutritional value and palatability to livestock would be severely reduced to the point that they might lose money cutting and baling it. Understanding this constraint on the farmers' part makes clear that asking a farmer simply to delay cutting hay is not a viable option for saving the birds.

But is there no way that we can expect farmers to provide suitable nesting habitat for grassland birds? In fact, such a solution exists and is being implemented across many small landholdings in rural North America. Cool-season grasses have been planted extensively in the southeastern United States because they green up early and provide needed forage after the winter. However, they grow little if at all in the heat of the summer. During hot, dry summers, many farmers must begin feeding hay in August because pasture forage is depleted. Feeding hay is expensive compared with grazing, and there is always a risk of not having enough hay for the winter. By moving livestock onto warm-season pasture, farmers can rest cool-season fields, allowing them to stockpile forage. Using this system, it is sometimes possible to delay feeding hay until November or December. The songbirds can use the warm-season pastures, and more cool-season hayfields may be converted to pastures in which birds also have higher breeding success. Converting some pastures and/or hayfields to native warm-season grasses can provide important benefits to both farmers and grassland birds. Policy incentives have been developed to facilitate these practices, and similar strategies may be applicable in other countries.

Other practices that may provide little or no benefit to farmers but important ecosystem services to others may require direct financial compensation for adoption by land users. Some examples of payment for ecosystem services include park revenues being used to assist communities maintaining adjacent buffer zones (Budhathoki, 2004) and water charges or tariffs being used to conserve forest cover, thus maintaining hydrological regimes, in important watersheds (Pagiola et al. 2004). Some nongovernmental organizations have also provided payments to conserve biodiversity through conservation concessions that compete with logging concessions or other economic activities by leasing rights to manage land (Hardner and Rice 2002). An important component of this practice is to avoid the creation of "perverse incentives." For example, if farmers can be paid for planting trees with no other constraints, they may cut down native forest so they have a place in which to plant trees (Pagiola et al. 2004). A better incentive would be to pay farmers annually to maintain native forest and to pay a lesser amount for planting trees on degraded lands.

Examples of ecosystem services that may have benefits to both farmers and off-farm members of the community are probably the most common. These cross-scale interactions and linkages, when made visible to and valued by all stakeholders, are what can help to bring about successful natural resource management on agricultural lands at the ecosystem level. In the following three examples, we focus first at the field and farm enterprise scale, then at the watershed scale, and finally at the ecosystem scale, although we consider effects for each at all scales.

Field/Farm Enterprise Scale: Soil Fertility, Waste Disposal, and On-Farm Recycling Services

As discussed in chapter 2, increased soil organic matter brings multiple benefits such as increased water-holding capacity, soil microorganisms, and availability of nutrients. In some parts of the world, there is a clear link between health of soils and health of the local people (Sanchez and Swaminathan 2005). Management practices that retain and recycle as much organic material (crop residue, manure, post-consumer food waste) on the farm as possible are better able to maintain or improve soil quality. (See chapter 2 for more information.) Despite the importance of good soil management, loss of nutrients and high soil erosion rates are a growing problem globally, and desertification—the process of degradation of soils to the point that they can no longer support plant life—affects 20 million to 32 million square kilometers of land worldwide (Stringer 2008). These are instances in which nutrient cycles need to be restored. The use of composted night soil (human excrement) in fields in developing countries is a valuable way to return nutrients and organic matter to the soil (King 1911) that is paralleled today in industrialized countries when sewage sludge is applied to fields. However, safety measures are important to reduce the risk of disease transmission or spread of anthropogenic contaminants. When farmers fail to use crop residues or livestock manure on fields, it is usually because these resources are diverted for use as fodder, fuel, or building materials. In this case, creating a more diverse cropping system is essential. A fast-growing leguminous cover crop can be planted as a green manure and incorporated into the ground after food crops are harvested. Establishing a woody field border managed as a coppice (continuous harvest and regrowth) system can provide a source of fuel wood and provide more diverse habitat for wildlife, including pollinators and predators of crop pests. Then not only can crop residues and livestock manure be applied to the fields rather than burned as fuel, but tree leaves can be used as fodder or to increase soil organic matter. An additional nutrient benefit would be available if nitrogen-fixing plant species were used. Leguminous tree fallows have been successfully used in eastern, western, and southern Africa to restore soil fertility. They are planted with a crop such as maize during the rainy season. After the maize is harvested, the trees continue to grow through the dry season, their long roots utilizing deeper soil water. The field is kept in tree fallow through the next dry season, when the fuel wood is harvested and leaves and remaining vegetation incorporated into the soil before planting the next maize crop, contributing 100 to 200 kg of nitrogen per hectare over a half-year to two-year period. On subsequent mineralization, the added nitrogen may double or quadruple maize yields over the next one to three growing seasons (Sanchez and Jama 2002; Sanchez and Swaminathan 2005). Where subsoil is extremely low in nutrients, use of woody vegetation for alley cropping or in rotations is unlikely to be able to add nutrients to surface soil. In these cases external fertilizer sources may be very important to improving productivity if the soils are able to hold nutrients long enough for plant uptake to occur (Lal 1989).

In addition to the important benefits on the farm, good soil and nutrient management helps to maintain water quality by reducing sedimentation and eutrophication. A major problem with industrial agriculture is nutrient imbalance. This also occurs commonly when smallholders specialize in one or a few products and/or when consumers of agricultural goods are distant from producers. Any field from which a crop is harvested repeatedly will lose nutrients. Any livestock provided with feed rather than grazing will concentrate nutrients (through manure and urine) in the areas where they are fed, potentially degrading water quality (Gerber and Menzi 2006). Sustainable agricultural practices balance nutrient loads by integrating livestock and crop production and/or by recycling waste onto fields. Diverse operations that rotate or combine production of livestock and diverse grain and vegetable crops on the same plot of land or in close proximity can simultaneously maintain soil fertility and address waste disposal needs (Gliessman 2007). Farmers benefit from sustained soil quality, and downstream users of water benefit from a cleaner water source. Focusing on the ecological principle of balance between inputs and outputs can help identify unsustainable systems that are vulnerable to collapse and negative off-site impacts. Farming operations that resemble natural systems by maximizing use of internal or local inputs are most likely to function sustainably.

Watershed Scale: Clean, Reliable Water and Water Sources

The dominant land cover has a major effect on provisioning of clean and reliable water. In general, when rainfall can infiltrate slowly into soils it is stored and is available over a longer period. This occurs, for instance, when rain falls on a forest canopy or on densely vegetated grassland. When rain falls on bare soil or packed or paved surfaces, much of it runs off (often carrying soil with it), causing flash flooding followed by periods of low water availability, for without water percolation through the soil and groundwater storage, there is reduced flow to rivers and streams in between precipitation events. The spatial arrangement of land-use types in a watershed has important implications as well. Crop fields separated from streams by a grassy or forested buffer are much less likely to contribute to sediment and nutrient loads in streams than fields cultivated right up to the water's edge. Important benefits accrue to native biodiversity (including some species that may be part of commercially important fisheries) as well because many aquatic species benefit from shade and inputs of woody debris and decline under increased sedimentation or eutrophication. Eutrophication, from the Greek "well nourished," describes the change in a water body in response to increased nutrients. Although in certain conditions the addition of nutrients can benefit fisheries, eutrophication is usually associated with a decline in water quality and aquatic resources. See the last paragraph in this watershed section for a discussion of anoxic or "dead" zones that can result from eutrophication.

Downstream effects of forest clearing

An example of how land-use practices at the field scale can have watershed-level effects was driven home to one of the authors on a trip to the Philippines in the early 1990s. At the Davao City airport on the southern island of Mindanao, there was no power to operate conveyor belts and other electrical equipment. The city had been suffering from frequent brown-outs despite substantial investments in hydroelectric power. Power generation requires sufficient flow of clear water to turn the turbines. Forest cover had been lost rapidly in the watershed through a combination of logging concessions and an influx of slash-and-burn farmers who gained access along logging roads. Soil loss rates from crop cultivation on the steep slopes of Mindanao have been known to exceed 340 to 400 t/ha/year (Proud 2004) (400 t/ha/year ≈ 2.5 cm depth of soil lost per year). The combination of deforestation and field cultivation caused severe siltation of the reservoirs, diminishing their power-generating capabilities and requiring more frequent repair or replacement of equipment than anticipated (Banos 2006). In addition, rivers that formerly had substantial flow rates through the year now showed the extreme high and low flows typical of deforested watersheds. As Proud (2004) pointed out, the economic value to the mountain farmers of the corn and cassava that were produced was minuscule compared with the societal costs of reduced electric power, flood damage, crop failure, and less reliable water supply in the lowlands. No rational planner would have encouraged these tradeoffs, but to a farmer in the highlands trying to feed a family, the decision to till highly erodible soil on hillsides with greater than 50% slope seemed reasonable without other available options. Similar to the tragedy of the commons (Harding 1968), the "tyranny of small decisions" (Odum 1982) can have far-reaching societal effects.

Managing water has important on-farm implications as well. In areas with limited rainfall during the growing season, various practices are used, some of which have a long history. Irrigation is an obvious solution, but it requires significant initial and continued investments, can result in salinization of soils, often competes with other water users (such as downstream industry, urban, and rural residents), may negatively affect native plant and animal life, may result in increased pest and disease problems, and may also result in local climatic changes (Gliessman 2007; Molden et al. 2007). Consideration of the potential negative impacts of irrigation is essential, and many systems still cannot be sustainably irrigated (Gliessman 2007; Molden 2007; Molden et al. 2007). An alternative to irrigated farming in semiarid regions is "dryland farming" and involves summer fallows or rest seasons that allow soil moisture to build up by reducing evapotranspiration (Gliessman 2007). Cultivation of the surface during the growing season removes weeds, allows moisture to penetrate, and can create a "dust mulch" to reduce evaporation. This system was used historically on small farms in China (King 1911), where farmers would plant in alternate plots over time. It is commonly used today in major grain-producing areas of the United States and Canada, and is used in Australia in a grain-pasture rotation (Gliessman 2007). Although this system makes very effective use of limited precipitation, there is an increased risk of soil erosion during the fallow period, and it may require cultivating more acres because crops can be produced only every other year. It is certainly not appropriate to use on marginal soils that are damaged by cultivation of any kind. Other techniques that may be used include building structures for harvesting seasonal rainfall (Bruins et al. 1986; Gliessman 2007, chapter 6) or planting woody shelterbelts that can provide shade, draw water up from deeper levels using tree species that may have deep taproots, and capture blowing snow in regions with significant precipitation as snowfall.

A more suitable option for semiarid and other tropical areas may be conservation tillage systems in which crop residues are maintained on the soil surface after harvest and planting to provide a mulch cover, which protects the soil from erosion and enhances infiltration. Maintaining plant residues on the soil surface can be a challenge due to foraging livestock and wildlife, but it has been shown to increase soil quality in terms of organic matter, structure, water-holding capacity, and fertility. If managed correctly (adequate weed control), it can increase yields within two to five years (National Research Council 2008).

In many arid and semiarid regions, the most sustainable use of the land for agriculture may be for grazing livestock. Grasslands and savannas provide important ecosystem services (including better carbon storage than some forests and supporting many threatened and declining species), but because of ease of conversion and cultural perceptions they may be destroyed faster than forests (Samson and Knopf 1994). The Millennium Ecosystem Assessment has documented that globally, more than 70% of the world's natural grasslands had been lost by 1950 and that another 15% was lost between 1950 and 2000 (MEA 2005b). Grasslands or shrublands that evolved with large native herbivores are more likely to be able to sustain grazing from introduced livestock such as cattle, sheep, or goats. When properly managed, livestock can often sustainably graze native vegetation and may improve soils and vegetation diversity (e.g., Reid and Ellis 1995). Following the principle of mimicking natural disturbance patterns, grazing practices like those of native grazers are likely to function well in a system. For instance, management-intensive rotational grazing practices common in much of North America are thought to mimic a herd of bison that puts intense pressure on a pasture for a short period of time before moving on. This "holistic resource management" was developed in Africa to restore degraded lands by concentrating livestock in small areas for brief periods of time (similar to native herding animals) to stimulate plant growth and provide enough soil surface disturbance to encourage seedling establishment and water infiltration (Savory and Butterfield 1999).

In times of scarcity or drought, farmers are often pushed to overgraze, to cultivate marginal land, or to remove woody vegetation. This can quickly lead to a long-term decline in productivity through loss of topsoil and can have regional consequences through dust storms, changing albedo, and shifting precipitation patterns (Smith 1953; Asner et al. 2004; DeFries and Bounoua 2004; Sampaio et al. 2007). It is important for governments to get involved in planning for droughts and having enforceable agreements that provide for livestock forage but prevent grazing of marginal lands that would be easily degraded. For instance, grass-banking can be used to provide dry-season or drought-year reserves (Neely and Hatfield 2007). During the time that they are not being grazed, these fields provide valuable wildlife habitat.

In areas with adequate rainfall, on-farm water and nutrient management still has important consequences both on and off the farm. Erosion can cause long-term declines of productivity. Flushing of nutrients downstream from excessive nutrients applied on farms can contribute to eutrophication and resulting oxygen depletion and "dead zones" in distant water bodies. These dead zones are formed when excessive nutrients cause algal blooms or rapid growth of other aquatic plants. When these plants die and decay, decomposing bacteria consume so much oxygen that the oxygen in surrounding waters is depleted. Fish must move elsewhere, and organisms that cannot disperse, such as shellfish, die from the lack of oxygen, adding to the oxygen demand problem. Such dead zones can affect large areas and result in massive losses of productivity from aquatic habitats, affecting availability of protein sources for local diets and of important commercial products. Diaz and Rosenberg (2008) report that dead zones are growing exponentially around the world, and there are now more than 400 such zones covering 245,000 km^2. Following the principle of thinking at multiple scales, there could be clear benefits to downstream users to create incentives for upstream farmers to better manage nutrient runoff from their fields (Pagiola et al. 2004). In response to a growing hypoxic zone in the Gulf of Mexico, the Land Stewardship Project started a training and monitoring project for farmers interested in holistic management (Jackson 2002; DeVore 2002).

Ecosystem Scale: Maintaining Native Biodiversity through Dominant Vegetation

Preserving native biodiversity in and around agricultural fields has benefits to both farmers and the surrounding community. Farmers benefit from pollination and pest control services provided by many native species (see textbox below). The larger community may benefit from the same services, from increased ecotourism opportunities, and from the intrinsic cultural and aesthetic values of species conservation. In areas where hunting and fishing occur sustainably, native fish and wildlife can provide an important protein source.

Pest control by native wildlife

Recent studies have documented the importance of bat populations in controlling arthropod densities. By creating mesh structures that were installed only by day or only by night, researchers were able to exclude bats alone, birds alone, or birds and bats from foraging on or around certain plants. In Mexican coffee agroforest during the wet season, arthropod densities were 84% higher in bat-only exclosures than on control plots (Williams-Guillén et al. 2008). A similar study conducted in Panamanian tropical lowland forest demonstrated that arthropod density was 153% higher on plants in the bat-only exclosures compared with control plants and twice as much leaf area was lost to herbivory (Kalka et al. 2008). In both systems, birds also played important roles. By protecting populations of native birds and bats, farmers may gain valuable services in controlling populations of leaf-eating insects.

Because of increasing prices of food and biofuels, and because of expanding human populations, there is pressure to convert more natural habitats to agriculture, although around the globe much of the most productive land is already farmed (Rights and Resources Initiative 2008). Land conversion usually has negative effects on native biodiversity and many ecosystem services provided by the natural habitats (see tables 1[a] and 1[b]). Because most of the land remaining to be converted has only marginal value for agriculture, it may be productive for only a short time or not at all, resulting in a financial loss for those who made the effort to convert it. Agricultural practices that are compatible with or resemble in structure the dominant native vegetation will require the fewest external inputs to implement and maintain. They may have the highest likelihood of success because they are compatible with natural patterns of rainfall, disturbance, and fertility. They also may be most likely to maintain native biodiversity and to provide ecosystem services similar to those of the native vegetation. However, such systems require the farmer to have an intimate knowledge of the land and the different crop and wild species involved. Such knowledge is often lost when communities are displaced or when farming is not passed through generations (Brush 2004). Humans can obtain resources in a semiarid prairie or savanna historically grazed by native ungulates as part of a functioning native ecosystem by harvesting wild ungulates for protein and harvesting native plants as a food or medicinal source. Grazing domestic livestock in such a system would retain the native plant cover and possibly much of the native wildlife but allow more control. Tilling the soil would be much more disruptive; however, if crops were to be planted, grain crops that were similar to the native grasses might better survive with natural precipitation than alternative crops. A polyculture (e.g., multiple species growing in the same field) is likely to produce more annual net primary productivity than a monoculture, thus more harvestable biomass (Flombaum and Sala 2008). A polyculture will also provide habitat to support a greater diversity of native animals.

Even if agricultural practices must differ drastically from the structure and disturbance regime of the dominant native vegetation, providing buffers or corridors of native or semi-native vegetation around or through the crop fields can provide many benefits in the form of ecosystem services. (See the following section on landscape level issues, dispersal corridors, and riparian buffers.) Vegetative buffers have been adopted to reduce erosion on steep slopes (Cramb and Culasero 2003; Gliessman 2007). Wider buffer zones around crops can support a higher plant diversity (Ma et al. 2002) and higher ratios of predatory to herbivorous insects (Denys and Tscharntke 2002). When buffer zones or corridors of native vegetation provide direct as well as indirect economic benefits (e.g., as sources of medicinal plants, fruit or nut crops, edible greens, or fuel wood and timber), they will be more likely to be incorporated and maintained in agricultural landscapes (Current et al. 1995).

Ecosystem-Level Forest Management in Complex Adaptive Systems

Value of Natural Forest Cover

In areas with natural forest cover, maintaining as much forest cover as possible is likely to have benefits to both local producers and the larger society. Forests provide many important ecosystem services such as water regulation (flood control) and purification, soil retention, climate modulation, carbon sequestration, material for timber and fuel, biodiversity protection, and cultural services. Retaining old-growth forest reserves can have important benefits, including maintenance of intact soil fauna, habitat for old-growth dependent wildlife, carbon and other nutrient storage, as well as disease reduction (Foley et al. 2007). Communities that live close to native forest stands may appreciate these as religious sites and will have access to native plants that may have important food, cultural, or medicinal value, and access to native wildlife that can serve as a protein source (Bhagwat and Rutte 2006). In fact, such ecosystem services appear to attract human settlement near protected reserves (Wittemyer et al. 2008). Forests may be managed for the production of timber and wood fiber as well as for non-timber forest products such as rattan and medicines (MEA 2005b, 2005c). Extraction of nonwood forest products may have great importance to local people and is usually of most importance to those in greatest poverty (MEA 2005c). One of these forest products, "bushmeat," has received attention from conservation groups. There is certainly a risk of driving some wildlife species into severe declines through overharvesting, primarily when roads provide access from urban to remote areas and market hunting increases (Robinson et al. 1999; Brashares et al. 2004). Loss of species that play a keystone role in the system, such as fruit bats that serve as major seed dispersers, could have severe negative consequences. Likewise, certain species may have higher value in certain cultural roles or through ecotourism than as harvested game. However, sustainable harvesting of wild game for local use (not usually as a commercial enterprise) has been practiced historically around the globe, and under certain circumstances it can be highly sustainable (e.g., Berkes 1999; Pei 1999; see textbox below). Partnerships among local communities, scientists who can provide larger scale information, and government organizations can produce effective management schemes (e.g., Lewis 1995).

Sustainable hunting practices and ecosystem management

The key to responsible harvesting of wildlife is to harvest only a sustainable yield (Caughley and Sinclair 1994). This yield can be described as the rate of increase in the population. Working with a trained wildlife biologist is critical to designing a sustainable harvest. Wildlife biologists refer to additive and compensatory mortality. Additive sources of mortality are those that will accrue in a population regardless of other sources of mortality. For instance, the number of deer in a population that are killed in vehicle collisions would probably be the same whether some animals were also killed by hunters in that area or not. Being hit by a vehicle and being killed by a hunter are considered additive sources of mortality. In contrast, the number of deer that starve to death during the dry season would likely be reduced if hunters killed a lot of deer the previous season. Food outside the growing season can be a limiting resource for deer, and if fewer deer are competing for it, each of them is more likely to get enough food to survive, so the incidence of starvation declines. Hunting is then considered to be a compensatory form of mortality because the post dry-season population size is likely to be the same whether animals were hunted or not. (In unhunted populations more animals starve, while in hunted populations fewer animals starve.) When hunting mortality is compensatory in relation to other major forms of mortality, it is relatively easy to harvest animals sustainably, that is, without reducing the standing crop of livestock. Animals with short life spans and high reproductive rates can usually be harvested sustainably. In contrast, animals that are long-lived require many years until they are old enough to reproduce, and generally produce only a few young each year can be very difficult to manage through sustainable harvests. When harvests target individuals that have low reproductive value, the effect of harvest on the population is reduced (Gotelli 1995). For example, the reticulated python (*Python reticulatus*) is harvested in Sumatra for the commercial leather industry. Although harvest of several temperate zone snakes has been shown to be unsustainable, the python population appears to have been able to persist despite large removals. This species has rapid growth, early maturation, and high fecundity (mean clutch size of 24, produced every two to four years). Large females produce the largest number of young and reproduce most frequently. An important factor in the sustainability of this harvest may be that large females were rarely harvested, probably because they prey on large native mammals in mature forest and thus avoid disturbed areas where humans most often collect snakes (harvesting smaller individuals that eat rats and mice around houses and fields). The combination of several factors has contributed to the sustainability of this harvesting system (Shine et al. 1999).

Old-growth stands may remain on the landscape for cultural or religious reasons, or because the topography is too steep or access is otherwise limited. When new technologies such as helicopter logging become available or access is increased through road construction, when population pressures require an expansion of land in cultivation, or when immigrants arrive who do not share cultural or religious practices, these old-growth forest stands are at risk (Bhagwat and Rutte 2006). Costs and benefits of forest conversion should be carefully weighed at a landscape and long-term scale, and policies and infrastructure should be designed to achieve societal goals for retention of forest cover and management of existing old-growth stands (Carvalho et al. 2001; Soares-Filho et al. 2004).

Landscape-Level Issues, Dispersal Corridors, and Riparian Buffers

The spatial distribution of forest openings has a major effect on many ecosystem processes and services. For instance, clearing native vegetation may change local rainfall patterns (Turner and Chapin 2005; Chapin et al. 2008). Human communities may benefit from retaining forest reserves, and these function best when surrounded by at least a partially wooded landscape. (Even when isolated, old-growth patches or even individual trees can provide important benefits, such as trees in Costa Rican pastures that support forest wildlife [Harvey and Haber 1999] and can help natural reforestation of abandoned pastures). The ability of remnant forest patches to support native biodiversity varies with the proportion of the landscape that remains in forest cover, the size of the patches, their distance from larger forests, and the connectedness between patches or the contrast between forest and surrounding land-use types (Robinson et al. 1995; Willson 2004; Newmark 2008). The amount and distribution of forest cover is also important in protecting freshwater systems (Saunders et al. 2002).

The term silviculture describes the long-term management of forests for production of trees as well as other objectives. Unlike silviculture, logging can be conducted without regard for long-term productivity of a forest (e.g., Grogan et al. 2008). Logging activities in areas that are planned to regenerate as forest should be designed and supervised by a trained silviculturalist with local knowledge. Although unsustainable timber harvest practices have caused severe environmental problems, well planned and executed management practices allow for sustainable harvest of wood products in many systems (Freer-Smith and Carnus 2008; Meijaard and Sheil 2008). Sustainable forestry practices could help maintain forests on the landscape while providing an income to local residents. Compared with most agricultural crops, trees grow on a much longer time scale. Because the benefits of sound silvicultural practices may occur primarily to future users, balancing current with future costs and benefits is challenging. Harris (1984) described a simple scheme for retaining old growth forest reserves while harvesting timber. Circular forest reserves are surrounded by managed forests, creating an important buffer between the forest reserve and agricultural fields and residential developments. The doughnut-shaped managed forest is then divided into wedges, and wedges are harvested in a determined order (figure 3). If wedges are harvested sequentially, each wedge would have at least one border with a similarly aged forest patch, reducing fragmentation and edge effects. Much of the managed forest would always be in a relatively mature state. The central reserve could provide a ready source for colonization to all the wedges, providing a seed source and pollination services as well as maintaining wildlife populations.

When permitting logging or mining concessions, it is important to consider future scenarios that include large-scale effects of many local decisions and that balance needs of different stakeholders (Jackson et al. 2007). For example, much of the western Amazon basin is currently remote and relatively undisturbed. It contains high levels of biodiversity, several uncontacted cultures, and is considered to be an important area for maintaining carbon stores. Current and proposed oil and gas drilling leases, however, would require that roads be built through much of this area. Once roads are built, the opportunity costs for timbering, market hunting, and farming are reduced, and these activities typically spread rapidly across the landscape. The distribution of all of these leased

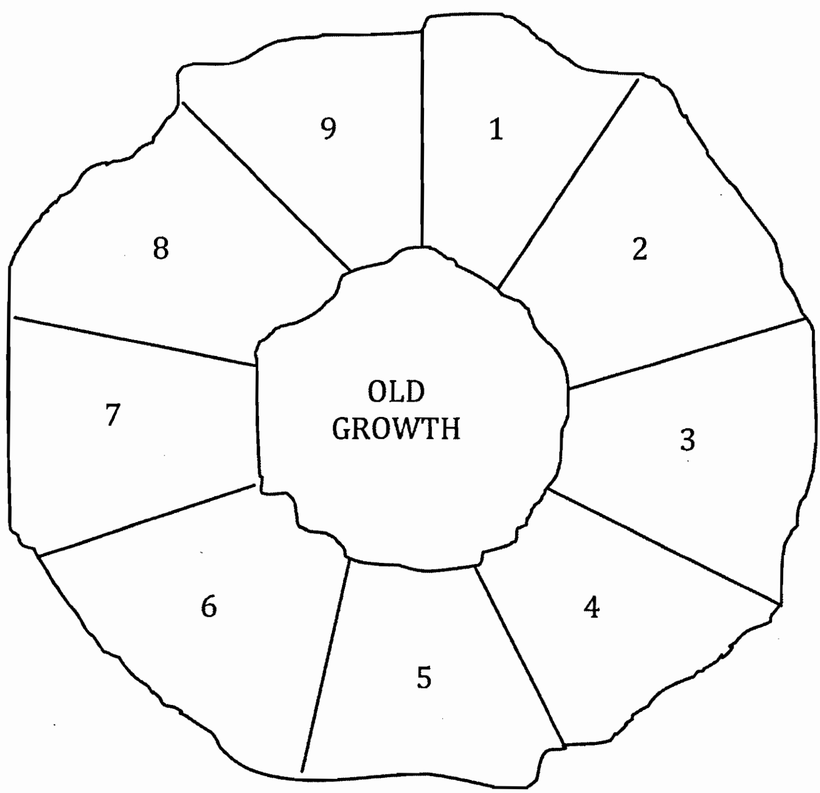

Figure 3. Schematic to demonstrate order of harvest of forest patches in a managed buffer area around an old-growth reserve. The wedges would be logged in sequential order. The entire area would be maintained under forest cover of varying age classes. This approach is based on Harris (1984).

areas was apparently not considered as a whole, so the real costs associated with disturbance and destruction of such a large amount of the Amazon basin were not appropriately weighed against the benefits of fossil fuel extraction. If drilling leases were concentrated in a way that they could be accessed by fewer roads, the overall impact would be much reduced (Carvalho et al. 2001; Soares-Filho 2004; Finer et al. 2008).

When forests are harvested or cleared for agriculture or other purposes, the ability of forest remnants to function as wildlife habitat is usually improved by increasing connectivity among patches (Beier and Noss 1998; Tewksbury et al. 2002; Willson 2004). This can be done by maintaining or creating forest corridors or by ensuring that the matrix of land surrounding the forest remnants can support native wildlife (e.g., Koh 2008). Corridors can also facilitate pollination and seed dispersal (Tewksbury et al. 2002). It should be noted that, although corridors have largely been found to have positive or neutral effects, they do not always benefit intended species (e.g., Hannon and Schmiegelow 2002), and they can have negative effects by funneling movement of predators or disease vectors (e.g., Weldon 2006). When installation or protection of corridors comes at high expense compared with other conservation practices, the costs and benefits must be carefully weighed (Simberloff and Cox 1987; Simberloff et al. 1992). However, when corridors also function as windbreaks or riparian buffers, the benefits are clear.

Vegetation along streams slows water flow, holds soil, and adds material in the form of leaves or woody debris. An overhanging canopy shades the stream and can reduce water temperatures. Forest harvest and conversion to agriculture result in severe changes to riparian vegetation, stream microhabitats, and aquatic life (Heartsill-Scalley and Aide 2003). Riparian buffers are usually designed to protect streams from sedimentation and soil-bound nutrient runoff from adjacent lands. Dissolved nutrients, pesticides, and other pollutants typically require much larger buffer zones (Bentrup 2008). Buffers or wooded stream corridors may also function as habitat or dispersal corridors for terrestrial wildlife (Haas 1995; Machtans et al. 1996) or to improve in-stream habitat quality for fish (Naiman and Decamps 1997; Richards and Hollingsworth 2000). Riparian buffers can be composed of woody or herbaceous vegetation or some combination (Osborne and Kovacic 1993). Buffers installed along headwater streams (in the higher reaches of watersheds) will have effects over a larger downstream area and thus are more valuable to conservation (Tomer et al. 2008). However, the value of land for agricultural production is also likely to vary between the headwaters and lower sections of stream. In the central United States, where most farmers currently use heavy equipment and chemical inputs while facing a restricted growing season, lands that flood seasonally are not desirable for farming, thus farmers lose little income by converting these areas to riparian buffers (Frimpong et al. 2007). In contrast, certain traditional agricultural practices depend on fertile and moist floodplain soils that are regularly replenished (Adams 1986). Removing land from cultivation in these areas would likely have high costs, making installation of riparian buffers more expensive. Biophysical characteristics of land have been shown to be good predictors of the amount of forest cover on private land in a primarily agricultural area and need to be considered in cost-benefit planning and landowner compensation for adopting conservation practices (Frimpong et al. 2006, 2007). The widths required for effective buffers depend on the landform (soil type, slope, geology), adjacent land-use type (forestry, pasture, cultivated field), and objectives (sediment reduction, nutrient reduction, flow regime, in-stream fish and amphibian habitat, wildlife conservation). Although certain recommendations exist for buffer widths, there is still a great need for research to document effectiveness across a range of situations (Coleman and Kupfer 1996; Blinn and Kilgore 2001; Lee et al. 2004).

Agroforestry

Because light is so important to crop growth, most agriculture in forested areas starts by clearing the trees. However, for long-term productivity, maintaining some forest cover may benefit the producer as well as off-farm users of ecosystem services produced on the farm. Agricultural systems that incorporate some tree cover in the landscape include shifting cultivation (or slash-and-burn farming), silvo-pasture, and agroforestry.

Slash-and-burn farming techniques keep most of the farm in native tree cover at different stages of regeneration. After crops are cultivated for a period of three to five years, the land is allowed to rest as a tree fallow, ideally for a period of more than 10 to 20 years during which soil nutrients and productivity are restored. In areas where increasing population pressure has pushed farmers onto steep slopes and otherwise marginal lands or reduced the time of the fallow period, the system breaks down and is no longer sustainable as ecosystem processes degrade and cannot be restored quickly enough to meet the demands of the growing population.

Silvo-pasture systems, defined as agricultural systems where open-canopy and/or low-density trees are grown in livestock pastures, are used because sparsely planted trees can shelter forage crops growing beneath them from intense sun and heat, help to retain moisture in upper levels of the soil, and improve quantities of soil nutrients (Belsky 1993; Dagang and Nair 2003). Further, livestock will eat more and therefore produce more meat or milk when they can feed in the shade rather than in the heat of the sun (Fike et al. 2004). Some tree crops, including legumes, produce fruits or leaves that provide a valuable food source for livestock (Smith 1953; Fike et al. 2004). Farmers may be able to harvest fruit or nut crops, fuel wood, or timber from silvo-pasture systems.

Agroforestry is defined as the intentional co-planting of new or comanagement of existing high-density shade trees with agricultural crops (Bhagwat et al. 2008). It is differentiated from silviculture in that in silviculture, trees are solely managed for the production of fuel, fiber, or timber from the trees themselves. Several globally important cash crops such as coffee, cacao, ginseng, betelnut, and shiitake may benefit from or even require shade conditions that can be provided by growing these species under a native forest canopy or under tree crops (e.g., fruit trees) in the same fields. Maintaining a tree canopy provides multiple ecological benefits, including holding soil, slowing rainfall runoff and erosion, and providing habitat for a greater diversity of native wildlife species. A review of agricultural practices in Mesoamerica found that landscape mosaics with significant tree cover provided important habitat for a large proportion of the native biodiversity (Harvey et al. 2008). Another review reinforced the importance of the distribution of native vegetation on the landscape. As expected, the diversity of native forest birds and insects declines in fields at greater distances from native forest. Importantly, however, the presence of native canopy tree species in agricultural plots can greatly mitigate this effect (Tscharntke et al. 2008). The benefits of agroforestry for biodiversity are threefold (Schroth and do Socorro da Moto 2007): It can maintain habitat by reducing the conversion of natural forest into cultivated land, it can restore habitat quality to land already cultivated, and it can create a more favorable matrix between isolated patches of native forest. Agroforestry can have similar advantages for producers as the intercropping or polycultures of herbaceous species, namely, the diverse architecture of agroforests more efficiently absorbs sunlight, and the variety of root depths and peak demand times creates

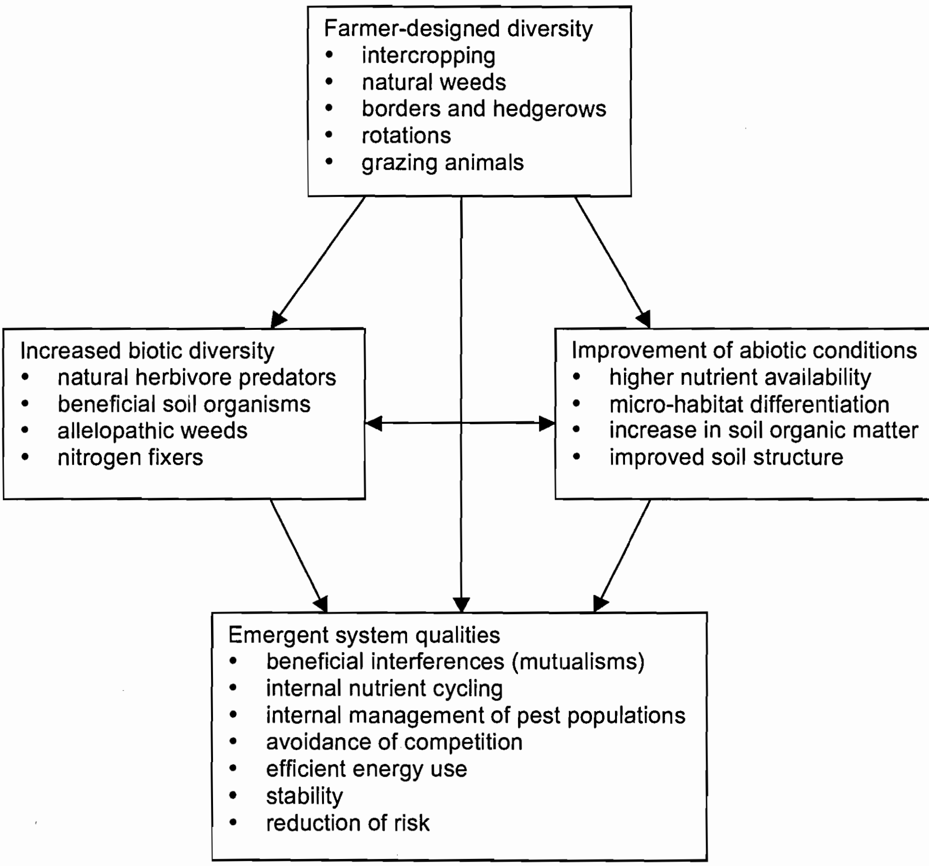

Figure 4. Multiple benefits derived from diversity in agricultural ecosystems (Gliessman 2007).

less competition for nutrients and water. Further, the species mix provides more habitat for beneficial insects and vertebrates, and it can slow the spread of pathogens and pests (figure 4; Gliessman 2007). The emergent system qualities listed in figure 4 can be observed in herbaceous polycultures as well as in agroforestry systems and most especially on farms with diversity (across space and time) within and among fields.

Agroforestry systems that maintain some native trees may provide important corridors or buffers to connect or protect larger areas of native habitat. Even nonnative trees may provide some structural components of wildlife habitat, although the manager must take care not to actively plant known or potential invasive species. Agroforestry that employs native trees may provide significant benefits to local inhabitants that were normally derived solely by living adjacent to natural forest stands.

Field to ecosystem level: Native trees as medicine and wildlife habitat, a community-driven case study of the value of restoring ecosystem services

Around the globe, agroforestry takes many forms ranging from farms that mix cash agricultural crops such as coffee under the canopy of native trees to monocultures of pine or eucalyptus that are ultimately clear-cut and harvested for timber. In one farm-field system in southeastern Madagascar, a local community has worked together with an international team of biologists to develop a medicinal plant-based agroforestry system on its privately owned field/farm system. The story of this medicinal agroforestry project's development is unique and illustrates the value of recognizing and respecting local beliefs and working in the context of those beliefs to protect and restore ecosystem services.

The genesis of the project was in co-author Sarah Karpanty's involvement with a local village for a research study of local raptor communities. For one species, the Madagascar harrier hawk, she found only one nest, located outside of the park boundaries on the edge of a small, subsistence farming village. In fact, 5 of 10 nests discovered during a pilot study were outside of the formal park boundaries.

After discovering the nests, the research team spent time in meetings with the families in ownership of particular field systems where birds were located. In these meetings they asked each family, if possible, if they would exclude the nest trees from any of their subsistence-level slash-and-burn agricultural activities for the three- to four-year period of the study. They all agreed.

The research team returned after a few months and began to check the status of the nests discovered earlier. From a conservation biologist's perspective, the picture that developed was disheartening at best. Within a week, the team found that 5 out of 10 nests, all located outside the park boundary, had been cut down in the process of clearing land for subsistence-level agriculture. At the last nest site visited, there was a bare tree still standing in the center of the blackened field, and in it was the harrier hawk nest, now with three chicks. The farmers had taken the team's request literally; they had not cut the tree and had invested a tremendous amount of effort in creating a fire-break around it. However, the harrier hawk chicks did not survive that season. Without the cooling effect of surrounding forest, they literally baked in the hot subtropical sun.

The village president, Tonga, told the team that he was upset about the incident too and that he wanted to talk about his idea to reforest areas of old farmland with trees of multiple uses to his villagers, especially trees of medicinal value. He recognized that there was very little forest left outside the national park boundaries, and he was worried about the future of his farming community, in particular its ability to harvest medicinal products, for this was prohibited within the national park. He also mentioned that, in his village's belief system, the ancestral spirits reside in the forest, and this was an equally important reason to plant new trees so that the ancestors' spiritual resting grounds would not be destroyed.

It was a meeting of like minds. That day a new partnership was sealed between the villagers and long-term researchers by an offering of the local rum, tokagasy, and a leaf-full of honey to the ancestral spirits. Now, eight years later, Tonga himself has passed away, yet his successor and all the villagers have been working in collaboration with scientists at the nearby field station to plant more than 20,000 native trees on fallow farmland in the village area bordering the national park. Most of the planted trees have medicinal values recognized and utilized by the villagers themselves; those without medicinal value will be used as fruit trees, construction materials, or firewood. An added indirect benefit of the project is that, by planting native trees, the villagers are ultimately creating wildlife habitat for the many threatened and endangered lemurs and other animals that are now confined to the national park. As an incentive for participation in the project, all families in the village were provided hands-on training in reforestation techniques, basic supplies for growing and planting their own native trees such as seedling bags, water buckets, wood to construct a nursery, and help during the planting phase each year. Educational materials for the local schools were also developed in the hope that the multiple values of the project will be communicated across generations.

In some ways, this example is a simple story of a community-based reforestation project that directly benefits the local village by providing trees of medicinal and other values on degraded farmland while providing wildlife habitat. Yet it also illustrates how, at the farm level, individual families and village units can have a profound effect on the watershed and ecosystem by directly restoring ecosystem provisioning services such as food, fuel, and medicine; ecosystem cultural services such as spiritual values; and indirectly, ecosystem regulating services such as erosion and water regulation to what was highly degraded, erosion-prone farmland providing few to no ecosystem services. The other profound lesson is that the motivation for restoring these degraded fields simultaneously came from two sources: foreign biologists with interests in protecting biodiversity and local people with interests primarily in the medicinal, food, and cultural values of the land. If the regional or national governance system had imposed this reforestation project on the villagers with the sole rationale of protecting biodiversity for ecotourism reasons, it likely would have failed within the first few years. However, given the villagers' own strong, multifaceted rationale for the project from its inception, it has been successful to date.

Role of Culture in Ecosystem-Level Management

Pacey's (1983) call to consider a countervailing approach to the dominant economics/technical fix worldview can bring much needed diversity to the planning and design of development projects. For example, in the Madagascar example (textbox above), working with the community to achieve cultural goals was critical for the success of a project that was important for biodiversity conservation as well as local wellbeing. If we decide we are most concerned with "not the material flow from resources through the economy but the immaterial flow to human wellbeing," we must measure success by looking at information beyond economic growth. Such metrics could include levels of education or literacy (among both sexes and across social classes), infant mortality, life expectancy, supplies of food energy (calories) and protein per person per day, availability of latrines or other sanitation measures, and participation in community organizations. These metrics may have much stronger correlations with each other (for instance, infant mortality is strongly inversely correlated with education) than with economic growth. The economics/technical fix encourages us to focus on production. When presented with information on malnutrition, the response is to boost food production. However, as Pacey points out, the real problem with malnutrition is inequalities in consumption, not production. By focusing on CAS, we can examine the variety of factors that are limiting consumption of necessary food items (e.g., production of cash crops on fields that formerly produced subsistence crops, collapse of local farm economies because of subsidized imports), and we can work across various levels to improve the situation.

Pacey's "matrix for assessing different points of view" (table 2; Pacey 1983) illustrates a strategy that can help planners broaden their thinking and incorporate a diversity of approaches. For instance, if the goals and worldviews of both local farmers (e.g., production of crops for subsistence use and markets, maintenance of water supplies) and more distant stakeholders (e.g., water supply, biodiversity conservation, carbon sequestration) are considered together, then programs (e.g., payment for ecosystem services) to achieve multiple goals can be developed (Pagiola et al. 2004).

Development activities have not always recognized the importance of women's role in agriculture and conservation. Especially in many sub-Saharan African countries, women have historically farmed most of the crops consumed in the household. When development projects target men to grow export crops, land that had been used for production of subsistence or locally sold foods often is converted to export crop production. Although this may increase household income, the nutritional status and health of women and children in those households may decline (Bryson 1981; review in Pacey 1983; Shell-Duncan and Obiero 2000). In many cultures, women hold much of the traditional knowledge of sustainable farming techniques and conservation, and use of native plants that may be important for medicinal or cultural practices (Howard 2003). Women's conservation efforts, such as the Green Belt Movement in Kenya, have often been very effective (Deda and Rubian 2004).

Table 2. Matrix (adapted from Pacey 1983) for assessing different points of view on any new development (e.g., installation of water harvest structures, road construction to facilitate transport of crops to market).

Queries	Expert views	User views
Practical benefits and costs		
What benefits are sought?	Very specific benefits (e.g., increased revenue from export crops)	Better living standards in general, including income, health, amenity, housing; reduced risk may be more important than increased production
What costs, what risks, and what environmental impacts are perceived?	Cost of implementation; risks as a statistic to be weighed against benefits	Costs in time, cash, amenity, organization, risk seen in personal and family terms
Who gains which benefits? Who loses?		Lowest income groups may not be able to participate
Status and political advantage		
What is the impact of the project in terms of status and prestige?	Visible progress, good for national prestige; professional advancement for the experts concerned	Status associated with possession of new farm amenity
Who gains or loses status, power or influence?	Some strengthening of central government authority	Some loss of control over lifestyle; fear of bureaucratic power
Basic values		
What is the cultural context?	Scientific/technical; the expert sphere	Domestic/traditional; the user sphere
What are the dominant values?	Technical interest and virtuosity; economic values	Need or users values; family welfare

Notes: The columns representing expert and lay (or user) views are initially blank and are filled in by promoters of the project as a means of testing its appropriateness in the community concerned. The matrix is shown partially completed; in practice, both questions and answers will usually need to be more detailed.

The model system we considered presumed that farmers actually owned the land that they were farming. In such a case, sustainable management practices will benefit the farmer and subsequent generations of his or her family. However, when farmers do not own or have long-term land tenure, their actions will be designed to maximize their short-term gains with no concern for long-term implications. For example, yields are high in the first few years of clearing a new plot for shifting cultivation. Developing an agroforestry plot takes several years with relatively low yield in early years. Without secure land tenure, short-rotation shifting cultivation will be preferred over agroforestry, propagating an unsustainable system over ever increasing areas of land. The ecosystem services of the second land-use scenario discussed above would not be realized. Successful management strategies must then work either to achieve land tenure for farmers or to provide short-term incentives for sustainable behaviors (Rights and Resources Initiative 2008). Farming techniques that provide short-term as well as long-term benefits will be more likely to be adopted in all conditions (Graves et al. 2004).

Another advantage of secure land tenure is the development of knowledge of particular fields, of locally adapted crops, and of knowledge that allows the farmer to work best in the context of surrounding native habitats. Farmers who have worked the same fields over several years (or several generations) can use past experience to implement appropriate management practices and choose crops best suited for particular fields or sections of fields. Traditional knowledge is often undervalued. Cultures that have persisted for long periods in a given system can accurately describe native biodiversity and the food and medicinal value of native plants and animals (Mayr 1932; Berkes 1999; Bumacas et al. 2007; Molnar et al. 2007). Indigenous crops and farming practices are particularly well adapted to the local environment. Although certain traditional practices may not function well as situations change (because of climate change, rapid human population increase, shift to a cash economy), many of the basic techniques are still valuable, and perhaps a new structure for the practices can return them to sustainability (King 1911). The continued use of locally developed crops should be encouraged. Although new varieties may produce higher yields under certain conditions, small farms with high crop diversity have lower risk for dietary imbalances or for complete crop failure (Eilu et al. 2003; Altieri 2004; Negash and Niehof 2004; Thompson et al. 2007). In addition, maintaining the genetic diversity of these traditional crops will be critical for future plant breeding. Detailed knowledge of local crop varieties and wild plant and animal species may be lost as farmers are displaced or their practices are modified. When indigenous languages and cultures are lost, generations worth of knowledge of sustainable farming systems may disappear as well (Cox 2000). Retaining this knowledge and in situ crop diversity (with associated genetics) will be crucial to efforts to feed a growing human population (Berkes 1999; Brush 2004).

Whatever one's worldview, when faced with choices of bettering one's own lot or benefiting society by conserving biodiversity or providing other ecosystem services, we cannot expect individuals to act against their self-interest. The "tragedy of the commons" explains why environmental degradation often results when resources are exploited by many with little or no regulation (Hardin 1968). Either formal or informal regulation of natural resource use is required for such use to be sustainable. In many cases, existing social contracts at the local level (such as those described in the Madagascar textbox above; Ostrom 1990; Berkes 1999; Pei 1999) have functioned well for managing communal lands or other common resources. But even in these cases, the "tyranny of small decisions" can still be important (Odum 1982). What works well for a small community may still have negative implications for downstream residents, for example. As we have come to understand the importance of multiple spatial and temporal scales in ecosystem processes (Lovett et al.

2005) and thus natural resource management (Possingham et al. 2005), it is clear that sustainable management requires the involvement of stakeholders who may not reside in the local community and should include regional and national natural resource managers, planners, and policy makers. Our model example focused on hierarchical levels up to the ecosystem level. It will be necessary to develop a parallel model of the market and policy system and to combine these with the ecosystem model to obtain scenarios that reflect the real complexity in natural resource decision-making. Encouraging a collaborative learning process in which stakeholders use a CAS model to evaluate the effects of alternate strategies and to assign rights and responsibilities may help to create better functioning structures (Wilson 2002). The often contrasting worldviews of stakeholders suggest that a first step should be to describe the "larger set of rights and obligations" required to achieve sustainable management (Berkes 1999). The concept of "bridging social capital" suggests that synergistic goals can be achieved by dynamically managing linkages among stakeholders at different levels of the CAS (Woolcock 1998; Woolcock and Narayan 2000). Where fields are placed with respect to streams and rivers or steep slopes, what percent of the land remains in native vegetative cover, what the condition is of land between native reserves, who has access to certain resources, and who has responsibility to maintain them will all have major effects on the ability to provide ecosystem services, but these decisions cannot be made solely by individuals or even local communities. To achieve the equitable distribution of benefits called for in the International Assessment of Agricultural Science and Technology for Development (IAASTD 2008), it will be necessary to equally distribute the costs as well. Designing, developing, and maintaining the social, political, and economic structures that can sustain coordinated natural resource management decision making at large spatial scales will be the major challenge for the near future.

Conclusions

The ecosystem level of management integrates activities at the field, farm, and watershed levels. Connections to the policy/market sphere are critical, especially when important decisions have effects across political boundaries. Ecosystem services fall into several categories: provisioning, regulating, and cultural services. Simple models such as the scenarios described in this chapter can be used to help evaluate the response of each of these types of services to proposed activities. Real situations, however, involve extreme complexity. Basic principles can help to guide decision-making:

- Long-term sustainability of the ecosystem is critically dependent on the sustainability of the practices adopted by individuals and households who control the smaller land parcels (e.g., fields and farms) nested in the ecosystem. Thus, focus on long-term and large-scale consequences, but include short-term and local incentives to encourage adoption of sustainable practices.
- Maintain local diversity (biological and cultural) and local cycling of materials such as soil amendments to benefit local ecological, economic, and social systems. A focus on local materials and markets can help to balance energy, nutrient, and water flows in a system.
- Work with rather than against the natural environment. Natural systems have natural climatic and disturbance regimes that influence the type of native vegetation and the percent of the land that is in early successional stages at a given point in time. Management systems that incorporate and/or approximate these natural patterns will likely be most sustainable in the long term and meet the different needs across the hierarchy of scales in the complex adaptive system.

Resources

To learn more about efforts to achieve production/economic goals, societal/community goals, and environmental goals simultaneously, readers may wish to investigate the following movements and organizations:

- Ecoagriculture Partners (www.ecoagriculture.org)
- Holistic Management (www.holisticmanagement.org)
- Landcare International (http://www.worldagroforestry.org/sea/landcareinternational/default.asp)

Authorship Statement

C.A. Haas developed the original outline, drafted much of the text, and incorporated comments in revised drafts. S.J. Karpanty wrote the Introduction and the Madagascar textbox. E.A. Frimpong developed the conceptual model example, including figures and tables, and wrote the accompanying text. All authors contributed to the overall concept, organization, and literature review. C.A. Haas is listed as first author because of her lead role. E.A. Frimpong and S.J. Karpanty contributed equally as co-authors. The order of listing here is alphabetical and does not reflect differences in contribution.

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Chapter 7

Sustainable Agriculture and Natural Resource Management: A Policy Perspective

Gerald Shively and Dileep Birur

Forests, soils, grazing lands, and water provide the necessary foundation for agricultural activity and sustain the rural economies of most developing countries. At a conceptual level, the connections between rural populations and their natural resource base include an interlinked set of biophysical, economic, and social systems. These systems co-evolve in response to human desires and needs on the one hand and to environmental health and resilience on the other. At a more practical level, the ways in which land managers adapt to their physical environment are influenced by a policy environment defined by explicit or implicit incentives and constraints. These are determined by local, regional, and national policy makers. Policy makers establish the rules for legitimate behavior, observe outcomes, and subsequently adjust policies in light of competing interests and whatever mandate they may possess. For their part, farmers adjust their behavior in response to changing needs and in reaction to shifts in prices and policies. Of course, sometimes the extent to which farmers can respond may be quite limited. Equally important is that natural systems respond to human activity, sometimes abruptly, sometimes slowly, and sometimes in unanticipated ways. The aggregate patterns we observe are jointly created and evolve through this interplay, suggesting that an essential element of any strategy aimed at promoting sustainable agriculture and natural resource management must be flexible and adaptive at its core. It is quite important to recognize that pure subsistence is rare, and few, if any, smallholders operate completely detached from the market. As a result, the choices and tradeoffs made by national governments and international actors establish the incentives and constraints that farmers face and, ultimately, the crops and cropping systems they choose. Patterns of innovation, adoption, and adaptation reflect the social and economic fabric of rural communities and therefore differ markedly across time and space.

This rural fabric of farmers, their natural environment, and the policy setting in which farmers operate constitutes a complex system. The key feature of a complex system, as underscored by Arthur (1999), is that outcomes are not deterministic and cannot always be easily predicted. Instead, outcomes are process-dependent and evolve over time. The policy part of this complex system includes three key components: (1) prices and markets, (2) public institutions and the rules and norms under which farmers operate, and (3) the spectrum of agricultural technologies created and made available both publicly and privately. Because most forms of agricultural production lead to degradation of resources in some way and because poverty reduction, food security, and unemployment are major challenges faced by developing countries, the problem of finding flexible and adaptive policies to ensure sustainable agricultural development is not easily solved. Nevertheless, environmental concerns and economic goals can be approached together through an adaptive learning process. Ideally, such a process will specifically acknowledge markets for what they are: a filter through which incentives for adaptation and change are transmitted.

It will be clear to the reader that policies related to agricultural prices and markets—for example, domestic price support programs—often directly influence smallholder performance. By extension, these policies also influence a range of important outcomes. These include rates of deforestation, water pollution, land degradation, and biodiversity loss on the one hand and rates of forest protection, soil and water conservation, and biotic conservation on the other. What may not be so clear is that policies not specifically directed at agriculture also play an important role in shaping agricultural outcomes because they influence the ways in which resources such as land, labor, and capital are used. Moreover, many cases of resource degradation in the developing world can be traced either to a lack of clearly defined and enforceable property rights or to the lack of implementation or enforcement of existing rights. For this reason, land tenure institutions are an integral part of the agricultural policy system. As Stiglitz (2003) points out, developing countries often suffer from limited competition in markets and imperfect information on the part of decision makers. As a result, Adam Smith's oft-celebrated "invisible hand" may not align private and social interests; therefore, institutions—including regulatory institutions and other functions of the state that shape the market—take on considerable importance in the realm of promoting sustainable development.

Moreover, because the technology of agricultural production, like that of most productive activities, is subject to innovation and adaptation, technology policy plays an important role in shaping the conditions under which smallholders operate. As Ascher and Healy (1990) have argued, many developing countries have adopted a policy bias in favor of agricultural modernization, taking the view that traditional peasant agriculture should be replaced by a more scientific, market-oriented, and specialized form of production. In some cases, the key to sustaining rural livelihoods may indeed be found in technological progress. However, as the experience of the Green Revolution has shown, the promotion of specialized monocultural systems has sometimes led to overexploitation of land and water resources and has sometimes generated unintended local and off-site effects. Thus technology cannot be viewed as an easy fix to smallholders' problems but rather as a component to be managed in a strategic and adaptive way.

Agriculture and Natural Resources: An Overview

Agricultural Expansion and Deforestation

Agricultural expansion is one important factor influencing rates of tropical deforestation and biodiversity loss. Global tropical deforestation exceeds 130,000 square kilometers a year and poses an enormous threat to biodiversity and the resilience of local and global environmental systems (Sterner 2003). Forest degradation, defined as a decrease in density or a disturbance in the forest ecosystem, is also a serious ongoing problem. Table 1 provides an overview of global trends in forest degradation. Forest loss over the three decades covered by the data in table 1 has been most acute in Central America (where the share of forest in total land area declined by 6.5%), East and Southeast Asia (6.5%), and Central Africa (2.8%).

Deforestation has many causes. In some settings, rates of deforestation are closely linked to changes in agricultural input and output prices, timber prices, tenure security, credit availability,

Table 1. Forest degradation and agricultural expansion (www.faostat.fao.org).

Region	Share of forest area to all land			% change in agricultural area (1961 to 2002)
	1961	1994	Change	
Africa	24.81	24.05	-0.75	4.97
Central Africa	56.05	53.25	-2.79	2.50
Eastern Africa	28.36	28.36	0.00	-1.63
Southern Africa	27.22	27.20	-0.02	-0.24
Western Africa	16.21	15.15	-1.06	10.74
Asia	21.99	20.71	-1.28	59.41
East and Southeast Asia	48.46	41.99	-6.47	8.22
South Asia	17.49	20.54	3.05	6.34
North and Central America	39.34	38.55	-0.79	-3.01
North America developed	40.85	40.77	-0.08	-7.34
Central America	35.48	28.99	-6.48	13.57
South America	54.24	53.13	-1.10	29.61
Europe	30.15	—	—	—
Eastern Europe	29.24	30.37	1.13	-8.89
Western Europe	30.44	34.33	3.90	-14.20
Australia	18.95	18.87	-0.08	-3.16
Summary				
Developed countries	36.50	34.86	-1.64	-3.25
Developing countries	31.36	29.88	-1.48	21.34
World	33.50	31.96	-1.55	11.06

and technological progress (Barbier and Burgess 2001). Macroeconomic policies are also implicated in deforestation. The textbox below highlights three important cases of agriculture-induced deforestation, providing examples of how economic policies have influenced rates of deforestation in Brazil, Cameroon, and Indonesia.

Deforestation in Brazil, Cameroon, and Indonesia

Binswanger (1991) and Hecht (1993) examined the complex interplay of major government polices such as tax exemptions, special tax incentives, land allocation rules, and agricultural credit and their effect on deforestation in the Amazon. The tax exemption policies for the agricultural sector in Brazil led private and corporate sectors to invest heavily in agriculture. With very high land ceilings, investments in agriculture resulted in accumulation of large land holdings. Because forestland was considered unused, a farm containing forests was taxed at higher rates than the one containing pastures or cropland. This provided an incentive for farmers to convert forested property into large pasturelands, leading to large-scale deforestation. A number of regional and sectoral tax breaks also encouraged investments in enterprises using cleared forestland. These structural changes in agriculture (reduced labor demand, increased mechanization) marginalized small farmers.

Gbetntom (2005) studied the causes and consequences of deforestation in Cameroon over three decades. An average of 130,000 hectares of forest was cleared each year in Cameroon during this period. Deforestation increased faster after Cameroon's boom, the adoption of structural adjustment policies, and the devaluation of the CFA franc. During the oil boom in the late 1970s, higher international prices for coffee and cocoa encouraged farmers to clear forests to plant these crops. Also, the oil boom stimulated construction, which generated greater domestic demand for timber. While structural adjustment policies reduced coffee and cocoa prices by 60% and 40%, respectively, and led farmers to eventually abandon these crops, food crop expansion led to even greater rates of deforestation. The prices paid to producers of coffee, cocoa, and food crops, as well as to exporters of timber, effectively influenced the speed of forest clearing in Cameroon. However, Gbetntom's results show that short-run responses to changes in perennial prices were weaker than responses to changes in food crop prices, indicating more rapid forest clearing for annual crops than perennials.

Indonesia also illustrates how economic policies influence rates of deforestation. Sunderlin et al. (2001) examined the effect of Indonesia's economic crisis in the 1990s on small farmers' welfare, their agricultural practices, and natural forest cover. Because of a drastic decline in real household income during the East Asian economic crisis, farmers relied on nearby forest resources rather than waiting for additional income from agricultural production. An increase in timber and rattan harvesting was observed during the crisis due to combined effects of economic hardship, favorable timber prices, and reduced forest policing. Despite a decline in rubber prices, forest clearing to establish rubber production increased because rubber provided a safety net for farmers. Higher prices also increased the area under pepper.

Land Degradation and Soil Erosion

Land degradation is a major problem facing agriculturally dependent populations in the developing world. Table 2 provides data on rates of land degradation worldwide. Soil erosion in tropical and subtropical watersheds leads to siltation, water flow irregularities, a decline in irrigation efficiency, and water pollution through soil and agrochemical runoff. One estimate suggests that during the early history of agriculture (beginning roughly 10,000 years ago) approximately 25

Table 2. Land degradation due to agricultural activities (FAO, http://www.fao.org/ag/agl/agll/terrastat/).

Region	Total area (1,000 km²)	Total degradation (1,000 km²)	Degradation due to agriculture (1,000 km²)	Total area degraded (%)	Degradation due to agriculture (%)
Asia and Pacific	28,989	8,407	3,506	29.0	41.7
Europe	6,889	3,274	727	47.5	22.2
North Africa and Near East	12,379	4,260	759	34.4	17.8
North America	19,237	3,158	2,427	16.4	76.9
North Asia, east of Urals	21,033	4,421	1,180	21.0	26.7
South and Central America	20,498	5,552	1,795	27.1	32.3
Sub-Saharan Africa	23,754	5,931	1,996	25.0	33.7
World	134,907	35,005	12,391	25.9	35.4

million metric tons of soil was lost each year worldwide. This annual loss rate has accelerated to 300 million tons in the past 300 years and to 760 million tons in the past 50 years (McNeely and Scherr 2003).

Approximately 550 million hectares of land globally are degraded due to agricultural mismanagement—primarily due to water erosion and soil loss. Another 40 million hectares are affected by soil salinization and water logging (UNEP 2002). The extent of soil erosion depends on the complex interaction of a number of factors such as the resilience of the natural resource base, institutional conditions, population growth, and the policy environment (Ananda and Herath 2003). (Of course, population growth need not necessarily lead to land degradation. As Boserup [1981] pointed out, population growth can promote more intensive practices and more favorable technological and organizational innovation that will not only increase productivity but also improve environmental quality.)

The drive among smallholders to achieve food security (or profit) often leads to high rates of chemical use and soil depletion. The relative prices for inputs and outputs are often facilitating factors. For example, Barbier and Burgess (1992) show how higher crop prices in Thailand led to agricultural expansion and how government subsidies of fertilizer in Malawi encouraged overuse of fertilizers by smallholders without providing complementary improvements in cropping systems and resource conservation. Yet the logic of input subsidization is sometimes supported. For example, Fan et al. (2008) demonstrate how subsidies for credit, fertilizer, and irrigation were crucial for small Indian farmers to adopt new technologies, particularly during the initial stage of the Green Revolution in the late 1960s and 1970s. But they also show that investments in agricultural research, education, and rural roads were the three most effective public spending items in promoting agricultural growth and reducing poverty, suggesting that expensive subsidies that crowd out these other forms of public investment may be counterproductive in the long run. Similarly, looking across three continents, Rios, Masters, and Shively (2008) find that improvements in agricultural productivity are more conducive to participation in agricultural markets than are improvements in market infrastructure and access.

Biofuels also illustrate how economic policies affect the environment. Interest in biofuels has been growing at a rapid pace in recent years. Rising concerns over energy security and mitigation of greenhouse gases has led many developed countries to undertake biofuel programs supported in large part with massive subsidies. The US Energy Independence and Security Act of 2007 mandates the use of biofuels to increase to 36 billion gallons by 2022 from 7 billion gallons in 2007. The European Union biofuels directive requires its member states to realize a 10% share of biofuels on the liquid fuels market by 2020 from the current share of about 3%. These ambitious mandates depend on large-scale production of feedstock that directly or indirectly competes for land and water resources. Although, biofuels are considered by many observers to offer some economic benefits, they also pose enormous challenges to the environment. Accounting for emissions from land-use change, Searchinger et al. (2008) found that use of corn-based ethanol nearly doubles greenhouse gasses over 30 years instead of producing a 20% savings, as widely perceived. The same study argues that biofuels from switchgrass, if grown on US lands, would increase emissions by 50%. The environmental effects of biofuel programs largely depend on the type of feedstock used for production. Fargione et al. (2008) assert that the net effect of biofuel production through clearing of carbon-rich habitats such as rainforests and grasslands would result in an increase in CO_2 emissions relative to fossil fuel use. While these findings are still being debated, concerns about deforestation and land degradation are also being voiced across the world, a synthesis of which is given in the textbox below.

Impact of biofuel programs on the environment

Rising interest in crop-based biofuels in developed countries, particularly the European Union and the United States, has spurred the demand for feedstock. The demands have been transmitted to a number of other locations, including Brazil and Southeast Asian countries, which have comparative advantages in producing these crops. While the United States mainly produces corn-based ethanol, the European Union countries have been focusing on vegetable oil-based biodiesel. Expansion of corn area in the United States has been displacing soybean production to the Brazilian Amazon. Altieri and Bravo (2007) report that soybean cultivation has already resulted in the loss of 53 million acres of forests in Brazil, 35 million acres in Argentina, 5 million acres in Paraguay, and 1.5 million acres in Bolivia. Oil palm is another feedstock, grown mainly in Southeast Asia. It is gaining in popularity because it is cheap and efficient for biodiesel production. EU imports of palm oil have escalated in recent years, resulting in expansion of oil palm plantations in Indonesia, Malaysia, and Thailand. The Friends of Earth (2005) reports that about 8 million acres of forest were cut for oil palm cultivation in Indonesia, and about 1.9 million acres were converted in Malaysia by 2003. Rapid increases in palm oil prices in recent years (from an average of $479 per metric ton in 2006 to a peak of $1,390 per metric ton in March 2008) have exacerbated the rate of deforestation in oil palm-growing regions.

Another potential problem associated with crop-based biofuels is land degradation. For example, higher corn prices in the United States could induce farmers to withdraw lands from the United States Department of Agriculture's voluntary Conservation Reserve Program (CRP) to increase corn production (Dufey 2007). The USDA reports that about 37 million acres are under CRP, of which 7 million acres are suitable for corn production. Other land could be used to support production of non-food crop biofuel feedstocks. However, conversion of these lands could result in high rates of soil loss and reductions in soil quality, highlighted by the extent to which subsidy policies for biofuel programs play a crucial role in determining the scope of agriculture's impact on the environment.

Water Use and Management

Globally, about 250 million hectares are under irrigation for agriculture, a major portion of which is in India, China, and Pakistan. Many developing country governments provide irrigation water either free or at highly subsidized prices. This has led to inefficient and unsustainable patterns of water use and depletion of water resources. Although water scarcity typically reflects inadequate rainfall, even rain-abundant countries experience scarcity because flawed policies undermine efficient water use and management. Pingali (2001) argues that, in Asia, government policies aimed at food self-sufficiency have led to degradation of water resources and reduced agricultural productivity. Estimates suggest that water tables have been falling by up to 1 m annually in the North China Plain and by 25 to 30 m per decade in parts of India (McNeely and Scherr 2003).

Externalities from Agricultural Chemicals

Agricultural advancement and market-oriented production is generally accompanied by intensified use of chemical inputs, particularly fertilizers and pesticides. Indiscriminate use of these chemicals has serious repercussions for the environment. High rates of chemical fertilizer use tend to decrease soil organic matter and pesticides can pollute water, air, soil, and even alter the ecosystem by harming non-target organisms. The misuse of agrochemicals in many developing countries reflects two facts. First, policies have only in recent years been formulated and legislated in many countries, and not all countries have the regulations to implement the policies that have been promulgated. Second, in places where it is possible, there has often been a lack of implementation of environmental regulations and policies governing agrochemical use.

Chemical inputs are widely perceived to benefit agricultural production. But some studies question the value of indiscriminate use of agrochemicals. For example, in a study of rice production in the Philippines, Antle and Pingali (1994) concluded that reduced use of insecticides would have a small overall effect on productivity because crop losses from reduced pest control would be offset by labor productivity improvements from the better health of farmers. They concluded that policies aimed at reducing insecticide use in rice production, including reduction or elimination of subsidies, would likely improve overall farmer welfare. Garcia and Shively (2008) measured the impact of pesticide reductions on the efficiency of smallholder coffee producers in Vietnam and found that modest restrictions on pesticide intensity had very small deleterious effects on overall productive efficiency. Their finding largely reflects the fact that the least efficient farms in the sample were generally those that were applying pesticides at rates above those that were optimal.

Role of Policy

As stated above, the perspective of this chapter is that the policy system has three distinct points of entry to smallholder agriculture: markets, institutions, and technologies. We illustrate the basic conceptual linkages among these in figure 1 and further explain the key relationships suggested by this schematic in table 3. The entries in table 3 aim to highlight the ways in which each policy dimension influences particular smallholder decisions that influence natural resource management. We elaborate below.

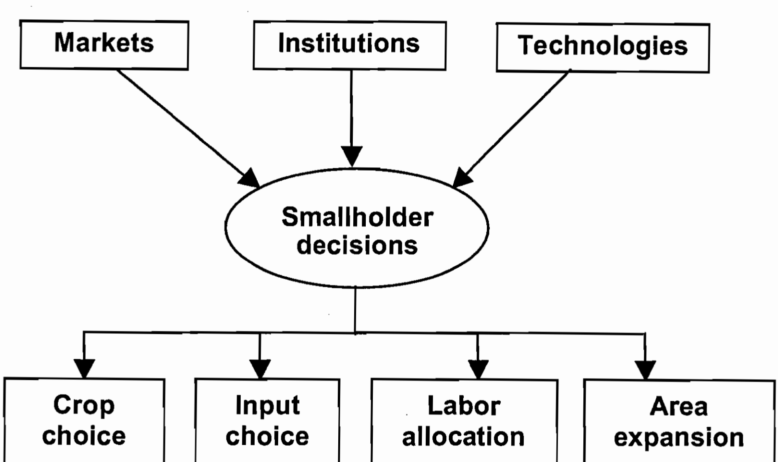

Figure 1. Smallholder decisions and the policy system.

Table 3. Policy focus and smallholder decisions.

Policy focus	Choice of crops	Input choices	Labor allocation	Area expansion
Markets	Producer prices drive cropping patterns	Input intensity depends on subsidies, credit, insurance, etc.	Off-farm opportunities influence on-farm labor allocation	Markets for agri-products influence decisions for agri-expansion vs. agri-intensification
Institutions	Institutional framework (e.g., property rights) influence planning horizons and incentives to invest in strategies with long-term payback	Banks, co-operatives, market agencies influence input use	Property rights and tenure security influence rates of urban/rural migration	Tax and legal framework may influence forest conversion to agriculture
Technology	Crops choice will reflect profitable and easily adoptable technologies that favor particular crops	Some technologies may favor certain inputs (labor or chemicals) and may be input-intensive or input-saving	Technologies may be labor-intensive or labor-saving	Profitable technologies may promote intensification or expansion depending on their scale characteristics

In traditional smallholder production systems, optimal resource allocation is frequently determined year by year, with farmers adjusting to changing conditions over time through trial and error (Tomich et al. 1995). Typically, and conditional on biophysical and socio-cultural factors, a farmer's crop choice is strongly influenced by current market prices and expectations for future prices. Concerns regarding price variability also influence crop choice. In thinking about how policies influence crop choice by way of prices, it is important to recognize that price support programs may encourage farmers to plant some crops rather than others and that trade and import restrictions, including phytosanitary regulations in many countries, may indirectly raise the domestic price of a commodity and encourage its production. Moreover, policies that reduce the uncertainty or variability of crop prices will, other things equal, make those crops more attractive to farmers (Coxhead et al. 2002; Shively 1998).

The institutional framework can also influence crop choice. Farmers tend to produce only those commodities for which markets are well established. Furthermore, secure property rights regimes have been widely shown to influence farmers' decisions to plant perennial crops, which are generally more environmentally desirable than annual crops (due to less soil disturbance and greater year-round canopy) but also require long planning horizons and some incentive to invest in strategies with long-term payoffs. Many improved agricultural technologies have been criticized for being biased towards large farms and unaffordable for smallholders. Available technology may influence the choice of crop, for example, if the availability of irrigation or germplasm causes some crops to be favored over others.

The input choices of smallholders depend on the relative cost of inputs, as well as access to financing in cases where farmers must borrow to purchase inputs at the beginning of the cropping season. As a result, the overall intensity of input use may depend on specific input subsidies (e.g., for fertilizer), access to credit, and access to insurance, remittances, or other sources of income, for overuse of inputs is often a strategy employed to reduce risk. Even farm size, largely under the influence of policymakers in areas with active land reform programs, may influence the intensity of input use. Land constraints tend to encourage higher cropping intensity, which can reduce forest clearing but also lead to intensive use of inputs.

Labor availability and labor allocation have been shown to be important factors influencing natural resource management by smallholders. While abundant labor is a stylized feature of rural areas of developing countries, labor shortages, especially at peak times in the agricultural calendar, often undermine labor-intensive resource management schemes. In contrast, abundant labor may depress wages, and as the opportunity cost of rural labor falls, incentives to engage in environmentally degrading activities with short-run payoffs increase. Using data from Colombia, Heath and Binswanger (1998) show that intensification-led resource management is not automatic. Instead, it arises as an outcome of investment decisions made by farmers and requires enabling policies and institutional support. Using data from the Philippines, Shively and Fisher (2005) demonstrate how competition for labor off farm can strongly influence a farmer's decision to intensify or expand production on farm.

Technology choice can also influence outcomes. Other things equal, as agricultural commodity prices rise, smallholders have incentives to expand agricultural area. If available technologies favor adoption of machinery, then the agricultural sector will shift from labor-intensive to capital-intensive forms of production. In turn, economies of scale in mechanized production may favor agricultural expansion. The effectiveness of the legal framework in a country also influences incentives for area expansion. In Brazil, for example, individuals seeking tax shelters available to agricultural producers helped to precipitate deforestation. Area expansion also depends on whether the available agricultural technology promotes intensification or expansion. Shively (2001) relates data from the Philippines showing that irrigation of lowland farms acted as a magnet to pull labor away from forest margins, thereby reducing local rates of deforestation to some extent. Tomich et al. (1995) argue that specialization and technological change are the primary driving forces available for transforming an agrarian economy into a diversified and highly productive economy.

Toward a Framework for Policy Analysis and Design

"Getting prices right" has been a foundation for economic development policy over the past four decades. Allowing farmers to participate in markets and allocate resources on the basis of market signals has been a powerful mechanism for achieving food sufficiency in many countries. However, agricultural development has failed to alleviate poverty in many settings. As a result, increasing attention has come to be placed on market failures, in particular on the weakness or absence of institutions to support market development. Bator (1958) defined market failure as "the failure of a more or less idealized system of price-market institutions to sustain desirable activities or to stop undesirable activities." In fact, many of the policy failures reflected in very low or negative national income growth in sub-Saharan African countries since 1970 have come to be blamed as much on institutional failures as on market imperfections manifested in "incorrect" prices (Bruce and Mearns 2004; Gabre-Madhin and Haggblade 2001).

But what, exactly, are institutions? Different disciplines tend to define the term differently. Among economists, Bromley (1989) building on Matthews (1986) and the early work of Commons (1934) defines institutions as rights and obligations. These may be general conventions (regularities in human behavior) or specific entitlements (sets of legal ordered relations). In this sense, many of the organizations that one might regard as "institutions" (banks, informal credit markets, government ministries) may be more accurately thought of as entities created and defined by underlying institutionally ordered relations. In examining links between policies and natural resource use, Sterner (2003) highlights institutional failure as a key causal factor precipitating resource degradation. Institutional failure is typically equated with a lack of enforced rights of access to and use of an environmental resource, resulting in degradation of the resource (primarily because agents do not internalize the costs of damage to the resource). Yet institutional failure can be construed more broadly. Governments and government agencies, whether national, provincial, or local, are frequently the primary institutions through which policies are implemented. Faulty policies, an absence of policies, or the failure to enforce policies and laws all constitute institutional failure. Though many norms exist in rural communities with respect to water sharing, community grazing, and use of fisheries, there is always a threat of losing these norms in the process of development if communities and governments fail to maintain, adapt, and enforce policies and practices consistent with goals of sustainable development. Arguably, effective adaptive management requires effective governance, and institutional failure is therefore somewhat synonymous with ineffective governance.

Equally important to failures to achieve agricultural development, let alone sustainable agricultural development, is a shortage of appropriate technologies for smallholders operating in challenging or "least favored" environments. Where markets and institutions have been seen to fail, attention has been refocused on the possibility that new technologies might increase agricultural production while simultaneously conserving natural resources. Of course, new technologies alone are insufficient. Complementary policies are needed to stimulate an innovative learning environment, disseminate new technologies, evaluate and monitor their adoption and effectiveness, and modify both the technologies and the policy environment. When these complementary policies are in place, one might then regard technology policy as adaptive and therefore consistent with the aims of sustainability.

Our perspective is that single strategies to pursuing sustainable development—whether through markets, institutions, or technologies—are good. But single strategies are unlikely to succeed. In figure 2 we combine and intersect the three spheres of the policy system as a way of encouraging

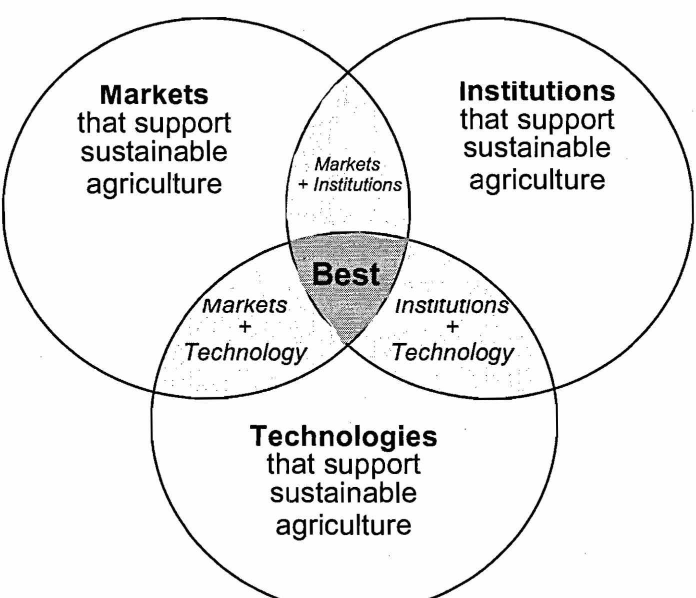

Figure 2. Schematic diagram of the market-institution-technology nexus.

Table 4. Examples of economic polices influencing the environment in selected developing countries.

Country	Economic policies	Findings and example
Brazil	Tax policies, land ceiling legislation, credit and subsidies for livestock production	Tax exemptions in agriculture led private and corporate sectors to invest in the agricultural sector. Very high land ceilings resulted in accumulation of huge holdings by a few companies, marginalizing small farmers. Regional tax credit schemes encouraged uneconomical corporate livestock production, leading to conversion of forest land into large-scale ranches. (Binswanger 1991; Hecht 1993; Mertens et al. 2002)
Cameroon	Structural adjustment policies and devaluation of CFA franc	High international coffee and cocoa prices during the late 1970s encouraged forest clearing. Though policies gave greater importance to food crops, devaluation of the CFA franc in 1994 doubled timber prices, which stimulated timber production. (Gbetntom 2005)
Philippines	Policies on support prices, import reduction, trade interventions, and R&D support to develop yield-raising and pest-resistant technologies	As a result of the policy mix, the area under corn and vegetables expanded in Manupali River watershed, leading to a steady decline in forest cover, an increase in soil erosion and sedimentation, and an increase in pesticide use. (Shively 1998; Coxhead 2000)
	Agricultural intensification	Irrigation development led to labor absorption and a reduction in forest clearing in Palawan. (Shively and Pagiola 2004)
Morocco	Trade liberalization and water policies	The water allocation system existing before liberalization favored area expansion in water intensive crops such as sugarcane, leading to an unsustainable pattern of water use. A low urban water tariff is projected to produce a water deficiency in Morocco by 2020. A rise in the water tax would reduce real GDP slightly but reduce water use significantly. (Munasinghe and Cruz 1995; Tyner 2004)
Vietnam	Trade liberalization, greater access to the world market	Higher coffee prices in the 1990s brought more barren and forested land under coffee production, and increased migration. Forest cover decreased from about 90% in the 1960s to less than 50% in the late 1990s (Oxfam 2002b).

the reader to consider interactions among the three. Our view is that, to move toward sustainable use of resources, the best development strategy will be one that aims to get all three mechanisms working together, that is, one that aligns incentives through adaptive processes in ways that are individually and together consistent with the goal of sustainable use of resources.

The ways in which each policy sphere can affect behavior, decisions, and adaptation on farms is further articulated in table 3. It is important to note that one key aspect of complex adaptive systems is that agents acting in those systems adapt as conditions (i.e., policies) change. These adaptations in turn create a policy environment in which other agents may make further reactive behavioral changes and so on. In such dynamic settings, it is not just that multiple "strategies" are important for successful adaptation on the part of agents but also that the policy process itself must become iterative to deal rapidly with unintended consequences, on the one hand, and the responsiveness of agents on the other. This is one reason why many observers regard local, democratic institutions as most desirable.

Table 4 provides examples of situations in which specific economic policies have been linked to environmental outcomes. We summarize the basic linkages below.

Markets

Several studies have analyzed the relationship between policies, the market for agricultural goods, and the natural environment. Trade policy reforms are the most noteworthy example of policies that can directly or indirectly affect agricultural producers. Trade reforms tend to boost income and production. By relocating production globally, they can also lead to positive environmental changes (Anderson 1998). However, trade policies rarely embody environmental considerations. Because agricultural producers may not have to pay for damages to the environment, international trade that promotes agricultural expansion in environmentally sensitive areas can lead to an increase in environmental damage.

In evaluating the effects of economic liberalization, Thorbecke (2000) makes a distinction between two types of policies: those that focus on "getting the prices right," such as currency devaluation and elimination of subsidies, and those that focus on "getting the prices and institutions right," thereby improve market efficiency. So, for example, removing agricultural subsidies is advocated by many economists based on the principle that scarce resources ought to be allocated based on their "true" prices (ideally the shadow values of those resources). Lifting output prices or reducing input prices below market levels can lead to overuse of natural resources in agricultural production, thereby contributing to environmental degradation. By reducing input subsidies and thereby increasing prices for modern inputs, policies can discourage the cultivation of crops requiring heavy use of machinery and chemicals, leading smallholders instead to increase the intensity of labor use (Young and Bishop 1995). Getting prices right by correcting market distortions caused by input subsidies can promote a more efficient and sustainable use of resources. In many cases, inputs such as fertilizer are subsidized on the grounds that lower prices are required to generate their use, in some cases because farms lack access to credit to purchase the inputs. But in these cases, it may be far preferable to eliminate the original distortion (the credit constraint) rather than introduce a new distortion (a subsidy) to compensate.

In evaluating the effects of trade liberalization on natural resource use in agriculture, it is important to consider what are referred to as scale, composition, and technique effects. (The Environmental Kuznets Curve purports that economic growth and environmental pollution typically follow an inverted "U" shape. At early stages of economic growth, economic development tends to induce increased pollution. As incomes rise, environmental degradation may reach a peak and then start to decline, due to increased demand for higher quality environmental services and to changes in the composition and technique of production.) The scale effect refers to whether the scale of production in a specific location or country increases as a result of new trade patterns. Other things equal, if output increases, then any environmental impacts associated with production will increase also. The composition effect, sometimes called the structural effect, refers to the change in the composition of activities toward those sectors with comparative advantage. So, for example, a trade liberalization policy might increase the comparative advantage of a country in producing a certain good by tilting relative prices in favor of that good. If the favored good replaces one that is more environmentally damaging, then liberalization would have an environmentally beneficial impact, judged on the basis of the composition effect. For example, a policy that caused smallholders to replace annual crops with perennials might be judged beneficial on the grounds that perennial systems provide greater year-round ground cover, less soil disturbance, and greater biodiversity opportunities.

Finally, changes in the regulation of markets that lead to technology transfer can generate shifts in the composition and location of production and consumption. The technology effect refers to a nation's access to resource-efficient production processes due to trade liberalization. For example, during the 1990s Vietnam experienced a change in the composition and scale of agricultural activity as a result of trade liberalization. Production of modern varieties of coffee expanded, as did other export-oriented agricultural activities. However, rather than replacing annual crops, in Vietnam coffee tended to expand into previously forested areas. The textbox below highlights this process and underscores the importance of local features in shaping whether trade liberalization has positive or negative environmental effects. In contrast, Shively (1998) analyzed the influence of changes in agricultural prices on land-use decisions and environmental outcomes in the Philippines, focusing on agricultural households that were choosing among a portfolio of crops and making investment decisions regarding tree crops. That analysis found that pricing policies favoring perennial crops and policies aimed at liberalizing agricultural trade would tend to encourage tree planting, which was judged less environmentally damaging than the production of annual crops. Crop diversification was shown to have beneficial impacts on both soil erosion rates and species diversity.

Trade liberalization and coffee expansion in Vietnam

Vietnam experienced rapid growth in coffee production and coffee area during the 1990s. Two studies looked carefully at the growth in Vietnam's coffee sector: International Institute for Sustainable Development (1999) and Oxfam (2002b). One of the main reasons for the rapid increase in coffee cultivation in Vietnam was a sudden rise in the world coffee price in the early 1990s and government response through market and trade liberalization. Due to severe frost in 1994, Brazil lost a substantial portion of its production, and global coffee prices rose. The higher profitability of coffee made it popular in Vietnam, and the area expanded to cover about 21% of total crop area by 2000, compared with less than 2% of crop area in 1994. This area expansion came directly at the expense of forest and arose in response to both spontaneous and state-sponsored migration to upland coffee-growing areas. Among the difficulties generated by the rapid expansion in coffee production have been indiscriminate use of chemical pesticides and high rates of water extraction for irrigation.

Focusing on a range of Asian countries, Young and Bishop (1995) argue that removal of price distortions in input and output markets would enable farmers to allocate the resources more judiciously, which would encourage diversification away from rice and wheat. For example, gradually dismantling pesticide subsidies would result in decline in use of pesticides for cereals compared with higher value crops (Pingali 2001). Predicted impacts, even within a country, are rarely uniform, however, and overall environmental effects tend to hinge on whether new agricultural activities will be more or less damaging than those they replace (Coxhead 1997).

Achieving food security is a primary concern of any developing country. Climatic challenges are often a significant obstacle to food production and also compromise attempts to manage natural resources. In the case of arid lands, Tyner (2004) reports a significant increase in production of common wheat in Morocco during the past two decades. This increase is credited to government pressure on farmers, higher price incentives, greater use of improved seeds and fertilizer, and expansion of area under irrigation. While successful from the perspective of food production, this increase came at a high cost for the agriculture sector, rural development, and the environment. In another study of Morocco, Karaky and Arndt (2002) cite the tariff policy for wheat, which is set based on world prices with the objective of minimizing domestic price fluctuations around a target price. Similar kinds of distorting policies have persisted in sugar and meat products, which have increased the production of high-value crops and marginalized area under traditional crops such as barley. The latter tends to be less intensive in the use of water and chemical inputs. These policies have transformed Morocco from a net exporter to a net importer of barley and have undermined environmental quality.

Institutions

Domestic rules and international agreements can be very important in fostering or hindering sustainable agricultural development. Investment in research and development, market infrastructure, and dissemination of advanced technologies all influence environmental outcomes in the long run. Although many factors contribute to the global movement of production, including the cost of labor, raw materials, and transport, in the case of both agriculture and industry it is sometimes the case that a combination of strict environmental regulations in developed regions and weak environmental standards in developing regions can encourage the movement of polluting industries across borders—the "pollution haven" hypothesis. Conversely, institutions to support and create identity around environmentally sound cropping practices (whether through organic labeling, fair trade labeling, or environmental branding) can provide both markets and—through higher prices—incentives for farmers to participate in new activities and adapt to new opportunities.

Environmental clauses of the World Trade Organization agreements also influence natural resource use in the agriculture sector. World Trade Organization guidelines typically prevent trade restrictions based on the method of production, thereby making it difficult to use environmental considerations to block trade. However, sanitary and phytosanitary (SPS) regulations may still apply to exporting companies. Damodaran (2002) studied coffee enterprises in India, examining those companies' attempts to comply with SPS regulations and other national and international environmental rules. SPS-complying farms were found to have experienced an increase in labor input per unit of land, largely as a result of replanting and altering the intensity of cultural operations. Compared with non-SPS complying farms, complying farms were found to engage in more biodiversity-depleting activities. These included felling of endemic trees, stumping of non-endemic trees, and converting tanks and ponds for wastewater storage. Such evidence suggests a strong need to create formal institutions that can harmonize such disparate issues as SPS and biodiversity conservation, and to do so in ways that fit within the terms of national laws and international agreements.

The institutional feature most widely acknowledged in playing a local and fundamental role in promoting sustainable activities is security of land tenure. Security of tenure helps to reinforce a farmer's long-term perspective in his land and also often provides a form of collateral that facilitates borrowing and investment in productive activities such as tree planting. (Raintree [1987] provides a comprehensive catalog of empirical evidence regarding the influence of tenure on natural resource management.) Although security of tenure is often equated with private property rights, a private property rights regime is neither necessary nor sufficient to ensure the sustainability of activities. Indeed, the literature contains many examples of sustainable systems built on common property regimes (Bromley 1992).

Technology

In the past, the bulk of attention on technological approaches to agriculture has focused on promoting particular specialized types of innovations, either with narrow applications or with clear benefits for outsiders who are responsible for developing and marketing the technologies, such as improved varieties. In recent years, however, new thinking on the topic of innovation and technology adoption has arisen. This thinking acknowledges that there are roles for policies that promote innovation in general (for example, Douthwaite 2006) and for policies that promote innovations that more specifically hold out promise to be developed locally in an adaptive management context. The latter may especially improve local—and possibly global—competitiveness and profitability of highly localized (and sometimes specialized) production processes.

Of course, the application of biotechnology is fundamentally changing the structure of agriculture in the 21st century, especially in industrialized countries. The introduction of genetically modified (GM) crops and their possible economic and environmental implications has emerged as a subject of contentious debate. Much of the early literature on this subject focuses on developed countries because many of those have been relatively slow in opening up to GM crops. Qaim and Zilberman (2003) analyzed the yield effects of GM crops in developing countries based on the example of Bt-cotton in India. As indicated in table 5, the yield effect of GM crops is high in tropical and subtropical regions, largely because the pest pressure is also high in those regions compared with temperate areas.

Though trials indicate some positive yield effects and also reductions in pesticide use, concern over potential environmental and health risks associated with GM crops has resulted in limited acceptance of GMs by policy makers in developing countries. It has been argued that, because many GM crops are developed for pest resistance, they would be easier to manage at the farm level and could increase smallholder yields while reducing pesticide use. At this time, greater public investments are justified to evaluate the spillovers of the technology and the potential effects on natural resource management.

Integrated pest management (IPM) involves control of pests and diseases through the use of eco-friendly methods aimed at reducing (not always eliminating) pesticide usage. Cuyno et al. (2001) analyzed the environmental benefits of IPM in the Philippines using contingent valuation and found that practicing IPM proved to be a win-win situation. Farmers' willingness to pay to reduce pesticide risk was quite high, and the savings in direct pesticide costs were almost twice the environmental benefits. The study called for public policies to encourage IPM adoption and also institutional support for research and information dissemination.

Table 5. Expected effects of pest-resistant genetically modified crops (adapted from Qaim and Zilberman 2003).

Region	Effect on pest pressure	Incentive to adopt chemical alternatives	Effect on yields
Developed countries	Low to medium	High	Low
Latin America (commercial)	Medium	High	Low to medium
China	Medium	High	Low to medium
Latin America (non-commercial)	Medium	Low	Medium to low
South and Southeast Asia	High	Low to medium	High
Africa	High	Low	High

Summary

There are few strict lessons for adaptive management of complex adaptive systems. However, tradeoffs and opportunities do emerge in various settings.

In the case of markets and pricing policies, innovations that can be sustained over time will have to serve the interests of both agricultural producers and policy makers. Those that will tend to support sustainable agriculture and natural resource management will be those that accomplish the following:

- Remove input subsidies, especially on chemical inputs. In settings where subsidies have been justified to correct policy failures, the original market failure should be addressed.
- Encourage perennial crops over annual crops. To the extent that perennial crops can compete financially with annual crops and provide reliable income for farmers, they often are a better option for provision of environmental services and protection of natural resources.
- Promote resource-conserving methods rather than area expansion. Where area expansion has occurred as a reaction to limited access to other productive resources or specific markets, policies should aim to facilitate farmers' access to resources and markets and—importantly—aim to increase rates of on-farm productivity to alleviate poverty-led area expansion.
- Encourage labor use where labor is abundant and discourage labor intensity where labor is scarce. To be successful, policies must be aligned with the economic logic of household production. It should also be emphasized that the economic logic of household production is itself a moving target.

Institutional innovations that will tend to support sustainable agriculture and natural resource management will be those that accomplish the following:

- Reduce smallholder production and income risk, either by reducing yield risk at the farm level or by reducing price risk at the market level.
- Strengthen local institutions, especially in ways that promote local accountability for resource use.
- Support property rights and establish mechanisms through which those secure rights can be mobilized in support of forward-looking investments to make resource use more efficient and sustainable.
- Support the building of human, social, and physical assets so that natural forms of capital are transformed into more productive forms of capital, rather than merely consumed or squandered.
- Expand the scope for combining and coordinating the efforts of national line agencies such as ministries agriculture and the environment (such efforts will help to ensure resource allocation patterns serve the broadest set of interests).
- Link smallholders to markets to support rural livelihoods, keeping in mind that "market linkages" are more than just roads and bridges but include communication, education and training, and support to help farmers realize the gains in efficiency that result in marketable surpluses.

Technology innovations to support sustainable agriculture and natural resource management must accomplish the following:

- Aim to be favorable to smallholders and cognizant of scale efficiencies and possible resource constraints that limit adoption and/or adaptation.

- Be consistent with market and institutional incentives, especially in situations where markets for particular products are thin or seasonal.
- Where possible, promote perennial crops, especially when such promotion serves to improve environmental conditions through soil and water conservation or biodiversity protection.
- Where possible, encourage agroforestry or multi-species systems over monocultural systems to increase the resilience of the overall system and help moderate economic variability.

Opportunities on the Horizon

We close this chapter by briefly highlighting three emerging areas of policy for those interested in sustainable agriculture and natural resource management. Each represents a potential opportunity to align the economic interests of smallholders more closely with concerns regarding environmental management.

Clean Development Mechanism of the Kyoto Protocol

It has been widely argued that industrialized economies, which constitute only one-fifth of the world's population, are causing disproportionate environmental damage through their emissions of carbon dioxide and other greenhouse gases (Oxfam 2002a). As described by the United Nations Framework Convention on Climate Change (UNFCC 2006), the 1997 Kyoto Protocol is the main legally binding instrument for carbon emissions in the developed countries. The protocol identifies annex I (industrial) countries that pledged to reduce their emissions of greenhouse gases to 5.2% below 1990 levels. (Substantial literature addresses the potential for increased energy prices due to the Kyoto Protocol. The higher energy prices would lead to changes in acreage of irrigated and dry land crops, their yield, total output, and prices of both output and inputs. The increase in variable cost due to energy price might cause farmers to substitute inputs and alter cropping patterns. See Manne and Richels [2004].)

Annex II countries (developing) were not assigned caps on their emission of greenhouse gases. The clean development mechanism provides for high-income countries to implement project activities that reduce emissions in low-income countries in return for certified emission reductions that could be used to meet their emissions targets under the Kyoto Protocol. These provisions enable technical cooperation between developed and developing countries resulting in sustainable development. The development of biomass fuels is one area where the aims of the clean development mechanism closely align with the goals of sustainable agriculture and natural resource management.

Payments for Environmental Services

Command-and-control policy instruments existing to conserve environmental and ecological resources have rarely succeeded in their purpose. The main principle behind PES is that those who provide valuable environmental services should be compensated for doing so, and those who benefit from environmental services should pay for them (Pagiola et al. 2005). Wunder (2005) defines PES as a voluntary transaction where a well-defined environmental service is being bought from a provider if and only if the provider secures the provision. Unlike command-and-control regulations, which aim directly at protecting resources, PES schemes use economic incentives to conserve or restore resources of concern (USAID 2007).

PES programs have been implemented in several Latin American countries, including Costa Rica, Colombia, Ecuador, El Salvador, and Mexico (Pagiola and Platais 2006). To slow deforestation, PES programs in these countries rely on the governments offering cash to communities in exchange for agreeing to conserve forest resources. Costa Rica introduced Pago por Servicios Ambientales, a PES program under which private landowners are paid by the Costa Rican society, water users, and carbon buyers, for conservation of native forest and reforestation (Pagiola and Platais). In Mexico, under Pago por Servicios Ambientales Hidrologicos—Payment for Hydrological Environmental Services—water users pay *ejidos* in priority watersheds for avoiding deforestation. In Heredia, Costa Rica, and in Quito, Ecuador, water users pay an additional fee to private landowners for protecting the town's water supplies. Similarly in Cauca Valley, Colombia, local municipalities pay private landowners for protecting water supplies. In Yamabal, El Salvador, municipalities pay for enhancing recharge of water sources by practicing land uses that promote infiltration in the aquifer recharge area (Pagiola and Platais).

Pagiola et al. (2005) elucidate several potential applications of PES in the Philippines. A current program requires operators of hydroelectric power facilities to pay a small fee per kilowatt-hour of electricity sales, a portion of which goes into a special fund to assist with watershed reforestation and management. In most settings, however, PES systems are very new, and their overall effectiveness remains uncertain, however promising. Rather than being a drawback to their implementation, though, they offer an exciting opportunity for adaptive management to ascertain what kinds of incentives elicit desired behavior on the part of resource managers and what kinds of environmental services can be expected as a result.

Ecoagriculture and Organics

McNeely and Scherr (2003) define ecoagriculture as the management of landscape for food production while conserving the ecosystem, particularly the wild biodiversity. Today, agricultural expansion likely poses a greater threat to wild biodiversity than agricultural intensification on existing agricultural lands. Converting native forests into pastures, croplands, or even agroforestry leads to the loss of most native plant species and the animals that depend on them. For example, one-fourth of North America's wild domestic honeybees have disappeared since 1988, due mainly to an epidemic of mites that prey on the bees. This loss costs American farmers $5.7 billion a year in crop yield losses (Nabhan and Buchmann 1997).

Because trade and agricultural polices directly affect smallholder agriculture, they indirectly affect the prospects for biodiversity conservation in ecologically fragile areas. Producer price supports and input subsidies encourage agricultural production and land conversion while promoting economically and environmentally degrading resource exploitation. Reducing subsidies for agricultural chemicals can often indirectly benefit biodiversity in agricultural regions. In Indonesia, for example, banning of 56 brands of rice pesticides in 1986 and establishing a national IPM program reduced pesticide use by more than half while increasing rice yield by 0.5 tons per hectare. Re-colonization of plant and animal species was also observed in rice fields.

Trade directed toward developed-country demand for perennial crops such as coffee, cocoa, rubber, cashew, and palm oil may also benefit biodiversity to some extent if the shift is away from annual crops. Land conversion from forests to perennial crops is undesirable, however, and a significant challenge is finding ways to promote land conversion from annuals to perennials while at the same time not creating incentives to establish perennials on forest land.

In the context of the European Union, Dabbert (2003) analyzed the environmental impact of organic farming compared with conventional farming. Organic farming uses no synthetic pesticides and nitrogen fertilizers, which helps to conserve the soil fertility and lower leaching rates by 50% or more. (The same study found that CO_2 emissions were 40% to 60% lower in organic farming systems, with similar results for N_2O and CH_4 emissions.) Although organic farming can underperform conventional farming in terms of yields, lower input costs can be an offsetting advantage. The overall scope for organic production by smallholders in developing countries is relatively unexplored.

Note

We use the term "land managers" deliberately here. In most developing country contexts, discussions regarding sustainable agriculture necessarily focus on smallholder farmers, and for most of this chapter we will accordingly focus our attention on policies aimed at benefiting smallholders. However, we readily acknowledge that a more comprehensive, hence more realistic and effective, approach to the policy system must take into account other primary producers—not just smallholders—as well as other active and passive players in the policy system, including those with a stake in markets and institutions, and not necessarily agriculture per se.

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Chapter 8

Building Innovation Systems for Managing Complex Landscapes

Louise E. Buck and Sara J. Scherr

This chapter guides development practitioners in fostering communication and learning to shape innovation systems for managing agriculture and natural resources across landscape systems and to jointly achieve sustainable production, ecosystem/biodiversity, and rural livelihood goals. This ecoagriculture landscape perspective accounts for the physical and biological features of an area together with the institutions and people who influence it. These features are dynamic and encompass diverse sustainable natural resource management practices. The landscape perspective merges ecosystem thinking with multi-stakeholder processes, sustainable production, and good governance of natural resources (International Agricultural Center 2006; Scherr and McNeely 2007). The landscape scale links grassroots, community-based initiatives in sustainable agriculture and integrated natural resource management with wider national or regional goals (Fry 2001).

In landscapes managed for sustainable production as well as conservation goals, producers and entrepreneurs are expected to deliver ecological and amenity benefits to society (ecosystem services) while also extracting value from the resources to secure their livelihoods. Interactions among market, public, and civic institutions generate incentives and capacities for producers and entrepreneurs to participate in the equitable allocation of capital resources: natural, human, social, financial, technical. The relationships and coordinating mechanisms of landscape-level governance systems are inherently diverse and subject to persistent change from internal and external sources (Flora 2001; Sayer and Campbell 2004). A robust and adaptive system of innovation is needed, therefore, to enable managers of landscape systems to coordinate and guide the diverse actors and complicated interactions required to realize the desired outcomes.

An innovation system comprises the actors—the organizations and people—who develop ideas and turn them into knowledge, information, products, or services. This actor-based concept of an innovation system emphasizes the interaction among people with a stake in the outcome of a management system and the learning required to bring about innovations that they consider important. Social learning is the name commonly given to this interactive process and practice (Engel 1997).

The innovation needed to support the management of biological and institutional complexity in multifunctional landscapes is rooted in social learning. The practice of social learning for natural resource management involves generating new insight and knowledge with diverse social actors. It also involves negotiating the development of knowledge processes and products that foster common understandings and lead to concerted action (Röling and Wagemakers 1998; Buck et al. 2001). The interactions comprise a system of innovation that may generate such knowledge products as studies and manuals, technologies and management practices, items for market, institutional coordination mechanisms, and policy change (Röling and Jiggins 1998).

The innovation systems perspective contrasts with the technology transfer approach. In the more conventional technology transfer framework, new ways of doing things are presumed to travel in a predictable, linear path from a research innovator to an extension educator or transfer agent and to a land user who adopts the new technology (Gillis and Southey 2005). The benefits to society are expected to derive from the cumulative effect of decisions by numerous individuals to adopt the new scientifically based practice. The principal task of the change agent in the technology transfer model is to deliver information and teach new skills to as many individuals as possible, the aim being to influence the cost-benefit metric that each person applies in deciding whether or not to adopt. As the name implies, the focus is on technical knowhow, which commonly is concerned with production and sometimes with marketing practices. Institutional and policy matters are considered to be outside the purview of the main actors (Röling 1992).

By contrast, the innovation systems concept emphasizes the coordination of people and institutions. It is concerned with "learning together for change" (Hagmann 1999; Sayer and Campbell 2004). The principal task of the innovation manager is to facilitate the coming together of stakeholders and specialists to analyze, to learn, to solve problems, and to create and capture new opportunities. The facilitator's role involves connecting people and requires that the facilitator be competent in working with groups (see chapter 5).

A landscape-based innovation system plays an important role when

- problem-solving and meaningful behavior change depend on group action because changes in individual behavior is relatively inconsequential, as in watershed management;
- concerted action is needed by farmers organizations, clubs, user groups, management associations, and the like;
- local ownership of solutions across different groups of actors is essential to ensure ongoing participation and cooperation;
- adaptation is important because management options are knowledge-intensive and solutions are unclear or unacceptable to some who are affected; and
- understanding of complex systems is needed to decide on strategic objectives, management strategies, and action.

This chapter aims to help rural development professionals become more fully aware of competencies they will need and tools they might use to facilitate the social learning that is anticipated to lead to innovation in landscape management. It discusses forms of social organization and strategies for stimulating the communication that can help to get ideas, knowledge, and information flowing across landscapes. The innovation system that these facilitators help to bring about will enable stakeholders to deal with the complex issues, inevitable conflicts, and changing opportunities they face in their efforts to manage natural resources in agricultural landscape mosaics for multiple outcomes.

The rest of this chapter introduces a framework for conceptualizing an innovation system for landscape management and highlights key roles of the facilitator. Competencies that facilitators will need to fulfill their roles in the innovation system then are identified. The chapter goes on to discuss approaches and tools that have proved effective or appear promising for facilitating the social learning needed to support adaptive collaborative management in complex landscapes. It concludes with a summary of the qualities that are desirable in a landscape innovation system and identifies issues to consider in realizing the potential of the system.

Conceptualizing Innovation in Adaptive Collaborative Management of Landscapes

Productive landscapes that are intended to deliver public benefits such as biodiversity and amenity values in addition to food, clean water, and other forms of livelihood support for the people who live there are inherently complex systems. What makes them adaptive systems is the capacity of the people and organizations within them to self-organize, to learn, and to change in response their social and biophysical environment (see chapter 1).

The innovation needed to help bring about adaptive, collaborative behavior in the management of agriculture and natural resources at landscape scale may be conceived as an actor-based system (Checkland and Scholes 2001). In this conception a landscape innovation system includes the stakeholders involved, the desirable practice to be implemented, the learning to support the practice, the facilitation to support the learning, the institutional support framework, and the conducive policy context (Buck 2003). Figure 1 illustrates these elements and relationships. The actors involved in the system are primary producers and users of agriculture and natural resource products and services. They also include regulators charged with ensuring that resources are not unduly damaged or overexploited. A variety of civic, public, and for-profit groups may have stakes in the resources.

The emergent property of a landscape innovation system is the capacity of actors in the landscape to learn to adapt to changing risks and opportunities. This innovative capacity is focused on the practice of managing complex adaptive agroecological systems at multiple scales in ways that improve the livelihoods of local stakeholders and sustain ecological performance. The central actor in the system is the facilitator, who fosters the communication and learning needed to coordinate interaction among the actors.

The desirable practice of adaptively managing landscapes through collaboration among stakeholders is meant to realize a balanced set of production, conservation, and livelihood outcomes. The social learning to support the practice engages groups in inductive learning by doing. These approaches draw on a suite of methods that motivate stakeholders to learn together and that contribute to practical problem solving. The learning is rooted in systems thinking to enable participants to engage creatively with the complex nature of the problems that are encountered.

The innovation system framework highlights the central role of facilitation in bringing about the communication and learning that drive the system. Among the most enduring effects of good facilitation are the development and strengthening of the institutional support that will sustain social learning over the long term. The strength and durability of the institutional support framework depend on the extent to which supportive policies are in place. Strong institutions, in turn, will help to bring about a more conducive policy context.

The facilitator, as manager of the communication and learning needed to create a supportive institutional environment for managing natural resources at landscape scale, also plays a key role in bringing the elements of the system into alignment. It is this alignment that enables the system to deliver the desired outcome: the adaptive collaborative management of the complex landscape. These critical roles of the facilitator warrant an exploration of the competencies that are needed to fulfill them.

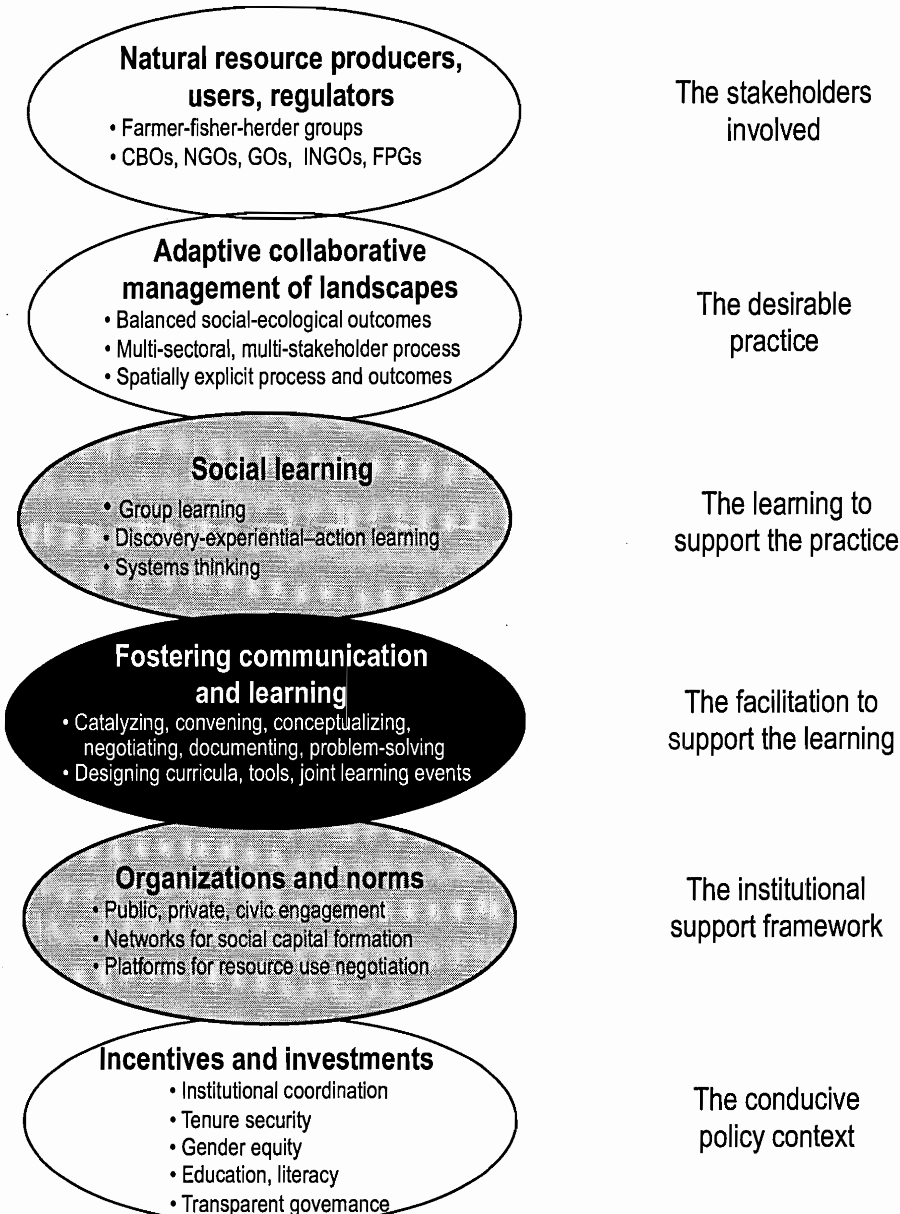

Figure 1. Elements of an innovation system for adaptive collaborative management of landscapes.

Competencies for Facilitating Landscape Innovation Systems

An effective facilitator believes in the creed, "You teach some by what you say, teach more by what you do, but most of all you teach most by who you are." While it is the learner's experience that is most important in the adult learning process, it is also important to be aware of the wealth of experience a good facilitator brings to the situation (Brookfield 1986; Kaner et al. 2007).

Good experiential facilitators are passionate about their work and are able to immerse participants totally in learning situations. They enable learners to gain new knowledge from their peers and their environment. These facilitators stimulate the imagination, keeping participants engaged in the learning experience.

A broad spectrum of competencies helps to prepare the facilitator for this role. Some are similar to those required of technology transfer specialists in the conventional innovation paradigm. These include the translation of research ideas and products into familiar terms and practical ideas, and sharing them with producers, entrepreneurs, consumers, and other stakeholders. The landscape innovation facilitator, however, also needs to be competent in creating strategic learning alliances (Lundy and Gottret 2005) and in managing participatory decision-making processes (Kaner et al. 2007).

Building Learning Alliances and Participatory Decision Processes

Behaving strategically is essential to success in landscape-wide innovation systems. Not all communication and learning activities are equally productive, and there are considerable transaction costs to consider in deciding how to invest in social interaction and learning. Who is it important to get together, why, when, where, and how? Strategic thinking in the first instance involves determining where in the landscape relevant knowledge lies and facilitating its application and adaptation across scales of land use (Lovell et al. 2002). It involves accessing external expertise and documenting local expertise for outsiders. It also involves building learning alliances with powerful external actors who will need to be part of the solution (see chapter 5).

Learning alliances are relationships among actors who have roles in various knowledge processes. In the technology transfer approach, boundaries between the actors and activities concerned with research, extension, and adoption were clear. The communication role lay principally with the extension worker and was comparatively straightforward. In the more dispersed configurations that are characteristic of complex adaptive systems, there are multiple loci of decision making at local, regional, or state levels and beyond, all of which can play out in the landscape. Boundaries between generators and users of knowledge are blurred. It is common for a variety of organizations to interact in particular theaters of innovation (Engle 1997) such as landscape management. Alliances between nongovernmental organizations (NGOs) and their networks are likely to be particularly effective in negotiating through the complexity (Wollenberg et al. 2005).

Capturing the potential for building learning alliances involves bridging gaps and differences. It may be useful for the facilitator to conjure the image of a bridge in fulfilling this core function in an innovation system. Members of communities that are bisected by a waterway know the bridge as a vital resource to be protected. The capacity to make connections is an essential competency for a landscape innovation leader. The section that follows on tools for landscape innovation facilitators suggests some concrete ways to build learning alliances.

The facilitator also helps to build teams of learners who engage in similar knowledge processes, such as management or research, and to help them be inclusive in establishing processes and rules for decision making. Good facilitation can transform interactions that occur in the participatory decision-making process into creative problem solving, leading to innovative outcomes and lasting commitments. A skillful facilitator employs a variety of tools in helping a team reach convergence of ideas and inclusive solutions that work for everyone who holds a stake in the outcome.

A key to becoming a good facilitator is to appreciate that facilitation is more than a set of techniques for conducting good meetings. It is also a style of leadership that helps to elicit and focus the intellectual capital and goodwill resident in members of a group. Facilitative leadership aids in building collaboration and helps a group to do its best thinking (Wondolleck and Yaffee 2000). The practice of facilitation can help a core landscape management team, for example, to delegate responsibilities to all team members, prevent any one person from controlling learning and decision-making processes, encourage all team members to participate during meetings, promote mutual understanding, and foster inclusive solutions.

In turn, the practice of facilitation will enable the core landscape management team to engage broader groups of stakeholders to do their best thinking and decision making. Most important, it will ensure that all perspectives are heard and incorporated into the alliance-building or team-building process.

Connecting People in Networks and Platforms

Networks and platforms are two useful metaphors for conceptualizing ways that people can organize to innovate in complex adaptive systems. These constructs for facilitating connections among people are explored below.

Networks

Networks are configurations of actors that make good use of people's social relationships. Good relationships among people can be used to address a wide variety of issues over extended periods. Networks tend to foster horizontal, peer-to-peer communication patterns and learning. It is useful to think about networks and networking as investments in social capital formation (Bourdieu 1991, as cited in Engle 1997). Building networks is a deliberate process of fostering relationships among people who are likely to have reason to form more or less durable patterns of interaction based on common interests such as professional pursuits, or security of place, family or community.

Social networks contribute to sustainable agriculture and natural resource management by facilitating information exchange, building awareness, and providing access to resources and services (Colchester et al. 2003). Networks of agricultural professionals and practitioners of various backgrounds and experience provide those involved with additional knowledge, perspectives, ideas, and techniques (Warner 2007). By bringing together strategies and experiences from different actors, networks raise awareness of possibilities and facilitate social learning that can be global in scope (Colchester et al. 2003, as cited in Wollenberg 2005). The Community Knowledge Service (CKS) for Biodiversity and Livelihoods is an example of an international NGO network organized to facilitate cross-regional knowledge sharing.

Community knowledge sharing about ecoagriculture

Community leadership is recognized as critical to the development and management of ecoagriculture landscapes that achieve sustainable agricultural production, ecosystem/ biodiversity conservation, and improved livelihoods. A key challenge is incompatibility among holistic management approaches employed by different communities. Most initiatives to provide knowledge and resources to local communities are driven by supply, not demand. The diverse information, materials, resources, and capacity development tools that exist rarely are designed by local community representatives or tailored to build on their existing expertise and capacity. Yet many local communities have developed relevant knowledge through the long-term, sustainable management of their natural resources that may be of value to another group in its own agroecosystem and around the world.

In a series of international community dialogue spaces since 2002, community-based experts and collaborators developed a set of recommendations to address these challenges. These highlight

- investment in processes that support community-led knowledge exchange and capacity development processes;
- access to more appropriate, timely information to support community practitioners;
- strengthened linkages and learning among networks of local communities worldwide experiencing similar challenges and opportunities; and
- strengthened representation of community expertise in policy decision-making processes locally, nationally, and internationally.

In 2006, a group of leaders from community-based organizations, their networks, and support organizations from research, public agencies, and the private sector took on these recommendations and established the Community Knowledge Service (CKS) for Biodiversity and Livelihoods. The goal of the CKS is to enable local communities to share their expertise more broadly and apply new knowledge to strengthen and scale up their work to enhance livelihoods and production while sustaining and conserving biodiversity. The Secretariat for the CKS is shared by the United Nations Environment Program's Equator Initiative and Ecoagriculture Partners.

Information about the CKS is at http://www.equatorinitiative.org/index.php.

Platforms

Platforms are forums for discussion, debate, learning, negotiation, and decision making about a particular issue, problem, or development strategy. Platforms emphasize vertical communication and learning patterns, bringing together diverse actors associated with a particular issue including policymakers, scientists, development educators/advisors, and local community leaders. Woodhill and Röling (1998) describe platforms as "customized mechanisms and processes for decision making on a scale appropriate to particular environmental issues, bioregions or communities." Platform formation takes into account that "what is good for one local community is not necessarily good for another or society at large" (Woodhill and Röling). The goal in creating platforms is to constructively engage stakeholder thought, skills, and organization toward innovation (Buck 1999). It requires building bridges between often divergent views and interests among stakeholders. Behavioral requirements for a platform include openness, accessibility, representation, transparency, and fairness.

Platforms can be constructed within networks. They can be organized around one or more of the following functions: expanding awareness, clarifying goals, negotiating resource use, and fostering joint decision making.

An effective platform commonly develops progressively from the first through the fourth level of activity. Platforms can be challenging to construct, requiring significant time, multiple cycles of interaction, and patience and determination on the part of the facilitator. Without them, however, meaningful progress in sustainable landscape management is unlikely to be achieved.

Cross visits

Farmer-to-farmer education or farm comparison groups are forms of peer learning that are appropriate to the horizontal learning model and have been found to be exceptionally effective in warming farmers up to sharing ideas. Practitioners may be interested already, for example, in how production is achieved at a higher volume or in using an alternative method, but they may be unable to imagine how to bring about the changes in their own operations. Encouraging comparison study groups among producers of similar products or among members of a cooperative can stimulate discussion and lead to farm visits.

Facilitators should carefully compose the groups of farmers. Members of cooperatives and producers who are less competitive or more sympathetic with each other are more likely to share information than producers who compete with one other. The landscape facilitator should help the groups create rules concerning who is welcome and what information can be exposed in visits, meetings, and in print (Leeuwis 2004, p. 219). Within farming communities, it can be instructive to link elders and children in dialogue about historical events and implications for future activity.

Facilitators need to ensure that no farm visited is meant to be the shining example or a poor example. This avoids competition for anyone's favor or insulting members, which could threaten trust and participation. Farmers probably will recognize challenges and innovations and engage each other. Neighboring farmers tend to learn readily from each other (Foster and Rosenzweig 1995). However, the learning does not necessarily spill over to the rest of the village. Facilitators can aim to bridge smaller learning networks, building outward in geographical and professional proximity.

The facilitator may encourage exchange of specific information leading up to or during farm visits. Crop yields or occurrence of disease can be highlighted, for example, to increase the community's collective memory and generate feedback on differences among farms and production methods. Before a group of peers, people may not report accurately about their success. Thus, it may be helpful to ask questions of individuals before a farm is visited by the group or to do a systematic collection of information on the farm or a standard survey (Leeuwis 2004). With permission of the farmer, it is useful to provide the group with the data collected about the farm in written format or to ask individuals similar questions during farm visits and comparison meetings, whichever seems more feasible.

Shaping Landscapes

Landscapes are shaped by the decisions of multiple stakeholders. Improving landscapes requires influencing the behavior of these stakeholders. This can rarely be achieved without social agreement on rules and regulations, and how they are enforced. To realize the goals of multifunctional landscapes we need to build social movements that have shared landscape values. Tapping into social networks that have the potential for landscape-wide influence is a good place to begin. Networks of growers, fishers, forest users, and others who depend on natural resources in the landscape can be influenced and strengthened through peer-based learning exchanges across landscapes.

Shaping landscapes is primarily a process of negotiation. It is increasingly common for managers and facilitators to think about "negotiating landscapes" as they find that their efforts to plan for landscape-level outcomes are not as fruitful as expected (Sayer and Buck 2008). Fostering perceptions of common interest among diverse stakeholders becomes a key task of the landscape innovation facilitator to ripen conditions for resource-use negotiation among them.

What kind of learning is needed to strengthen networks among locally based resource users and in fostering shared values about the landscape? How can communication and learning be organized to foster ongoing innovation at landscape scale? What are some social learning tools that may be useful in strengthening networks among locally based resource users and in fostering shared values about the landscape? What communication and learning activities can help to build constituencies and negotiate deals that will influence people's behavior to achieve a balance between development and conservation outcomes through their agricultural practices and other land-use choices? We explore these questions in the sections that follow.

Tools for Facilitating Innovation in Landscape Management

Landscapes are constantly evolving under a variety of internal and outside pressures, and the aspirations of people who influence landscapes also change. So there can be no fixed target or endpoint to guide landscape managers who seek to find a balance between agriculture development, natural resource conservation, and livelihood security outcomes. Facilitators need to encourage ongoing experimenting, listening, learning, and adapting—and these need to be shared processes in which everyone involved is learning and adapting (Sayer and Buck 2008).

How can the facilitator foster social learning at the scale of landscapes in ways that will encourage people in the landscape to continue learning together over time? We address this question first by identifying modes of learning that facilitators can draw on to create a perpetual learning environment. We follow with a proposition that developing shared frameworks for assessing change in landscapes can open up a plethora of tools and techniques that engage diverse stakeholders in innovation processes at multiple scales. We then present information about tools that we have found to be useful in evaluating change and fostering innovation in landscapes.

The methods and techniques that are described have been found to stimulate genuine participation throughout the process of assessing change in landscapes—from setting goals to identifying performance criteria and deciding what indicators to measure through the collection of data and interpretation of results. Their use has led to ownership and responsibility of the process by stakeholders involved. The use of the tools by capable facilitators has been demonstrated to enhance engagement, awareness, and understanding, and to foster the transparency and legitimacy that lead to trust (Sayer and Buck 2008). Use the tools to generate ideas about what might be done and knowledge about what can be done while establishing the trust that is the basis for negotiating agreements that form the foundation for behavioral change.

Inquiry-Based Learning

Discovery learning, experiential learning, and action learning belong to a family of methods that are rooted in a learning by doing approach that supports adaptive management. This suite of adult learning methods puts the learner or group of learners at the center of the experience and enables them to construct meaning from the reality that they experience. The methods tend to be motivational—they evoke in the learner an urge to learn more and to act on that learning to solve problems that are posed by the learning situation. They stand in contrast to conventional teaching methods that focus on the presentation of knowledge and skills, commonly known as instructional methods. Familiarity with tools and activities rooted in inquiry-based learning should be in the repertoire of every facilitator of landscape innovation systems.

In discovery learning, the learner draws on his or her own past experience and existing knowledge to discover facts, relationships, and new truths to be learned (Bruner 1961). The method is rooted in the belief that it is best for learners to discover facts and relationships for themselves. Students interact with the world by exploring and manipulating objects, wrestling with questions and controversies, or performing experiments. As a result, learners may be more likely to remember concepts and knowledge discovered on their own, in contrast to a transmission-oriented model. Models based on discovery learning include guided discovery, problem-based learning, simulation-based learning, case-based learning, and incidental learning among others. Farmer field schools are rooted in a discovery learning approach.

Farmer field schools

Established in 1989 in Central Java to develop integrated pest management (IPM) field training methods, farmer field schools (FFSs) have continued to be most popular in IPM because of the significant extent to which farmers' knowledge about pests can inform the discipline (Gallagher 1999). FFSs take place in the field over the course of a whole growing season. Groups of 25 farmers meet weekly for four-hour sessions during which small groups monitor observation plots and report findings to the others. With facilitation, farmers teach each other and solve problems collaboratively. Sessions focus on currently occurring problems, and follow-up activities typically occur after the initial season (Van de Fliert 2003). Having been adapted to work with various crops and diseases, FFSs have spread rapidly across Asia, Africa, and Latin America (Nelson et al. 2001).

FFSs were named from an Indonesian expression that means field school. The name was created to reflect the educational goals; the courses took place in the field, and the field conditions defined most of the curriculum. Real field problems were observed and analyzed, from the planting of the crop (rice) to the harvest. Group decisions on crop management could be evaluated at the end of the season by measuring the yield. A field was established by the participants with a research study to compare IPM methods and farmers' conventional methods. Pre- and post-tests were given, the same farmers and facilitators attended throughout the season, and graduation was based on attendance and learning performance. Certificates were awarded to farmers. Thus, the field school was an institution without walls that taught basic agroecology and management skills (Gallagher 1999).

Proponents point out that the discovery learning approach encourages active engagement; promotes motivation; promotes autonomy, responsibility, and independence; develops creativity and problem-solving skills; and enables a tailored learning experience.

Experiential learning is a method based on reflection on doing. It engages the learner at a personal level by addressing the needs and wants of the individual. Experiential learning requires qualities such as self-initiative and self-evaluation. For experiential learning to be fully effective, it should be employed through the entire learning cycle from goal setting to experimenting and observing, reviewing, and finally to action planning. This complete process allows one to learn new skills, new attitudes, or even entirely new ways of thinking.

Action learning is an educational process in which participants study their own actions and experience to improve performance (Revans 1982). This is done in conjunction with others in small groups called action-learning sets. It enables adult learners to reflect on and review the actions they have taken and the learning points arising. This then guides future action and improves performance. Action learning inquires into action taken and, as a result, knowledge emerges that should lead to the improvement of skills and performance. For example, CIALS are rooted in an action-learning approach.

CIALS

CIAL is an acronym in Spanish for Farmer Research Committees, which emerged in Latin America in the 1980s and later diffused to eastern and southern Africa. CIALs provide groups of farmers with a way to share the risks of trying an agricultural innovation where there is no reliable information or recommendation about its likely performance in their local circumstances. CIAL has become a farmer-run adaptive research service answerable to a client group such as a farmer association or community and electing a committee of farmers chosen for their interest in experimentation and willingness to serve (Ashby et al. 2000). The primary focus now for the majority of CIALs is on the use and conservation of genetic resources. Many have prioritized the rescue of local germplasm that has been disappearing from their local production systems, doing so through linkages with market-based enterprises (Ashby et al. 1995).

Using these inquiry-based experiential learning methods, facilitators can engage groups in self-directed learning and problem solving. Combining internal (local) and external (science-based) sources of knowledge and new experience can expose farmers to new realities and opportunities through farmer-led experimentation and farmer-to-farmer exchanges. Through an interactive process of experiential learning and concerted action, a thematic agenda can be designed to progress from field level to increasingly complex watershed- or landscape-level concerns.

Shared Frameworks for Assessing Change

Establishing a shared framework for measuring change can be a powerful tool in facilitating social learning and adaptation in landscapes. Experience suggests that fundamental to success is investing in the development of shared scenarios for the future of landscapes and in putting into place broad-based participatory approaches to measuring outcomes at the landscape scale. Measuring success first requires some shared understanding among stakeholders of what success looks like and how it differs from current conditions and trends (Sayer et al. 2008).

We acknowledge that creating a common vision for a landscape is a difficult challenge and that in reality all stakeholders never will share the same vision of a desirable future. It is nonetheless worthwhile for facilitators to catalyze and nurture the innovation processes that will enable the informed pursuit of the best set of production, conservation, and livelihood outcomes possible over time.

Before describing methods and tools to aid in this process, we offer some guidelines for facilitating the development of shared frameworks for assessing change in landscapes:

- Use an inclusive, transparent, and equitable facilitation process to negotiate desirable scenarios and effective measures of progress toward their achievement. This is likely to require efforts to level the playing field so that comparatively marginal stakeholders are empowered to interact effectively with more powerful actors (Edmunds and Wollenberg 2001).
- Begin the process of negotiating and assessing landscape performance on a small scale, and expand progressively as experience is gained and networks of collaborators grow.
- Focus on landscape functions. It is easier to reach agreement with multi-stakeholder groups if learning and negotiating focus on flows of goods and services.
- Strive to reach agreement among stakeholders on what an improved state of the landscape would look like, even though it may not be ideal from any one group's perspective.
- Strengthen networks gradually. Bringing together all possible contributors to a network may be ideal but generally is not practical. It is more pragmatic to strategically select representatives of different sources of innovation that are likely to lead to unique combinations of ideas and new applications of technologies.
- Combine indigenous and external sources of knowledge about landscape performance, drawing on not only locally based tools but also emerging technologies such geographic information systems and other models (e.g., watershed or crop growth) and software that allow for detection of patterns in landscape change.

Documenting Current Conditions

The initial set of activities in establishing a framework that multiple stakeholders can use to assess change in the landscape involves examining and documenting current conditions. Deciding what to document at the initial stage can be left to the people involved in the process based on what they consider to be important features and resource flows from the landscape. Useful approaches and tools for initiating the process of inventorying current conditions and reflecting on their status may be drawn from participatory rural appraisal and participatory land-use planning methods (see textbox below).

Participatory assessment and planning

Participatory rural appraisal (PRA) is an approach to tapping into local knowledge and enabling local people to make their own appraisals, analyses, and plans. It developed in the 1970s and 1980s to address problems of miscommunication between rural people and development workers. Animation exercises facilitate information sharing, analysis, and action among stakeholders. Originally developed for use in rural areas, PRA has been employed in diverse situations. For key tenets, tools, organization, and techniques, see the

World Bank Participation Sourcebook (1996). Among the most useful PRA tools for landscape scale innovation systems are three-dimensional maps and transects.

3D mapping involves creating physical three-dimensional relief maps that participants discuss and mark with points, lines, and polygons to delineate resources, boundaries, changes in landscape, and places of cultural or economic importance. The physical maps help local people communicate information about landscapes more conveniently than could be done in the field, for it is easier to bring many stakeholders together around a map than to tour the landscape together. Models also facilitate communication across language and cultural barriers, and maps provide records that can be transferred into a geographic information system for future reference and comparison. For further information, see the Integrated Approaches to Participatory Development Web site (http://www.iapad.org).

Transect maps or diagrams are cross sections of communities or landscapes generated by taking walks with people knowledgeable about the community or landscape. They show key features of different land-use zones in a region. Information about various types of physical and other aspects are recorded in rows of a table in columns headed by sketches of sections of the community or landscape. They are particularly useful when there is a range of land-use systems in an area, which often is the case when communities are on the coast, in hilly areas, on rivers or lakes, or in areas where soils vary over short distances (National Environment Secretariat et al. 1990). Joint transects involve team-based analysis and interpretation, which commonly needs to be negotiated. Transect maps allow participants to identify constraints and opportunities with reference to specific locations or particular ecosystems along a transect. Further information on transects and ways to prepare for transect walks is available from the Food and Agricultural Organization (http://www.fao.org/docrep/W8016E/w8016e01.htm).

Participatory land use planning engages local people in planning the use of their land and natural resources to reduce degradation and improve productivity. Various forms of participatory land use planning have been developed by communities around the world. A Web search will reveal a variety of them, including step-by-step guidelines for implementation.

Visioning Alternative Futures

Thinking about the future can help people imagine a time of better conditions and better cooperation. Visioning allows diverse actors to articulate an ideal future for a problem, identify common perceptions, and reconcile current differences. Actors may speak, write, draw, or act out visions, possibly in small groups of people of similar circumstances and status, to reduce intimidation by other stakeholders. Discussion and voting are useful for negotiating agreements among stakeholder groups (Evans et al. 2006b). Visioning builds networks through both the cooperation needed to come to agreements about plans and feelings of goodwill about future cooperation for mutual benefit. Visualization and scenario-building are two related sets of tools for visioning. The interpretation and sharing of maps can be a powerful communication tool in and across landscapes. The three methods are discussed below. Participatory map drawing can aid all three (see textbox below).

Participatory Map Drawing

Conservation and development organizations make presumptions about the sorts of landscape scale outcomes that stakeholders want. Biologists see protected forests, corridors, and riparian strips of vegetation. Villagers see arable land, land tenure rights, fuel and fruit trees, and water supplies. The International Union for Conservation of Nature's Livelihoods and Landscapes program has found that one of the most effective ways of engaging in a discussion about desired outcomes with local stakeholders is to allow them to draw maps expressing their understanding of the landscape and their wishes for the future (Boedhihartono and Barrow 2008).

Lessons learned from this process include the following:

- ***Listen, learn, and observe.*** Get to know the people first—spend time in the village, take part in ceremonies or sporting events, visit farmer fields, take an interest in the activities of the women and children.
- ***Let people express themselves.*** In general, give as few prompts as possible when asking people to draw landscapes. The process is often slow to start, but then debates flare up among participants to reveal obstacles and opportunities.
- ***Provide advice about scale.*** If people choose their own scale they will generally restrict themselves to their immediate surroundings—their own land, water, and fuel wood sources, for example. To get an idea of how they see and use the broader landscape, it is helpful to provide reference points.
- ***Encourage discussion.*** It may be more valuable than the drawings themselves. The process usually leads to debates; the extent to which innovation leaders take part in these debates and provide prompts depends on the specific objectives.
- ***Have different groups develop different maps.*** Sometimes a cross section of a community can draw a single map, but in many situations it is advisable to get men and women to work separately and to ask different ethnic or interest groups to draw separate maps.
- ***Compare landscape visions.*** Field workers can be used to collect maps from samples of stakeholders using standardized approaches so that the mapped elements can be scored and the scores of different stakeholders statistically analyzed. This technique has been used, for example, to demonstrate different appreciations of "forest" between local people and government officials.
- ***Archive and digitize the maps.*** When the drawings are complete, photograph them for the project archives. Photographs can also be manipulated using various software programs. This requires skill in the use of the software and some artistic talent.
- ***Display the product.*** The final agreed vision for the landscape can be laminated and given to the people to be displayed prominently and used to monitor progress.

More information is available at the following location:
http://cmsdata.iucn.org/downloads/a_avspecial_learning_from_landscapes.pdf.

Visualization

Visualization or visioning is a creative group activity. In it, stakeholders think about desired goals and then brainstorm strategies for reaching them. The approach encourages discussion about past and current changes in the landscape and how these may affect the future. The visioning and pathways approach developed by the Center for International Forestry Research (CIFOR) and partners applies. It is available in the *Guide for Participatory Tools for Forest Communities* (Evans et al. 2006a).

Visualization may be assisted by simulations, demonstrations, field trips, videos, and animations that help stakeholders and planners imagine alternative outcomes. An example applied at the scale of the farming system is an insect zoo where netted sections of crops can be observed over time to learn about the effects of particular insect species (Leeuwis 2004, p. 222). Creating diagrams of an integrated cropping and livestock system also aids joint visualization. Extrapolation, role playing, and mapping can be useful in predicting the feasibility of realizing alternative visions and can inspire stakeholders to act.

Scenarios

Similar to visualization, scenarios are "stories of what might be" (Wollenberg 2000). Unlike visualizations, scenarios do not need to represent what anyone thinks the future will be in reality. Scenarios provide individuals and groups the liberty to imagine what their ideal futures might be, and they help stakeholders identify factors that may affect the future of their landscape. They can be quantitative models or narratives conducted between participants that stimulate creative thinking and help stakeholders examine situations and plan from a new perspective. Scenarios can help change the way people think about relationships between current actions and long-term consequences. There are infinite ways of facilitating scenarios. Four fundamental styles of scenarios listed below are elaborated by Wollenberg et al. (2000):

- Vision scenarios use snapshot views to illustrate hopes for the future.
- Projection scenarios make predictions about a stakeholder-determined time.
- Pathway scenarios combine the above to plan strategies for a better course.
- Alternative scenarios broaden thinking by exploring a range of possible futures.

CIFOR's *Field Guide to the Future* (Evans et al. 2006b) is a useful resource for implementing scenarios. It identifies projections as the most appropriate for short-term thinking and visioning as the most useful for planning collaboration and reaching consensus on ways to move forward.

Maps

Maps can be used to portray important physical features of the landscape as well as relationships of communities to these features. They can be as simple as pen and paper diagrams that local people create or complex computer-based geographic information systems. The visualization power of maps and mapping help to focus attention, generate information and insight, frame debate, and plan future activity in open and transparent ways. Maps and mapping activity can enhance local community capacity to

- visualize the spatial interrelationships among conservation, livelihood, and food security strategies, thereby facilitating integrated landscape management planning;
- negotiate and defend land rights, resource entitlements, and land tenure;
- share innovations from one community to another; and
- illustrate the location of goals reached, challenges faced, and solutions offered through local and indigenous resource management.

These applications of mapping and uses of maps can be powerful aids in communicating with partners, advocating with policymakers, and showcasing to potential markets such as ecotourism and organic products. Resources on maps and mapping can be found at www.landscapemeasures.org.

Tracking Change

Tracking change in the landscape is important for tailoring the course of innovations, keeping stakeholders engaged, and justifying investments of financial and other resources. Monitoring performance against desirable outcomes for the landscape helps those involved appreciate in objective terms what has been achieved and enhances their understanding of it.

Engaging stakeholders in landscape monitoring plans involves creating a metric that can become a unifying language for the landscape to help foster joint learning and concerted action. Sayer et al. (2008) identify creative ways of engaging stakeholders in the development of performance criteria and deciding on appropriate indicators of the criteria and means of measuring them. In a multi-stakeholder workshop format they use scenario methods to help gain agreement on suitable performance criteria for the landscape. Indicators are selected through a participatory decision process (see textbox below). The multiday workshop continues by running a simple model that projects the values of the outcome indicators under different development scenarios that the model enables the facilitators to manipulate in a transparent fashion. The modeling activity is described further below.

Participatory monitoring

Since 2003, the World Wildlife Fund, IUCN, and CIFOR have collaborated to develop a shared monitoring system to track progress in landscapes where forest conservation and livelihood security are program goals. Multi-stakeholder groups are assembled and, using participatory drawing and flash cards, identify indicators that would tell the group if progress was being made towards a better landscape. About 30 indicators are selected to represent attributes that the participants agree would be easy to measure and represent a good approximation of progress or lack thereof. The group agrees on how each indicator could be scored on a 1-5 (Likert) scale.

A multi-stakeholder group is convened each year to reevaluate the indicators. The group always contains a majority of members from previous years, but as people move on, some renewal has occurred. Each year the discussions reveal a need to add or delete indicators and revise the scoring system. Although the changes from year to year are quite small, it is still possible to detect them. The debates during which the scores are awarded are an important event at which people take stock of progress. External organizations have adapted their programs to take account of the lessons learned from progress each year.

The organizations involved have drawn the following conclusions from the experience:

- Representative participation of all stakeholder groups has not been possible to achieve. The effort relies on NGOs and local government administrators to reflect the points of view of each stakeholder group.
- External convening and facilitation of the process is necessary.
- The scores obtained on the indicators are less important than the opinions that they represent.
- The people and organizations involved find that the annual dialogue on progress has opened up new thinking on what is needed to reconcile environmental and livelihood objectives for the area.

The full methodology is available in Sayer et al. (2007).

Additional ways of engaging stakeholders in identifying indicators of landscape performance and change are presented in an online clearinghouse, the Landscape Measures Resource Center (LMRC). See textbox below.

Landscape Measures Resource Center

The LMRC is an online clearinghouse of information and tools for stakeholders working in landscapes where farming, nature conservation, and livelihood security are being pursued. The LMRC helps people concerned with shaping landscapes to evaluate the flows of services and products coming from a landscape in terms that people who live and work there understand. The tools in the LMRC aid in choosing production, marketing, and land-use strategies that capture synergies and reduce tradeoffs among diverse goals for the landscape. The LMRC has been developed through a Landscape Measures Initiative coordinated by Ecoagriculture Partners and Cornell University.

The LMRC is organized around 20 criteria for ecoagriculture landscape performance that were identified through expert consultation. Indicators for each criterion are landscape specific and need to be determined by local stakeholders. The LMRC takes users through a process of deriving meaningful indicators for their landscapes. A landscape performance scorecard has proved to be an especially useful tool for deriving indicators and fostering discussion and debate about the status of the 20 criteria for landscape performance. Instructions for facilitating the use of the scorecard and examples of how it has been applied in particular landscapes are provided in LMRC (www.landscapemeasures.org).

Repeat landscape photography

Repeat photography is the process of selecting landscape features and key vantage points that will be monitored over time with the use of a digital camera and database to record how important characteristics change over time. Facilitators engage stakeholders in a deliberate process to decide which features are important to monitor. Photographs are meant to show both physical features and ways of life of the people. Ground-based photo-monitoring of ecological change can be conducted using rigorous sampling, data protocols, and archiving methodologies (Lassoie et al. 2006). Or the method can be adapted for use by local communities in participatory monitoring. Both approaches use global positioning system devices to record the longitude and latitude (spatial coordinates) of each photo point. The photographer captures images facing north, south, east, and west of each point to ensure that the same places are recorded each time the process is repeated. The photographer also records the direction of each photo as well as the date and time. The frequency of repeating the photograph depends on how rapidly change in the landscape seems to be occurring and resources available for the activity. It is important to archive the images in more than one location using a system that will endure staff changes, project completions, floods, and other disturbances. Details about the repeat photography method are available at www.landscapemeasures.org.

Assessing Landscape Performance

Assessing the performance of multifunctional landscapes involves analyzing indicators that stakeholders find meaningful to identify patterns of change. A variety of tools can aid the process. Some tools have multiple uses and have been identified above. Repeat landscape photography, for example, uses the collections of images gathered at different points in time to generate discussion among stakeholders about the nature, location, and pace of changes—both desirable and undesirable. Facilitators lead the discussion to consider how best to take advantage of positive changes and reduce the impacts of those considered undesirable.

Two robust tools for assessing change across multiple variables and scales in landscapes are simulation modeling and land-pattern analysis. Both tools require a blend of local knowledge and external science-based knowledge for effective implementation.

Simulation modeling

Modeling enables the linking of diverse issues and indicators so that synergies and tradeoffs can be better understood and discussed. CIFOR has developed a robust participatory modeling activity using the software package Stella for application in landscapes where conservation and livelihood goals need to be reconciled. Vensim and other user-friendly software packages can be purchased online. The models require quantitative data on land cover, benefit flows to households, and the nature and amount of environmental benefits. For the models to run effectively and to provide plausible simulations, the data need to be reasonably accurate. A task of the landscape facilitator therefore is to negotiate the engagement of researchers and modeling experts in the innovation process to help generate good data and build the models.

Examples of the Stella model in use can be accessed through CIFOR's Tools for Integrating Conservation and Development (http://www.cifor.cgiar.org/conservation/_ref/research/index.htm). Experience has taught that it is vital to fully document the sources and precision of data put into the model and to archive all versions of the models in locations and ways that make them accessible and understandable to future users. The research organizations involved should maintain backup copies of models, for civic employees change jobs and institutional memories can be short.

Further information about the method is in Sandker et al. (2007).

Land pattern analysis

Spatial analysis tools help to measure and assess how different phenomena vary across a landscape and thus to examine changing patterns. The use of spatial methods enables identification of the location and the distribution of environmental features, agricultural activity, and socioeconomic conditions. This information aids in understanding relationships and interactions among these variables. Such a relationship is commonly referred to as a landscape pattern.

The basic unit in landscape pattern analysis is land cover and land use. In the landscape measures approach, land cover-land use is an important integrative indicator because it provides information about many different aspects of the landscape. As the proportions of land uses change over time—natural habitat, cropland, rangeland, human settlement in rural and urban areas—so, too, will the potential to conserve wildlife, maintain ecosystem services, and produce agricultural goods. Facilitators of landscape innovation processes therefore can suggest and help arrange for land cover–land use to be applied to provide stakeholders with quantitative information about many of the 20 criteria for assessing ecoagriculture landscape performance (see last textbox above).

The LMRC provides guidance in how to analyze patterns of change in a landscape using spatial information about land cover–land use.

Summary and Ways Forward

Landscape approaches integrate the multiple scales of complex adaptive systems of agriculture, natural resources, and ecosystem services. Landscape-level outcomes are determined by the actions and interactions of many stakeholders. New ideas and competencies give people more choices for bringing about desired changes and adapting to changing circumstances.

The adaptive capacity of multifunctional landscapes depends on the effective facilitation of innovation processes that lead to new insights, technologies, livelihoods, market linkages, learning approaches, institutional coordinating mechanisms, and policies. The innovation systems needed to support integrative landscape management are rooted in social learning, which engages diverse actors in sharing perspectives, experience, and ways of learning and knowing. The organization of interaction around problems of common concern enables stakeholders to develop new understandings of complex situations and to respond. Communication is a key to the coordination of the landscape innovation system.

Leadership for landscape innovation systems may emerge from local communities, regional authorities, external research organizations, local or external NGOs, and/or other entities. From wherever it arises, effective leadership will depend on team-based approaches. Core competencies needed by facilitators of landscape innovation systems are convening power, capacity to guide without leading, familiarity with learning processes and tools that motivate ongoing action and interaction, group management and participatory decision-making skills, and a sense of humility and public service.

Shared frameworks for evaluating landscape change are promising forums for facilitating social learning and building innovation systems for landscape management. Stakeholders are encouraged to cooperate in identifying, measuring, and evaluating criteria and indicators of landscape performance based on scenarios for the future that they envision. Facilitators employ discovery, experiential and action learning to engage groups of stakeholders in tracking changes across the landscape over time. The density of learning networks and the quality of information that this landscape assessment activity generate gradually and iteratively improve the coherence of the landscape innovation system. New knowledge and understanding that emerge from the activity enhance transparency and objectivity in decision-making platforms and improve negotiation around resource use and management.

In working at a landscape scale we tacitly accept that there needs to be compromise between conservation and material development; that we cannot maximize biodiversity, for example, at the expense of local people. We also understand that compromise must be sought among different groups pursuing livelihoods in the landscape, for example between herders and farmers, commercial and subsistence farmers or fishers, community forest managers and herders, miners and producers of food and fiber, and so on. Similarly, agreement is needed between powerful and weak local actors and between the state and local communities to ensure adequate flows of products and services to maintain the health and resilience of the landscape system.

The landscape innovation system can reveal synergies between different land-use and livelihood options and lead to win-win outcomes. Engaging groups of stakeholders in assessing how their landscape is performing across a range of desired outcomes is a powerful tool rooted in inquiry-based learning. For example, landscape facilitators can help stakeholders discover how much development occurs and how much biodiversity is conserved under different scenarios of land use. Similarly, facilitators can guide them in measuring equity in the distribution of benefits across the landscape, encouraging negotiations that are widely perceived to be fair.

If measurement is a process that involves all stakeholders, then it also provides the framework through which compromise is achieved—it tells us how much development is traded off for how much conservation and where synergies between them can be found. If biodiversity values are very high, for example, and their conservation requires that local people forgo significant production and livelihood options, then progress is unlikely without rigorous regulations, environmental payments, or both. To develop regulations that people will live by or to develop sustainable payment schemes, it is important to measure progress in ways that are understandable and acceptable to all stakeholders concerned.

An innovation system is an intentional one constructed by the concerted action of the actors within it. This understanding provides the basis for addressing key issues that arise in contemplating the development and sustainability of a viable system. Perhaps foremost among such issues is the question of how the landscape facilitator is chosen, prepared for his or her roles, accepted by the people and organizations concerned, and supported over time. Ideally, significant responsibility would be vested in this near-mythical figure. The key to addressing the challenge of securing a viable facilitator is to begin where you are. Find a promising candidate; develop a shared vision for how the roles and responsibilities might evolve; and build activities and competencies to realize the vision as needs dictate and opportunities allow. Depending on the nature and scope of the landscape management objectives being pursued, farmer leaders, entrepreneurs, conservation authorities, district officers, NGO leaders, wildlife agency coordinators, watershed champions, and municipal planners may be viable candidates for facilitation roles.

For organizations to participate in an innovation system, the facilitator must be perceived as a reasonably neutral and unbiased actor. This could be achieved by seeking joint financial support for the position from several groups. Give thought, also, to building landscape facilitation teams comprising people with temperaments for collaboration who complement one another as to gender, experience, and expertise. Put into place incentives for them to work together. Much has been written about the qualities and skills of a good facilitator; become familiar with this work. Encourage candidate landscape facilitators to collaborate with other facilitators to accelerate their learning. At the national or regional level, consider incubating a landscape facilitators' guild to help raise the professional status of these important actors.

A less strategic question but an important one is how to make optimum use of spatial information in landscape innovation systems. A consequence of choosing to work at landscape scale is the importance of location in decision making about agriculture and natural resource management practices. Good spatial information is essential for dealing with the "where" questions in multistakeholder forums. Spatial literacy is notoriously uneven in landscapes, often making it difficult to share and compare experience. To improve spatial literacy in your landscape, find out where current competencies lie and build on them. Consider opportunities to coordinate the acquisition and use of spatial images and technologies, and to train a wide spectrum of people and organizations in the landscape to read maps and to make them.

A third issue is how to document information that your social learning activity generates and where to store it so that local communities and other stakeholders can access it. To help communities access and use information, consider storing it on small billboards and in school archives, journals, and posters that people will see. Support projects and organizations to understand the merits of using open-source platforms for storing and retrieving information about the landscape. Perceptions that important information is proprietary and inaccessible will erode the integrity of an innovation system.

How to sustain a landscape innovation process after projects end is a fourth compelling question. The answer is to consider this question when projects begin and to build this function into plans for sustaining project impacts. Keep in mind the value of learning alliances that cross project and institutional boundaries. Work to marshal support for facilitation from all quarters whenever opportunities for stretching out timelines are presented.

Other challenges will surface when people and organizations with interests in building a landscape innovation system come together around compelling issues in real settings. Address them by articulating and discussing them with all concerned. Build on previous knowledge and experience. Do not shy away from questioning old ideas and habitual ways of doing things and perhaps discarding them. Stay attuned to the reality that the rate at which a viable landscape innovation system emerges will depend in large part on the social capital (see chapter 5) of the landscape and how efforts are organized to nurture, expand, and sustain it.

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Part III

Case Studies across Landscape Systems: The Art

Chapter 9

Community-Based Wetland Comanagement in Bangladesh

Devona Bell Sherwood

To find new solutions to problems resulting from top-down approaches to resource conservation and sustainability, community-based comanagement recognizes that local communities should have direct control over the management, utilization, and benefits of local resources to value and use them in a sustainable manner. Developing successful community-based comanagement that enables entire wetland ecosystems while also ensuring productive fisheries and the needs of resource users is a major challenge. This case study brings together the importance of adaptive management, successful leadership, multidisciplinary approaches, and lessons drawn from more than eight years of experience to support community-based comanagement. The Management of Aquatic Ecosystems through Community Husbandry (MACH) project in Bangladesh used a holistic integrated approach and enabled the achievement of sustainable and environmentally sound development.

Background and Setting

Despite its small area (144,000 km^2), the inland freshwater fish production of Bangladesh ranks third in the world behind China and India. With extensive rivers and floodplain wetlands of the Ganges-Brahmaputra delta, more than half of the country can be termed as wetlands that are a source of food and income for about 70 million rural households.

In Bangladesh about 4 million hectares of land are inundated with water every year in the monsoon (rainy) season, and more than half the country is under water in an exceptional flood year (Ali 1997). In the dry season, the wetlands reduce in size to form a system of rivers, *beels* (depressions and lakes that hold water permanently or seasonally), and *baors* (oxbow lakes). The floodplains of Bangladesh are one of the world's most important wetlands and home to hundreds of species of plants, fish, birds, and other wildlife. The wetlands provide habitat for more than 260 fish species (Rahman 1989), hundreds of thousands of migrating birds (BirdLife International 2004), and are an important source of income and nutrition for millions of households in rural Bangladesh, especially the poor. As many as 80% of rural households catch fish for food or sale (Flood Action Plan 16 1995), and about 60% of animal protein consumption comes from fish (Bangladesh Bureau of Statistics 1999). See figure 1. In addition, poor and marginal households catch many small fish that are not included in official statistics or policies and use aquatic plants and animals for food or as feed for livestock.

Unfortunately, the wetland resources of Bangladesh are in decline due to overfishing and loss of habitat and connectivity. Wetlands in the past were thought to be wastelands in Bangladesh, and the goal of many government projects was to drain them and recover the land for agriculture production, albeit for one crop a year during the dry season. Even in areas that have not been converted to agriculture, wetland ecosystems have been threatened by other pressures:

- The government leases fishing rights in public water bodies, but short-term leases awarded to the highest bidders have encouraged maximum exploitation for short-term income at the expense of sustainable yields and conservation of resources for the next generation.
- Physical changes in watersheds and floodplains have drastically reduced the area and quality of wetlands. Flood embankments and water control structures have blocked fish migration routes and expanded cultivated areas; irrigation and expanding areas of winter rice cultivation have reduced the water available for aquatic life to survive in the six-month dry season; industrial development has caused locally severe pollution that kills breeding fish populations during the dry season; and loss of tree cover and poor hillside cultivation practices in watersheds have caused high rates of siltation in rivers and loss of floodplain wetlands.
- More and more people fish destructively using fine mesh nets to have high catch levels; loss of juvenile fish severely affects fish regeneration cycles.

> As the dry season progresses, water in even the deeper parts of wetlands becomes shallow, giving fish few places to shelter. Even worse, the water that remains is sometimes pumped out so that all remaining fish can be caught, also destroying other aquatic animals and plants. When this happens, parent fish stock is not available to breed in the next monsoon, resulting in declines of fish stocks. Similarly, populations of other aquatic flora and fauna, including waterfowl, are declining due to habitat degradation.

A recent review found that fish consumption fell by 11% between 1995 and 2000 and by 38% for the poorest households (Muir 2003). Having earlier grown at 5% annually, presumably through high fishing pressure, fisheries now appear to be in crisis, with catch numbers *falling* by 5% annually. Despite changes in national policies that call for an end to drainage of remaining wetlands (Ministry of Water Resources 1999), wetlands continue to be encroached with no sign of abatement. The decline in wetlands has resulted in more than 40% of freshwater fish species being classed as threatened with national extinction (IUCN Bangladesh 2000).

Since 1998, the United States Agency for International Development (USAID) has supported the MACH project, which translates as "fish" in Bengali. Before beginning the project, MACH staff built on lessons learned in previous fishery management projects. In the past, the central government used top-down approaches and tried to impose "best practices" that it thought would bring improved wetlands use and better livelihoods. These often failed because the local community was not involved in the planning, the projects were not locally feasible, and local communities were knowingly or unknowingly sabotaging the programs. In reaction to these failed programs, community-based management methods were tried but involved only the local poor fishing users in the planning and management of smaller wetland bodies of water. Some of these attempts have been successful, while many others have failed because the beneficiaries were dependent on unsustainable project activities, and there was no involvement of either local government or the local power structure. Consequently, after the project ended, the fisheries management system reverted to the previous situation, and elite in the area captured fish for their own benefit.

Figure 1. 80% of rural people in Bangladesh depend on wetlands for fish and other aquatic resources. But fish consumption fell by 11% in recent years, and about 40% of fish species are now threatened with national-level extinction.

Figure 2. Participatory planning was a vital first step in understanding problems and identifying possible solutions.

MACH benefited from these earlier examples by designing a project that integrates management activities into the fabric of the local community and the local government. First, MACH considered all users of the wetlands, including the poor rural fishers and the elite, who could strengthen the community-based organizations (CBOs) as champions for best management practices. Second, MACH engaged resource users and governmental bodies to share responsibilities and decisions.

Further, the MACH project was formulated to develop new approaches to floodplain and wetland resource conservation and management with the aim of ensuring food security, biodiversity, and sustainable productivity over an entire wetland ecosystem. The MACH project works in three large wetland systems covering about 25,000 hectares:

- Hail Haor, one of the large, deeply flooded basins in the northeast
- Turag-Bangshi floodplain, a typical river-floodplain system close to Dhaka in central Bangladesh
- Kangsha-Malijhee basin, a flash-flood prone system in Sherpur bordering the hills of India

Project Objectives and Approach

The dual goal of MACH is to improve wetland ecosystems and improve the livelihood of the resource users by demonstrating to communities, local government, and policy makers the viability of a community approach to natural resource management and habitat conservation in Bangladesh over an entire wetland. MACH adopted a multidisciplinary, multisectoral, participatory, and community-based management approach to address declining fisheries and environmental degradation of wetlands in Bangladesh. Rather than focus solely on fisheries management, MACH sought to increase the sustainable productivity of all floodplain resources, including fish, plants, and wildlife, over an entire floodplain ecosystem, recognizing that many wetland problems are actually watershed management issues. The relatively intensive MACH approach is most appropriate for larger wetland systems in need of restoration, preferably where there is the scope to protect sufficiently large areas to act as cores with restored wetland ecology that will enhance fish catches in the remaining areas.

> The internal design of MACH was well thought out and took account of previous experience in Bangladesh and elsewhere. In particular, the concept of comanagement built on past experience by avoiding a top-down, Department of Fisheries–led approach, on the one hand, or relying on user groups composed only of poor fishermen on the other. (External Project Evaluation Team, 2006)

Adaptive Management Approach

MACH is a process-based approach, not a blueprint project.

Adaptive management is based on a flexible framework that allows programs to change their behavior as situations change and merit different approaches and activities. Because adaptive management is a learning-by-doing approach, it involves some degree of uncertainty and trial and error. MACH took an adaptive approach to the design, implementation, and management of the program; MACH set activities as needs became apparent (e.g., communications strategy, tree planting, pineapple contour cultivation to reduce soil erosion, pollution abatement). Rather than being tied to long-term management plans, resource management plans are adapted, reviewed, and approved on an annual basis according to new information and the previous year's experiences. MACH's adaptive management allows for learning by doing and openly discussing and solving challenges and constraints. As Mohammad Ziaul Haque, the site coordinator from Sherpur, explained: "Mistakes are learning experiences and are not considered wrong."

MACH's participatory approach works with all local stakeholders to understand problems and identify possible solutions. Participatory planning in different forms took place in each site. Initially, participatory community planning workshops were used to identify problems and develop potential solutions (see figure 2). Then the project used a systematic approach termed participatory action plan development (PAPD). One-day workshops were held separately with randomly selected participants of each of four stakeholder types: fishers, farmers, landless, women. These workshops included a problem census and ranking, including a cause-effect analysis by the participants in each stakeholder group. Through a plenary with all groups, the main natural resource-related problems were identified. Next, the separate stakeholder groups agreed on and analyzed the feasibility of potential solutions, including their likely effects on stakeholders. Thus the main outcomes of the PAPD workshops were lists of ranked problems, then analyses of possible management and physical interventions to address these.

Resource user groups bring economic and social benefits to communities: "This support has opened up a new window of opportunities for the members, especially women. Traditionally, women are confined within the four walls of their houses. Now, with money in their hands, they have become economically empowered and more confident. This too has brought changes within their homes—children are getting more food, as well as more children in our locality are going to schools than before." (Toyobul Islam, imam and president of Kalapur FRUG, Sreemangal)

Comanagement is the foundation of the MACH approach, which has been promoted in the belief that a shift from top-down management to sharing decisions and responsibility among resource users and government at the resource level will improve the quality of decisions and local compliance with management plans. Therefore, the intention of comanagement is to empower fishers both as an end in itself and in the expectation of better management (Viswanathan et al. 2003). This requires major changes in institutions, organizations, and attitudes.

MACH has taken a three-pronged community-based comanagement approach:

- working with local communities and government to develop comanagement institutions
- building the capacity of those institutions to manage themselves and to restore and protect wetland ecosystems comprising water, fish, trees, and wildlife
- providing support to improve the livelihoods of poor people dependent on these wetlands

Much emphasis has been placed on developing local institutions and supporting communities and local government in the planning and sustainable use of natural aquatic resources. MACH helped develop two interacting organizations: community-based groups consisting of the users whose responsibility is to manage specific wetland areas; and local government committees that include officials, elected representatives, and CBO leaders to coordinate and guide the process.

Local community organizations for resource management were formed over several years through steps involving community, project, and local government. Community organizations were developed for resource management (resource management organizations [RMOs]) and for livelihood development (resource user groups [RUGs]). These groups were then linked to the government through local committees. Emphasis has been placed on making these institutions self-reliant and self-sustaining, providing funds that they could manage, and establishing transparent procedures that hold those making decisions more widely accountable.

RMOs are voluntary bodies that are registered with the government and have adopted best management practices in the river, *beel,* and floodplain units of the wetlands surrounding their villages. They also develop and enforce norms, practices, and interventions that will sustain wetland productivity. Their formation followed a lengthy participatory planning process involving all types of local wetland users and stakeholders. Special emphasis was placed on the poor who are most dependent on wetlands, ensuring that they made up a majority of the members and could have the strongest possible voice in these organizations.

RUGs are membership bodies limited to poor people who depend on the wetlands. The project has helped them with access to credit and training to increase their incomes while reducing fishing involvement. This has reduced their pressure on wetland resources and at the same time enhanced their incomes. To increase their sustainability, RUGs have been united into federations of resource user groups (FRUGs). To ensure that the poor hold a majority in the general body of the RMOs, 60% of the RMOs are people from RUGs.

> Flexibility was vital: The approach to developing community organizations was different in each site according to social, environmental, and administrative factors.

To link the local government with the community-based RMOs and FRUGs, MACH established local government committees (LGCs). The LGCs bring together the leaders of the RMOs and FRUGs with the local elected Union Parishad chairmen and local representatives of the *upazila* (subdistrict) government that belong to different governmental offices, such as the Department of Fisheries, Ministry of Land, or Department of Livestock. (Note the Union Parishads or local councils are a vital tier of government. The respective chairmen act as advisors to the RMOs, and they have invited the RMOs to attend their council meetings to represent wetland interests in their areas. The Union Parishads have played an important role in resolving local conflicts and in endorsing new wetland management practices.) Together this committee coordinates activities, resolves problems, oversees improved wetland management, and makes comanagement decisions. Local government committees are permanently mandated through government order and have been formed in each *upazila*, called *upazila* fisheries committees.

Unlike previous projects that ignored existing institutions, the MACH approach has formally recognized and linked community organizations and the local government. This is a way to overcome the limitations of each and build on the strengths of the other.

Results Achieved

MACH has addressed sustainable wetland resource management at the landscape level rather than just in individual rivers and lakes, working in three wetlands covering about 25,000 hectares. More than 110 villages inhabited by more than 184,000 people are directly involved in the project, while the total benefited population may exceed half a million. MACH has done this by

- mobilizing communities into registered organizations that are empowered to conserve resources,
- helping communities make resource management maps and plans,
- undertaking habitat restoration,
- adopting conservation measures for sustainable harvesting, and

- introducing alternative sources of income to reduce pressure on wetlands and improve livelihoods.

The management actions implemented through this arrangement have already resulted in dramatic changes for the better in the environment and in people's lives.

> Enormous social change really has empowered men and women; communities successfully link with nature and manage their resources, and have viable livelihood options that are compatible with sustainable wetland resource management. (Azharul Mazumder, Environment Unit Leader, USAID Bangladesh)

Wetland Habitat Rehabilitation

RMOs identified locations within their respective wetland management areas that were affected by siltation to the point that they dried out and could not support fish in the dry season. Re-excavating canals to improve flows and re-excavating *beels* (lakes or dry-season water) to increase the depth to maintain water year round restored the wetland habitats. Accomplishments include the following:

- 46 hectares of *beels* were excavated, and 30 kilometers of canals were expanded to retain dry-season water
- 56 sanctuaries in 173 hectares of area were established
- 605,000 trees were planted

These actions resulted in increased fish catches of two to five times over 1999 baselines of 58–171 kg per hectare, reaching 316–388 kg per hectare across the entire wetland system of nearly 25,000 hectares in 2004–2005. Increases in fish consumption of 45% over the same period benefited the landless as much as large landowners. The improved habitat is also crucial for fish to survive the dry months and facilitates breeding and regeneration of aquatic plants and animals. RMOs and local government formed project implementation committees to oversee contractors and in some cases employ the laborers required for earthworks. Though the total area excavated is modest compared with the total dry-season water area, these deeper fish refuges and canal connections directly serve and link with the majority of the dry-season water area in the three sites.

Wetland Sanctuaries

The single most important resource management intervention has been establishing 56 wetland sanctuaries at the three sites covering 173 hectares (427 acres) of wetlands (see figure 3). These are areas that range from less than 1 hectare to more than 100 hectares in size and retain water through the year; and where the community has banned all fishing to allow fish to breed and repopulate the wider floodplain during the monsoon. While the sanctuaries are primarily for protecting fish with the aim of restoring and enhancing yields from the rest of the wetland system outside the sanctuaries, they also benefit aquatic life in general, including water birds and plants. This is particularly the case in the large permanent sanctuary established in Hail Haor that within two years has attracted up to 7,000 wintering water birds where there were previously fewer than 100.

Most sanctuaries have been established by the RMOs within water bodies where they hold fishing rights for 5 to 10 years and are part of the local management plans designed to restore fish catches. A few sanctuaries have been declared directly by the Ministry of Land following propos-

Figure 3. The Ministry of Land has designated Baikka Beel, a 100-hectare area of the Hail Haor wetland in Bangladesh, as a permanent waterfowl sanctuary.

Figure 4. Resource management organizations along with fishers have banned fishing in the early monsoon when fish breed, allowing fish to repopulate the floodplain.

als made by the projects, which incorporate larger areas of national importance for overall wetland habitat protection. These have been removed from the fisheries leasing system permanently.

> The MACH project has been instrumental in restoring the diverse and productive Hail Haor wetland so it is now able to support the needs of local populations for fishing and a collection of aquatic plants. The fish that are protected year round here repopulate the haor in the wet season, helping to increase fish catches. Bird populations that dwindled in the 1980s are recovering in both numbers and species diversity. By early 2007, 111 bird species, including 55 water bird species, had been recorded in the sanctuary, including four that are globally threatened. The future of these birds looks secure. Resource management organizations with local government backing have successfully foiled attempts by local elites to shoot ducks in the sanctuary.

Closed Season and Fishing Norms

Sanctuaries alone cannot restore wetland productivity. Developing local institutions—sets of rules and norms—that are widely accepted in the local communities and result in sustainable fish catches has been important. Each RMO along with the fishers has banned fishing for two to three months in the early monsoon when fish breed, allowing fish protected in the sanctuaries to safely repopulate the floodplain. Fishing restrictions are the other key set of rules. The RMOs have banned complete dewatering of those water bodies under their direct management, which means that even outside the sanctuaries more fish can survive over the winter. RMOs advocate this practice to leaseholders in other water bodies within the sites. They have banned using fixed gears, particularly barriers such as *pati bundhs*—mats made of split bamboo—that close off channels, so that fish can once again move between habitats. Similarly, they have worked to stop use of other harmful fishing practices, including use of fine mesh seine nets, fishing that targeted shoals of juvenile catfish, fishing festivals where many people from outside the area were attracted to fish out a wetland, and current *jals*—monofilament nylon gill nets. The RMOs are also trying to restrict extraction of water for agriculture in the dry season to maintain sufficient water in the *beels*.

> Wetland productivity and biodiversity have been substantially enhanced, and a good start has been made on extending project innovations to other areas, most notably through the Inland Capture Fisheries Strategy of the Department of Fisheries." (External Project Evaluation Team, 2006)

Reintroduction of Locally Lost or Threatened Fish Species

Restored wetland habitats and sustainable fishing practice allowed some fish species to recover, but others needed a helping hand. MACH supported the RMOs in restocking about 1.19 million fish (mostly juveniles) of 15 native species. Before restocking, the fishers reported them as having been present in the sites, but project monitoring showed they had declined to negligible catches and were threatened with local extinction. See figure 4.

Increase in Fish Catches, Consumption, and Biodiversity

From the mid-1990s to 2000, national annual fish consumption declined by 14% to about 11 kg per person. By 2004, annual fish consumption was 17.5 kg per person, on average 52% higher than before MACH started. Project data shows that catch per hectare has increased by about 140% between 1999 and 2004 (see figure 5):

- Fish yields increased by two to five times over baseline yields of 58–171 kg per hectare, to 315–390 kg per hectare in 2004–2005.
- Eight to 10 threatened fish species were reestablished.
- Several locally rare fish species have been restored.

Before MACH Hail Haor, fishing rights in leased *jalmohals* were sold to investors and middlemen. Now, Dumuria RMO has awarded fishing rights directly within its area to 35 members of the fishing community.

Tree Planting and Improved Watershed Management

Tree planting for habitat restoration and improvement has been one of the MACH project's key interventions. Communities felt it was important to plant native trees to mitigate the past trend for loss of tree cover, including swamp forest in the wetlands and riparian areas. The habitat restoration program envisioned mitigation of the degraded environment and microclimate to benefit people and wildlife, and for soil and water conservation in the watersheds of the project wetlands. It also aimed to increase the national tree cover and generate financial returns for the country in general and for poor people in particular. Contour cultivation of pineapples can more than double profits and reduce soil erosion, which severely affects wetlands such as Hail Haor. Activities included contour planting of pineapple in the hills surrounding one site where siltation was raising the wetland bed by 5 cm annually. This has reduced runoff and erosion rates and at the same time permitted denser planting and improved soil fertility, which increased farmer incomes. A total of 605,365 saplings of 56 species (48 native and eight domesticated exotic) had been planted under the program by the end of 2005, 21% to restore swamp forest. Swamp forest will be preserved as a long-term investment in ecological restoration.

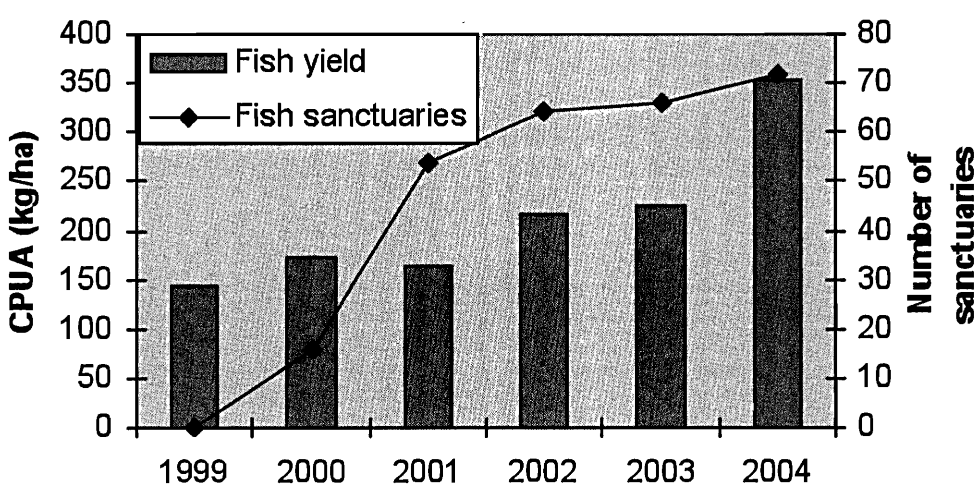

Figure 5. Fish yield and fish sanctuaries in Management of Aquatic Ecosystems through Community Husbandry sites.

Industrial Pollution Mitigation

One of the biggest industrial clusters in Bangladesh is in Kaliakoir, north of Dhaka, where there are many textile and dyeing factories. During participatory planning processes, the communities with which MACH has been working in the Turag River floodplains reported that these industries use the surrounding wetlands, particularly Mokesh Beel and Ratanpur Khal that flows through the beel, as a disposal ground for untreated waste. They reported that this resulted in poor catches of bad-smelling fish. Regular monitoring results indicated that water in the *beel* and *khal* has biological and chemical oxygen demands respectively more than double and more than four times higher than the national acceptable standard. They also have seasonally high pH levels and sulfide concentrations averaging 50% above the national acceptable standard, peaking at five times that level. The project has advised industries on setting up treatment plants. A new one has been established, and four more are under construction. In spite of efforts to mitigate industrial pollution, the problem is worsening due to the increased number of textile-related factories in the area, quadrupling from 20 to 80 in late 2005. Thus, there is an immediate need to increase the rate of implementation of proposed mitigation options if there is to be any reduction in pollution. Without this, the efforts of the communities and MACH that have seen fish yields in the greater Turag-Bangshi area restored from about 60 kg per hectare to about 300 kg per hectare by 2004 are likely to be irreplaceably lost.

Community Organization and Resource Management Organizations

The key building block has been establishing 16 RMOs, each representing the whole user community of the management area. The RMOs are registered with the government, with approved constitutions and annual budgets. They have secured access for 10 years to certain water bodies where their elected executive councils, in consultation with the wider community, make management plans and set rules for wetland use. About 60% of the resource user members are poor, receiving training and credit through separate organizations. Of 1,396 members, 53% come from RUGs, 21% are women, and 42% are fishers. To improve transparency and broaden participation in the RMOs, subcommittees have been formed in most RMOs, including audit, sanctuary management, and plantation subcommittees.

RMOs have adopted wise resource management measures such as creating fish sanctuaries, undertaking habitat restoration activities, and banning damaging practices like dewatering in dry season. Further, RMOs have followed good organization practices, like making and revising resource management maps and plans for their areas, following democratic principles by electing their office bearers, adhering to transparency and accountability through open meetings and audits, and ensuring that the poor get fair access to wetland resources.

Alternative and Enhanced Livelihoods for the Poor Who Use Wetlands

Realizing that a reduction in fishing is likely to be a critical part of reviving the wetland fisheries, MACH has identified and developed alternative income-generating opportunities for existing and potential new fishers and others directly dependent on wetland resources, especially poorer users. More than 5,500 of the poorest wetland-resource users have joined savings and credit RUGs. These consist of 15 to 30 men or women from poor households, generally those owning 0.2 hectare of land or less, laboring for part of the year, having a low education level, not belonging to any other nongovernmental organization (NGO) groups, and making use of the wetlands covered by resource management activities. These households were mostly from villages near the wetlands and generally were involved in fishing or collecting other aquatic resources for income or food.

Following normal NGO practice for credit and savings programs in Bangladesh, only one person per household could join a RUG. Membership is based on making regular personal savings in weekly group meetings. On the basis of savings, the members could propose income-generating activities for receiving loans from the project. The recipient members were also trained in skills they could apply when they used their loans to establish businesses. Typical enterprises include raising poultry and livestock, operating small shops, and individual skilled work such as tailoring or operating a tree nursery (see figure 6). The loan repayment rate averaged 89%. Initially, loan recipients faced some problems due to lack of skills. Training on specific trade helped them to overcome the difficulties. Sometimes natural disaster slowed their success. Borrowers have reduced their fishing by 20% to 30% on average.

Reduction in fishing pressure, along with restoration and reintroduction measures, allowed for the wetlands fish stocks to be restored. Fishers in the MACH project sites gained $4.7 million in 2004 from higher catches associated with resource management improvements, compared with baseline data from 1999. In addition, by 2005, those participating in training and credit activities earned an extra $800,000, mainly from new enterprises supported by the project, compared with their pre-participation incomes (daily incomes rose from about $1 per day in 1999 to $1.34 in 2005). This primarily affected the poor who are most dependent on aquatic resources. Over 85%

Figure 6. Raising poultry has been one of the most profitable enterprises for resource user group members.

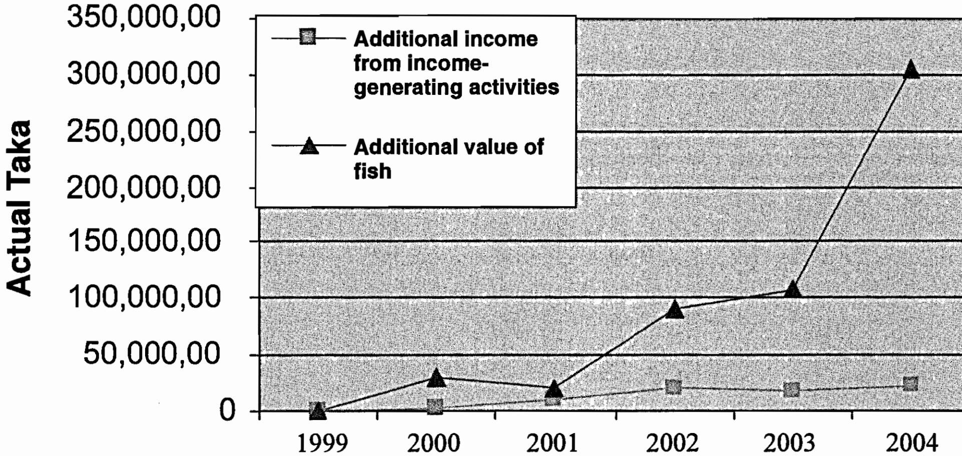

Figure 7. Increases in income in Management of Aquatic Ecosystems through Community Husbandry sites.

of households in the project areas are involved in fishing, and all of those supported with training and credit were low-income households; therefore, the poor have benefited the most from the project. By April 2005, 5,334 households had members belonging to the RUGs. Of the RUG members about 68% are men, and about 75% owning less than 0.2 hectare of land. By 2005, almost 4,000 families had increased annual income by 65% due to increased fish catches and new income-generating enterprises. See figures 7 and 8.

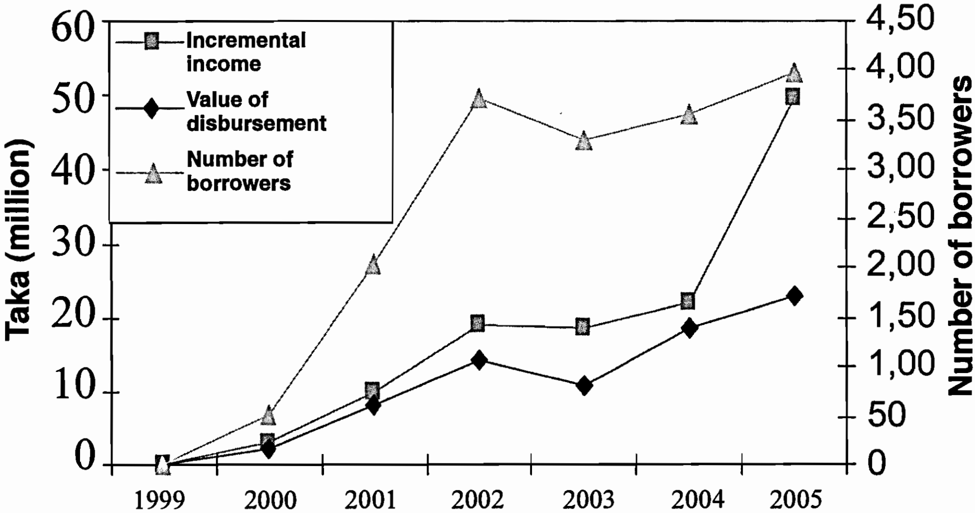

Figure 8. Micro-credit support.

Enhanced Governance and Precedents

The leaders of these formal CBOs now sit with local government officials and councilors in committees that oversee wetland management. These comanagement committees are in the process of being endowed with funds that will generate an annual return to be used for operations and small-scale wetland restoration. Similarly, the savings and credit groups are now federated into 13 legal entities—registered membership-based social welfare organizations with elected leaders who also sit on the comanagement committees. By 2006, eight federations employed former NGO staff to help their operations and received revolving funds totaling about $220,000 to sustain their programs after direct USAID support ends. Moreover, in a landmark policy decision, the government has designated eight "national" sanctuaries permanently set aside to protect wetland biodiversity and managed by the community organizations. The government no longer auctions off fishing rights in these sanctuaries. The Department of Fisheries, through its national Inland Capture Fisheries Strategy, is in the process of adopting these institutions and the sanctuary approach on a larger scale as part of a policy shift toward community-based comanagement.

Lessons Learned

MACH has learned key lessons that can offer guidance to others trying to replicate the model.

Comanagement, Networking, and Governance

Comanagement involves sharing responsibilities among key stakeholders and commonly involves delegating a greater share of management responsibilities from government to empower local communities. Local government plays a powerful role in all development work at the grassroots level. However, projects often do not strengthen linkages with local government. MACH made linkages among the RMOs, the Union Parishads, and the officers of line agencies who form the *upazila* administration to ensure synergies and to formalize the status of the RMOs. This included having RMO management plans endorsed by Department of Fisheries officers, encouraging relevant Union Parishads to invite RMOs to observe and report in their meetings, and encouraging knowledge sharing between RMOs. Building trust, understanding, and an effective working relationship among local government committees and community resource management organizations takes time.

Based on the experience of MACH, it is unlikely that government agencies alone will be able to facilitate the type of CBOs that seem to be effective in improving wetland management. Local government involvement is essential, and establishing *upazila*-level committees, as MACH has done, will be vital, but RMOs or their equivalent (CBOs) need support to develop before they can sit on such committees or take on resource management responsibilities; this initial support generally will need to come from NGOs skilled in social mobilization and with support from government or donor funds.

> Communities have complex structures. Communitywide organizations can benefit from the influence of local elites as champions of conservation and the poor, but their motivation needs to be understood. They may take control of resources to the detriment of the poor unless time is taken to establish practices for good governance that limit elite dominance in RMOs and in expropriating the resource.

Building Community Resource Management Institutions

Evidence showed that establishing sanctuaries for conservation of brood stock during the dry season created the basis for long-term success of fisheries management in an area by ensuring reproduction of fish and other aquatic life. However, the decision to develop sanctuaries must be made by CBOs to achieve sustainability. The development of CBOs for wetland management has empowered and recognized local bodies to take responsibility for decisions and actions to restore and sustain wetland uses and productivity. The key building block to the MACH approach for sustainable wetland management was establishing RMOs. The RMOs have worked to protect water bodies and to address problems identified by the communities; this has involved setting rules and limits on use, and restoring wetland habitat, including tree planting.

Empowering and Enabling the Poor

Wetlands harbor multiple resources, and multiple stakeholder groups use these resources for income and for subsistence. The MACH approach involves the whole community at all levels neighboring the wetlands, including rich and poor, influential and subordinate community members. In some cases, local elites dominated the process and took a leadership role. It sometimes became difficult to ensure that the poor were heard and to ensure their rights to access and decision making. Without a concerted effort to build institutions that empower the poor, the majority of people (who are poor) do not have bargaining power and do not understand their rights. MACH addressed this through general awareness-raising events such as popular theater, ensuring participation in Union Parishad and local government committees, and by helping the poor to form RUGs that have capacity-building programs and include their representatives in the RMOs.

Also, resource users who are poor needed to be a majority in RMOs to ensure that decisions did not favor the wealthy: By 2005, about 60% of the resource-user members were poor. Special efforts to develop the capacity of poorer participants were needed so they could hold key positions in RMOs. The poor must be aware of their rights and need leadership training to play a role in local institutions. Further, constitutional arrangements (secret ballots, eligibility for different posts, roles of leaders, term limits) governing the operation of the RMOs promote pro-poor participation. Alternative income-generating activities allowed poor fishers to increase income during times when fishing is closed. MACH reduced fishing pressure by almost 2,500 person-hours per day of fishing time to allow the resource to recover.

Participation of Women

Despite setting quotas for women's participation in RMOs, it is difficult to make the organizations accessible and relevant to women and to overcome cultural biases. Women do not fish and are not considered to have firsthand experience in managing the resource, yet their livelihood is affected by it. However, MACH set and successfully achieved women's participation through decisions made by each of the organizations. By the end of 2005, seven RMOs had general bodies in which at least 25% of members were women. About two-thirds of the women in RMOs were also RUG members. Women accounted for 36% of RUG members and 35% of the executive committee.

USAID's 2006 External Project Evaluation Team stated, "An outstanding achievement of the project has been the empowerment of women. The project has operated in conservative rural areas, where women have traditionally had few rights and little power over their lives or livelihoods. By insisting that a proportion of positions in RMOs and FRUGs be filled by women, and by setting up RUGs for women, the project has forced the pace of social change. At several sites, the team encountered women members who were willing to speak forthrightly about their concerns and their role in the project—even interrupting the men."

> Women are now earning income so are more valued in the home, as evidenced by two quotes from women in the Pakuria FRUG (2006):
>
> - "My husband was an angry man, but now because of my earnings he is more calm, quiet and our home life is better."
> - "I was poor but now earn money. Because of this, my husband allows me to leave the home and move around the community, when before I was not allowed. Now we make decisions jointly."

Best Practices to Ensure Good Governance

PAPD workshops were facilitated by the project to identify problems and develop a consensus on potential solutions involving all groups of the communities, including the poor. These should be repeated as local management evolves: The initial PAPDs may not have involved all the appropriate villages and areas covered by subsequent RMOs. Based on a general consensus and overall strategy, developing and updating detailed resource management plans must be an ongoing process, not a one-time event. Plans should be reviewed, activities evaluated and communicated to the wider community annually in line with the wetland resource leasing (Bangla) year. Further, leaders of the organizations need to be reminded to listen to resource users and inform them of major decisions, and resource users should understand what they should expect from their leaders.

Sustainability through Institutional Capacity Building

Project designs from the outset should place a major emphasis on institutional sustainability. The formal recognition of RMOs as independent organizations is essential for their survival. Sound financial management is a requirement for sustainability, and RMO representatives need to be trained in record keeping and financial management. The RMO needs to be able to prepare annual budgets that fit its resource management plans, raise funds in fair ways (such as fishing fees), and account for this to the members and wider community of users (fishers). Independent audit subcommittees can further strengthen transparency and good financial management practices. Thus projects should regularly evaluate the strength of community institutions and provide training to address the gaps. RMOs need to be trained on how they can interact effectively with local leaders and the local government.

Sustainability after Donor Funds End

A small fund used after the project ends to support the operation of founded committees and programs to improve the resource base can enhance sustainability. Generally, without continued resources after a project ends, the activities and institutions gradually weaken or disappear, and the benefits dwindle. After consultations with community groups and all levels of government from local to national, MACH established an endowment fund under government control, but with the comanagement committees responsible for decisions on the use of the annual interest income. In this arrangement, the principal can never be touched, but the accrued interest is used to carry on comanagement functions including meetings and especially for small grants to RMOs for restoring wetland habitats. MACH also established a revolving loan fund worth roughly $570,000 that goes to the FRUG to provide credit for alternative income-generating activities to keep continued support for small enterprises that relieve pressure on the fisheries. The FRUGs are responsible for managing the savings of their members, providing credit to them, and implementing income-generating activities by their own staff with oversight provided by comanagement committees. Interest earned from the revolving loan fund is to be used for financing employees, meetings, and other activities.

Effectiveness in Resource Management

To ensure sustainable management of wetland resources, RMOs adopted regulations covering their wetland areas. Over time, each RMO has agreed on a set of rules or norms regarding fishing within the areas it directly controls or influences. All 16 RMOs adopted four or more management rules that delineate fishing times, means of harvesting, and plans for physical interventions. Through these rules, exploitation of fishery resources is limited and the resource replenished.

Success Factors

Donor projects face a multitude of challenges in design and implementation. The following are key success factors learned from the MACH program.

Vision

MACH took on wetland landscape management encompassing the entire watershed in a holistic manner by incorporating a multifaceted, multidisciplinary, multisectoral approach. This includes participatory natural resource management for sustainable utilization and biodiversity conservation, income generation, alternative income generating activities, local capacity building, and institutional strengthening working with all the stakeholders, from local community fishermen, businesses, the poor and elite, local government, and district government to national-level ministries.

Participatory Methodology

Participatory methodology was utilized to address local issues, needs, and desires. MACH first went to communities developing the program through participatory planning with local communities identifying problems and solutions. MACH included the elite as well as the poor, thus avoiding elite capture. The participatory approach enables transparency and accountability.

Adaptive Design, Implementation, and Management

Adaptive design, implementation, and management set activities as the needs became apparent. For example, wetland resource management plans are adapted, reviewed, and approved annually according to new information and the previous year's experiences. Other examples include designing and implementing a public communications and awareness strategy, tree planting to reduce erosion, pineapple contour cultivation to reduce soil erosion, and adding a pollution abatement component to the project. Adaptive management allows for learning by doing and openly discussing and solving challenges and constraints.

Great Leadership and Management

Great leadership and management are important, from upper management to local site managers. Upper management continually energizes local staff to achieve outstanding results. MACH's project manager has vast local knowledge of the conditions and constraints facing the program and deep cultural insight and understanding stemming from 25 years of experience in Bangladesh, with a thorough technical understanding of wetlands and fisheries in Bangladesh and globally. Because donor projects often fail or succeed due to the leadership, getting the right leader is a key success factor. MACH also has good coordination of the project work at all levels, resulting in knowledge building among staff and leveraging of activities.

Local Champions

MACH has many unsung heroes who have enabled the program to succeed. Local people and leaders have embraced the MACH approach by experimenting with and promoting it. These champions have led the way in their communities by showing others how comanagement and alternative income-generating activities work to improve wetland resources while reducing poverty. Others followed their example, and the successes were widespread.

Effecting Behavior Change

Effecting behavior change is challenging. Due to the adaptive nature of the program, MACH was able to add a communications and outreach strategy for environmental awareness behavior change. Through community theater, local announcements, and other key culturally relevant strategies, MACH was able to effect significant behavior change for wetland conservation and biodiversity enhancement.

Sustainability

Sustainability is often difficult to achieve once donor funds end and there are no longer resources to continue the work needed. To ensure that wetland comanagement continued, MACH worked with the government of Bangladesh to create an endowment fund and established a revolving loan fund.

Institutional Strengthening

Institutional strengthening is a key enabling factor to achieve meaningful lasting results. For MACH, institutional strengthening was key for local accountability and transparency through backward and forward linkages (checks and balances).

Main Challenges

The combination of establishing CBOs such as the RMOs and comanagement institutions, along with extensive habitat restoration, makes for a costly and time-consuming program. This is a major challenge to scaling up. MACH provides a solid framework, but there are quality-control challenges to scaling up and replication.

Among challenges are ensuring that the CBOs adopt and continue to practice good governance, transparency, equity, and participatory decision making. Creating a sense of ownership of the organization by all of the members, including the back-bench members, is an issue for its sustainability.

Long-term government commitment supported by policy is a challenge in two regards. The extent that *upazila* fisheries committees, particularly the concerned government officials, are sincere and transparent in their activities is vital for the sustainability of both the comanagement system and the CBOs. Second, wetland resource management is dependent on use rights to water bodies being held by the CBOs and those rights being used to follow environmentally sustainable practices. There is a provision for extension of these long-term use rights provided the management performance is satisfactory, but this has yet to be demonstrated by the administration and remains a future challenge for the CBOs.

Conclusions

Management of natural resources—in this case, wetlands—is complex and fraught with many risks. Success is dependent on the local-user organizations' ability to retain control and keep up certain conservation and best management practices and then for the positive results from this to be felt by those communities living around the resources and sharing the benefits. It is important for these resource managers to have support from the local administration and government, the elite, and elected public servants. This local government support is essential for best management to be continued and for the resource to remain in the hands of the people who rely on it for their livelihoods. It is also important that all members of the community understand the need for this improved management to support the users in their effort to sometimes restore and then sustainably manage the natural capital that is their wetland. This management approach could be applied more widely to improve and sustain wetlands across Bangladesh and the region.

For donor-funded projects to be successful, their design, implementation, and management need to be adaptive, locally tailored, culturally relevant, technically sound, have the participation of the local communities in the design and implementation, and have strong, capable leadership and management. MACH has been able to achieve biodiversity conservation while using it as an entry to poverty reduction and good governance.

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Chapter 10

Adaptive Watershed Management in the South American Highlands: Learning and Teaching on the Fly

Jeffrey Alwang, Victor Barrera, Robert Andrade, Sarah Hamilton, and George W. Norton

The South American Andes are rife with environmental problems related to human activities within fragile ecosystems. Andean populations are generally among the poorest in South America; they also have only limited access to infrastructure and public services, and are dependent on rain-fed agriculture. These areas are rich in biodiversity yet extremely vulnerable to damage caused by farming. The Andes form the headwaters of many of the great river systems of South America, and runoff and agriculture-related pollution can have consequences far from their sources. Humans are increasingly encroaching in the fragile high plains as population pressures at lower elevations extend the agricultural frontier. This extension creates environmental damage by upsetting pristine areas and leads to runoff, loss of biodiversity, and lower water availability for population centers. Areas where people live just below the high plains are characterized by undulating, steeply sloped topography; this topography and the central importance of water to human and mammal populations make the watershed an obvious focus for solutions to environmental problems.

Solutions in such areas include the usual combinations of tools—regulations, assigning property rights, taxes, and subsidies—but a central component of any sustainable solution is to identify strategies to raise incomes while placing less strain on the environment. These strategies might include more environmentally benign agricultural technologies within the fragile areas, intensification of agricultural production in less fragile areas as a means of reducing pressure on more fragile areas, or strategies to raise income-earning potential through less land-intensive practices such as off-farm employment. Generally, however, efforts to improve natural resource management in agriculture-dependent areas focus on reducing environmental impacts in situ: technologies or public actions to reduce pressure where the damage is occurring.

The watershed approach to natural resource management has been tried in different settings in the highlands of South America with varying degrees of success. The watershed is now widely accepted as the appropriate unit of analysis in cases where water quality is a primary driving concern (Doolette and Magrath 1990) and watershed management is consistent with decentralized governance, which is rapidly gaining favor in Andean countries (Guerra-Garcia and Sample 2007). However, watershed analyses require extensive digitized data and tools that are of limited availability in high mountain areas, and watershed management often requires the cooperation of competing and overlapping levels of local and regional government. Also, ethnic diversity can be significant even in rather small watersheds, and attaining consensus can be a challenge in such environments. Thus, while watershed approaches to environmental problem-solving show promise, obstacles must be overcome during implementation.

A key element of any watershed approach is to recognize that watershed-level outcomes are a product of individual decisions about land use on fields spread across the catchment area. These decisions are results of livelihood strategies adopted by farmers and others who allocate their physical, human, natural, and other tangible and intangible assets to earn a living, increase their wellbeing, and manage the multiple risks they face (Siegel and Alwang 1999). Individual decisions such as management of a maize field have aggregate effects based on the physical characteristics (e.g., soil type, slopes, rainfall, natural and manmade barriers) and the decisions of others. Interdependence of decisions and their impact on aggregate economic and environmental outcomes result from a complex mosaic of economic, social, and physical networks that characterize all watersheds. The cross-scale spillovers from these different networks imply that solutions found at a single system level are not sufficient. However, the driving factor and the one most directly affected by watershed management is human decision making. This depends on policies and regulations, cultural and social factors, and individual objectives. Effective management must identify mechanisms for effecting change in human activities and options to raise incomes while reducing negative environmental consequences.

The literature shows that livelihood adoption depends on multiple objectives of the decision maker, his or her asset allocation, and the physical, economic, and institutional environment. Linkages across systems transmit signals to actors. For example, decisions at the policy level get transmitted through institutions to households. Household actions depend on field and watershed conditions. Within the household, decision making is shared by men and women (Hamilton 1998), and activities within a livelihood can be shared or differentiated. Concerns for income growth, risk management, food security, and system sustainability all influence household decisions (Reardon and Vosti 1995; Moser 1998; Rakodi 1999). Economic factors such as relative prices and profitability of alternatives drive adoption of new varieties and crop management practices, create incentives to begin new activities on and off the farm, invest in soil conservation, and generally alter land-use decisions (Winters et al. 2004; Coxhead and Demeke 2005). When combined with the interconnectedness of decisions within the watershed, these factors mean that modeling household decisions as a deterministic linear process will inadequately describe them. Yet typical watershed modeling approaches model household decisions as a linear process. (Dario-Estrada and Posner [1999] provide an overview of watershed modeling in the Andean region.) Approaches to watershed management rarely recognize that asset bases and livelihood strategies are fluid and that a successful management plan should introduce alternatives that contribute to higher incomes. Multiple feedback loops and interdependencies at different system levels complicate modeling and decision analysis, and building stakeholder acceptance under such complexity is also a challenge.

The purpose of this chapter is to describe an effort to manage the complex systems in the watersheds of Bolivar Province, Ecuador, that was part of the United States Agency for International Development–funded Sustainable Agriculture and Natural Resource Management (SANREM) Collaborative Research Support Program (OIRED 2008). We begin by describing the ecosystem context, then discuss the conceptual framework and our empirical plan. We present selected results showing that ethnic and agroecologic diversity in the watershed mean that technical interventions must be tailored to local conditions and that the process of moving knowledge to action is highly context specific.

Background on Study Site

The Chimbo watershed of Bolivar Province, Ecuador, on the western slopes of the Andes includes the cantons of Guaranda, Chimbo, San Miguel, and Chillanes. It provides 30% to 40% of the water of the Guayas River, the most important river system in western Ecuador. The watersheds make up three distinct ecological regions (páramo, Andean plain, subtropical regions) and four distinct Holdridge zones (subtropical humid forest, low temperate mountain, temperate mountain, boreal). They range from 300 to 4,500 m (980 to 14,760 feet) in elevation and receive between 250 and 2,500 mm (10 and 100 inches) of annual rainfall.

People in the watershed are highly dependent on agricultural incomes, yet small holdings, low productivity, and environmental degradation are associated with the highest rates of poverty in Ecuador. As a result of the central importance of the Chimbo River (figure 1), the government of Bolivar Province has expressed interest in a watershed approach to land-use planning. Together with the Comisión de Estudios para el Desarrollo de la Cuenca del Río Guayas (Commission for the study of development in the Guayas River watershed), the government in 2007 approved local funds for three environmental projects based on the watershed approach. One of these involves identifying alternatives for high-plain agricultural activities; the second provides incentives for reforestation and other soil conservation measures; the third funds environmental education in school curricula. Several local and international nongovernmental organizations work in the area and are using the watershed approach to natural resource management.

The Chimbo area is being buffeted by forces that change the way people live, probably permanently. Like many areas in South America, the region is becoming closely integrated with the

Figure 1. Cattle graze beside a cornfield along a tributary of Ecuador's Chimbo River, the country's most significant watershed.

national and global economy, a result of more open trading regimes, dollarization of the economy in 2000, and better transportation, communication, and information about markets elsewhere. Market integration places competitive stresses on traditional production systems but also provides opportunities for higher local capture of value added through post-production processing. Many stakeholders recognize potential opportunities but express frustration about small scales of production, access to markets and information, and perceived inability to compete in a globalized economy (Barrera et al. 2005). Stakeholders also recognize that environmental degradation is widespread and includes erosion and loss of productivity, loss of biodiversity and natural areas, and declining water quality and quantity. This degradation is perceived to be reducing agricultural competitiveness, although historical evidence on farm yields is not available. Many note that global climate change is reducing access to water and express the need to promote more sustainable use of scarce water resources.

Cross-Systems Management Approach

Programs to enhance environmental management in fragile areas must recognize two features of household decisions within complex systems: tradeoffs between actions at the extensive and intensive agricultural margin, and tradeoffs between on- and off-farm income earning activities. These decisions have implications across the systems. Extensification such as agricultural activities in the Andean high plains can create environmental damage such as increased erosion from sod-busting, long-term loss of soil fertility, agri-chemical pollution, loss of biodiversity, and diminished water availability due to more intensive water use and declining water tables. Pressure on these fragile lands is stimulated by low productivity, progressively smaller holdings, and limited income-earning opportunities at lower elevations. Thus, interactions occur across scales as household decisions at higher elevations imply changes at the field scale that eventually have impact at the watershed and larger scales.

Agricultural intensification can be associated with similar environmental problems, but because resource-conserving technologies are more readily available in intensively farmed areas and because productivity is usually higher in these areas (Southgate 1998), technology can be designed to raise incomes while maintaining or improving environmental quality. Higher incomes in intensive agriculture can stimulate investments in land- and soil-saving technologies and create "economic space" necessary to address environmental problems; they also can reduce pressure on fragile uplands. Cross-scale interactions are obvious.

Land-use patterns help determine the environmental effects of human activities, but the relationship between land use and wellbeing outcomes is fluid and can be affected by research-induced changes in the opportunity set. Nonfarm employment such as processing and adding value to agricultural products may be constrained by technical or market limitations; these limitations can be addressed through focused research and subsequent policy change. Such activities can be associated with increased income and, because their footprint on the landscape is small, minimal environmental degradation.

Our approach to watershed management in Bolivar Province combines a livelihood approach with scientific research to change the livelihood opportunity set. The adaptive management approach is used to integrate the research with planning decisions and promulgate policy to promote land uses consistent with environmental quality.

The adaptive watershed management approach involves several steps. First, we use science and local knowledge to evaluate economic, social, and environmental problems in the watershed.

Second, we engage stakeholders in a process of participatory goal setting based on our evaluation of problems and capabilities. Third, we build capacity to use science-based information to effect institutional change and influence land-use decisions. Fourth, we create the capacity and infrastructure necessary to monitor outcomes, identify the need for new alternatives, and alter the process as appropriate. Concurrent with capacity building, primary research was needed to identify economic, social, political, and environmental conditions in the watersheds and understand the determinants of these conditions; generate and validate environmentally sustainable alternatives to improve production systems and enhance income generation; and create a means of evaluating the effects of alternative actions, policies, and interventions.

Conceptual Framework

The adaptive management framework is well known (Salafsky et al. 2001). It begins with an assessment of conditions and identification of problems, and the community is engaged in a goal-setting exercise. Research findings are then used to produce watershed plans, which are implemented and monitored. Monitoring could lead to changes in plans over time, and the adaptive cycle begins again. We introduce two innovations to this standard framework: Plans are adapted on a regular basis as the research base and understanding of it grows, and the land-use plans include consideration of household decision making and how these decisions create impact across multiple systems.

The conceptual framework includes a focus on the household decision process, and cross-system interactions across the field, watershed, and larger system levels mean that household decisions have wide implications. The household decision process reflects livelihood choices. A livelihood refers to the capabilities, assets, and activities required for a means of living (Chambers and Conway 1992) or how labor, land, and other assets are distributed among productive and reproductive activities. The decision to adopt a livelihood (figure 2) is partly determined by the household asset base; available alternatives; institutional, policy, and social environments; exposure to risks and access to information; and the natural environment. Households allocate assets among activities to meet objectives such as utility maximization and food security. Decisions have effects on household wellbeing, the ability to save and invest (affecting the future asset position), and the natural environment. For example, adoption of a modern maize technology affects labor and land allocations, income, and risk exposure; and may affect erosion, runoff, and future soil quality. Changes in a household's wellbeing and its asset position emerge following adoption, and impacts are seen on soil quality and quantity, biodiversity, runoff and water quality. The latter effects will be felt at the field and farm levels, but through the geographic interlinkages within the watershed, impacts are aggregated to the watershed, ecosystem, and market levels. Some local actions have environmental impact on a larger scale, such as atmospheric carbon emissions.

A physical watershed model is used to reflect cross-systems linkages—how human activity leads to field-scale changes in land use and how these affect watershed outcomes such as total runoff, erosion, and river-water quality. This physical model is a central component of our framework: The assessment and problem identification stage generates information to populate the model. Model runs are used to create and evaluate community land-use management plans. Acceptance of model findings requires the buy-in and active participation of local decision makers in the research. Goals are set, and institutional changes to achieve goals are explored as a part of this research. This participation is attained by involving stakeholders in field research, development, and validation of the watershed and economic models, and selection of alternative management

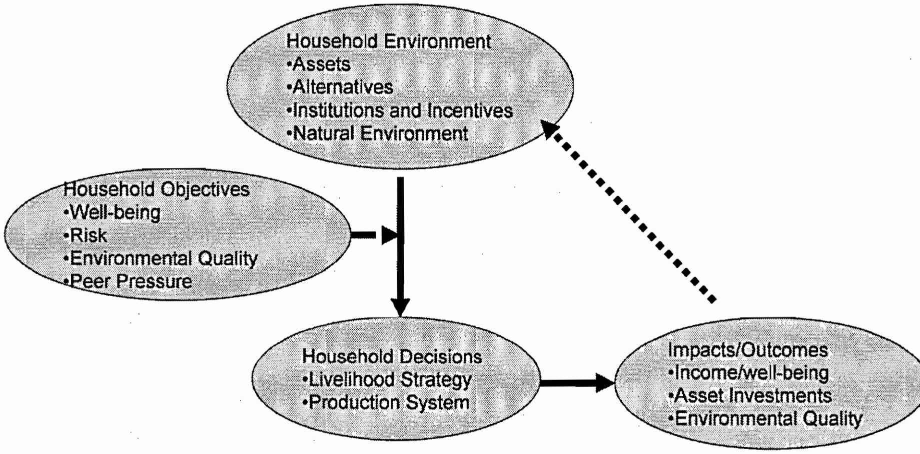

Figure 2. Conceptual framework: Household decision processes.

scenarios; all this engagement is essential to adaptive management (Salafsky et al. 2001). The process should produce agreed-upon land use plans that have wide acceptance in the watershed.

Methods

Project activities include data and information generation, research into determinants of and impacts on wellbeing of livelihood adoption, research to identify new income-generating alternatives inside and outside agriculture, modeling biophysical and social-economic processes in the watershed, and engagement of stakeholders. Stakeholders provide information, define objectives, evaluate results, create and implement plans, and monitor outcomes.

We began by describing the watershed's economic, social, and physical characteristics. These data were used to evaluate current conditions, create an information baseline for monitoring changes over time, and as input into our three basic models. These were models of physical production (soil and environmental attributes, productivity); models of household decisions; and models of physical impacts of individual and aggregate decisions (the watershed model). The data were also used as input into the community goal-setting exercise—to enable assessment of current conditions and to create a vision of where the community wanted to go. This goal-setting exercise, which consisted of several meetings over three months, led to the first adaptation: Instead of focusing primarily on water quality, the community identified three interrelated goals: water quality, availability, and improved soil resources.

The research to identify alternatives includes information on improved production practices (new varieties, management practices), the relationship between improved practices and outcomes (income, soil loss, productivity), alternative production and livelihood activities, market evaluation and market-chain analysis, and obstacles to adoption of new activities. Information on these alternatives is incorporated into the household models to simulate how livelihood changes will result from changes in policy and incentives.

The watershed models create the linkage across scales, from field- and farm-level activities to watershed outcomes such as water quantity and quality, soil loss, and sedimentation. They take information on the spatial distribution of natural conditions, rainfall, human decisions, prices, institutions, and incentives; relate it to aggregate outcomes; and subsequently use it to simulate the aggregate impacts of alternative policies.

Engagement is a critical component. Early experience indicated substantial doubt about the approach among stakeholders. This skepticism is fueled by two factors: their experience with development programs that provide resources and stimulate rent-seeking, and skepticism that mathematical and computer models would provide useful information for everyday decisions. While the first objection could be reduced only by interacting with the community over time, the second led to increased stakeholder involvement in tools testing and scenario development.

We began our process of involvement in research by engaging local youth to monitor rainfall and stream flows—essential inputs into the watershed modeling effort. We tested differences between hand-collected rainfall information and data from automated weather stations. The experience showed a reasonable correspondence, which helped create confidence in our data collection methods. Maps of land use and soil erosivity were generated using data from our initial assessments, satellite imagery, and other digitized data. These maps were presented at meetings in the watershed; feedback from the community helped us with our estimates and also built ownership among stakeholders, who began to recognize the relationship between land use and environmental outcomes. Our most dramatic experience with respect to skepticism and ownership came when community members insisted on more transparent modeling of land use and outcomes, which led us to rely much less heavily on the Soil and Water Assessment Tool (SWAT; see http://www.brc.tamus.edu/swat/) and more heavily on less complex tools such as simple maps showing flows of runoff and areas where erosion potential was most acute. These maps were generated using field-level estimates of erosion and runoff (from our experimental plots) that were aggregated to the watershed scale using knowledge of the slopes and land uses across the watershed.

Central Issues in the Chimbo Watershed

Because of the watershed's size, the project team decided to conduct activities in two subwatersheds of the Chimbo—the Illangama and Alumbre river watersheds. These were selected because of differences in agroecological and social conditions (table 1), which allowed us to test the adaptive management framework in two environments. Our research partner, the Autonomous National Agricultural Research Institute (INIAP), had ample experience working with farmers and local governments in the upper Illangama watershed but virtually no history of interactions in the lower-elevation Alumbre. The difference in experience in interactions with INIAP allowed us to test different models of bringing knowledge to action, for engagement in Illangama was immediate, while introductions and confidence building were necessary in Alumbre. Agricultural activities predominate in both watersheds, with the cooler, higher-elevation Illangama comprising mainly a potato-pasture system and the warmer, higher-rainfall Alumbre being more diversified with maize-bean associations, other row crops, and some perennials (table 1).

The survey found that remittances and repatriation of funds earned during seasonal migration are important sources of income in both watersheds but more important in the lower watershed. A baseline household survey was conducted in September–November 2006. A random sample of farms was constructed based on farm census data provided by the Ministry of Agriculture, from census data from a national nongovernmental organization, and information from local authorities. Of the 700 farms in the lower watershed, 169 were included in the sample, and 117 of the 500 farms in the upper watershed were included. One representative of each farm was interviewed; about 70% of interviewees were men. Main challenges to income earning include low productivity

Table 1. Principal income-generating activities in the subwatersheds of the Chimbo River watershed, Bolivar province, Ecuador (SANREM participatory assessment and baseline survey).

Subwatershed	Environmental conditions	Principal income-generating activities
Illangama	***Region:*** Páramo and Andean Plain ***Holdridge life zones:*** Sub-alpine, mountain, low mountain ***Soils***: Inceptisol 39%, Entisol 28% and Mollisoles and rock 33%. ***Average temperature:*** 7°C–13°C ***Elevation:*** 2800–5000 m ***Precipitation:*** 500–1300 mm per year.	Agriculture (potatoes, pasture, cereals), livestock (cattle, sheep, pigs, others), tourism, small-scale commerce, handicrafts
Alumbre	***Region:*** Andean Plain and Sub-tropical ***Holdridge life zones***: Low mountain and pre-mountain ***Soils:*** Inceptisol 13.9%, Inceptisol and Entisol 32.7%, and Mollisol and Inceltisol 52.5%. ***Average temperaure:*** 15°C–19°C ***Elevation:*** 2000–2800 m ***Precipitation:*** 750–1400 mm per year	Agriculture (maize, beans, peas), livestock, agro-industry (including medicinal plants, cacao and organic coffee), tourism, small-scale commerce

in agriculture, declining quality of the natural resource base, inadequate access to final markets, low local capture of value added, and inadequate diversification of income-earning inside and outside agriculture.

Stark differences are evident across the two watersheds. The social structure is quite distinct: In the Illangama watershed, all households are indigenous, compared with 38% in Alumbre (table 2). About 12% of households are headed by women in Illangama, compared with 17% in the lower watershed. Conditions faced by women differed from those faced by men; while overall levels of education are similar in the watersheds, adult women are far less likely to be educated compared with males, with the mean education of male adults being about 6 years compared with 4.8 years for women. In the Illangama watershed, female adults averaged less than 3.9 years of education compared with 5.3 years in Alumbre. Households in both watersheds expressed concern about retention of youths, and our survey indicated that 53% of households in Illangama send migrants out either temporarily or permanently, compared with 40% in Alumbre. However, far higher percentages of migrants from Illangama went to Quito; Alumbre households are far more likely to send migrants to coastal areas and abroad. Differences in migration patterns reflect ethnicity. Due to language and other barriers, indigenous migrants have fewer destinations and generally travel to highland destinations. None of the indigenous households in the lower Alumbre watershed sent migrants to non-highland destinations. Migration destinations have important implications for income; households from the lower watershed, despite participating relatively less in migration, receive greater shares of income from migration.

In both areas, farmers and other community members face decisions between livelihood strategies that exploit the extensive and intensive agricultural margins, and decisions about investments in on- versus off-farm productive assets. The settlements are relatively young; the upper watershed was populated by resettled indigenous groups in the early 1980s, while many parts of the Alumbre were unpopulated until the early 1990s. Population pressure in lowlands induced migration into the area. New settlement places obvious pressure on the natural environment. Environmental degradation is evident through obvious erosion on steeply sloped hillsides, absence of soil conservation measures, limited undisturbed natural areas, and turbidity in waterways. Both areas

Table 2. Description of survey households (SANREM baseline survey of households).

	Alumbre	Illangama
Male-headed (percentage)	82.8%	87.2%
Household size	4.7	5.8
Dependency ratio	0.47	0.50
Years education (head)	4.3	4.5
Highest educated family member (years)		
Male	6.2	5.9
Female	5.3	3.9
Percent indigenous	34.9%	100%
Percent with migrants	40.2%	53.0%
Percent migrants to Quito	67.4%	87.1%
Percent migrants other Ecuador	13.2%	12.9%
Percent migrants international	19.1%	0%

Note: N = 286.

remain largely dependent on agricultural livelihoods, but families are increasingly seeking off-farm opportunities. Off-farm income makes up about 57% of income for families in Alumbre compared with 27% for those in Illangama.

Households in Alumbre are more integrated into labor markets, more frequently rely on migration income, and are less reliant on livestock income than those in Illangama. Overall means mask important differences across livelihood strategies. For example, although income from self-owned business and migration make up only 7.4% and 10% respectively of total income in Alumbre, they account for 36.7% and 42.4% of income for those households engaged in these activities. Likewise, all households in both watersheds rely on agriculture to some extent, but income sources are clearly diversified. For example, in Illangama, for the 51% of households who participated in off-farm wage employment, this employment contributed to an average of 30% of household income. Agriculture is also much more diversified in Alumbre (table 3). The Illangama watershed is almost entirely composed of a potato-pasture rotation—95% have pasture, and 100% plant potatoes)—with a small number of farms planting maize and chocho (*Lupinus mutabilis*, a local legume). Alumbre farm households plant small grains, maize and beans, and some perennials and Andean fruits.

To better understand how livelihood strategies differ, nine distinct livelihood clusters were identified using a cluster analysis (see the appendix), five in Illangama and four in Alumbre. These livelihood clusters reflect how people use their assets to earn a living. For example, the Illangama clusters include dairy, pasture, and potato production, while grains and legumes dominate in Alumbre. Households in the wealthiest clusters, however, had more diversified income sources, with on-farm activities being complemented with off-farm and often nonagricultural incomes. Households in the poorest clusters tended to be dependent on agricultural wages or agricultural income with small land holdings.

During the participatory assessment and later during meetings in the area, farmers, artisans, and other community members noted that limited access to productive assets constrains their economic possibilities. When discussing assets, farmers generally focused on land and other physical assets such as agricultural equipment. Land holding is unequal in the Chimbo; Gini coefficients, a

Table 3. Household income sources and their distribution by subwatershed (SANREM baseline survey of households).

Income source	Alumbre		Illangama	
	Percent total household income from each source	Percent household income coming from this source for those with income source (percent households receiving income from source)	Percent total household income from each source	Percent household income coming from this source for those with income source (percent households receiving income from source)
Agricultural production	36.1	36.1 (100)	57.8	57.8 (100)
Livestock	6.8	16.4 (41.4)	15.1	17.9 (84.6)
Self-owned business	7.4	36.7 (20.1)	4.8	22.6 (21.4)
Off-farm agriculture wage	21.9	42.6 (51.5)	4.2	25.6 (16.2)
Off-farm wage	17.0	42.1 (40.2)	14.9	29.0 (51.3)
Migration	10.0	42.4 (23.7)	1.9	24.6 (7.7)
Transfers	0.8	20.5 (4.1)	1.3	9.2 (13.7)
Total	100.0		100.0	

Note: N = 286.

measure of inequality, for landownership, were 0.62 and 0.65 in the upper and lower watersheds, respectively. Gini coefficients for land holding in South America are generally in a range of 0.5 to 0.85.) Land access among small-scale farmers is somewhat more equal, with households in the upper Illangama watershed generally having less access (1.2 to 4.2 hectares interquartile range with a mean of 3.5 in Illangama compared with 1.4 to 6.4 with a mean of 5.8 in Alumbre) and lower-productivity lands. About 70% of all land in Bolivar Province is titled, but in our survey 84% of the land was titled, and 12% was rented and may or may not be titled. In Illangama, common management of community woodlands is frequent, and about 38% of households report having access to irrigation, compared with only 9% in Alumbre. Most households with access to irrigation noted that irrigation water was inadequate even when the distribution infrastructure was in place.

As noted, the poorest livelihood clusters in both watersheds have not been able to diversify into nonagricultural businesses, receive most of their wellbeing from meager on-farm earnings, and participate in daily labor markets. An econometric analysis of the determinants of entry into each livelihood using a multinomial logit model showed that location, access to markets, proximity to water sources, and basic human assets such as education, experience, and family structure all affect livelihood decisions (Andrade 2008). Access to assets such as irrigation and credit were also powerful determinants of livelihood choice. For example, credit access was associated with more frequent entry into market-linked livelihoods and the formation of nonfarm businesses. Model results were combined with our geographic information system to reflect the spatial spread of livelihoods and how this spread is affected by changes in policies. This combination is being used to help guide political decisions in the watershed as part of the adaptive watershed management program. See table 4.

Environmental Challenges

Farmers and other members of the community recognize that environmental degradation represents a major challenge to improved wellbeing. The primary environmental problems affecting both subwatersheds are water contamination from agrochemical runoff; loss of soil moisture storage capacity due to erosion and loss of soil organic matter; loss of soil fertility from erosion and lack of adequate fertilization; and loss of biodiversity reflected through a decline in populations of native animal and plant species. Human waste-related pollution of waterways (sewage, garbage) and sedimentation were also viewed as important, especially by women and children in the lower watershed, who collect water for drinking, cooking, washing clothes, and for animal consumption. Surveys and administrative data showed substantial evidence of health problems, particularly gastrointestinal infections, due to poor quality water. This information confirmed the perceptions of the women and children.

Land degradation and deforestation are recognized as serious problems by roughly 90% of the people who responded to our survey; and soil moisture-holding capacity and risk of drought by about 85% (a more common problem in Alumbre). Despite widespread recognition by farm families of the role of soil erosion in reducing agricultural productivity, fewer than 5% of respondents take actions to conserve soils, and many claim they are unaware of soil conservation practices. A similar discord between stated concerns for natural resource quality and use of conservation practices exists with regard to quality of the páramo—the high Andean plain. More than 80% of the farmers in Illangama state that the páramo is threatened by human activity, and respondents recognize the link between its degradation and water quantity and quality at lower elevations. However, only 31% of these same people refrain from using the páramo for productive activities; 61%, 6%, and 3% of farmers, respectively, use the fragile páramo for wood and firewood, cultivation, and pasture land.

Table 4. Agricultural lands and crops planted by subwatershed (SANREM baseline survey of households).

	Alumbre		Illangama	
	Percent of farmers planting	Percent of total area in ...	Percent of farmers planting	Percent of total area in ...
Leguminous (peas, beans, faba beans, chocho, lentils)	35	20	17	6
Grains (corn, wheat, barley, quinoa)	76	42	12	7
Grains and leguminous (corn/beans)	27	34	0	0
Roots (potatoes, mashua, melloco, oca)	5	1	100	84
Andean Fruits (tree tomato, blackberry)	7	3	0	0
Others (onions, sugarcane, carrots, tomatoes, sambo, squash)	2	0	6	2
Pasture	46	n.a.	95	n.a.

Note: N = 286.

Due to stated concerns about biodiversity, an assessment was conducted during the first project year by SANREM partner ECOCIENIA (Calles and Pena 2007). This assessment, which focused on animals (birds, mammals, amphibians) and plants (mainly tree species), identified a rich biodiversity. In particular, several endangered bird and mammal species and important reserves of native tree species are found in both watersheds. Amphibian populations are limited, and competition between induced exotics and native tree species threaten biodiversity. Fragmentation of remnant wooded areas threatens mammal and bird species. Follow-up research will investigate the relationship between fragmentation and viability, a research area identified through community meetings where results of the assessment were presented.

Research was designed with community input to address environmental issues and rectify the apparent conflict between human activities and attitudes with respect to the environment. Activities were prioritized during consultations with beneficiaries who recognize environmental concerns but are familiar with few alternatives to preserve the environment. Intensive engagement of stakeholders was required to build confidence that environmental quality and long-term income generation are not competing objectives, but the close focus on environmental quality (other than water quality) was a product of adaptive management. Sites were identified to monitor weather events and stream flows, analyses of soil nutrient and water-holding capacity were undertaken, and a protocol was established to measure water quality and aquatic biodiversity. Local youth were engaged in monitoring efforts, and close connections between the study team and stakeholders helped stimulate interest. Several study plots were established to analyze the relationship between field management practices and soil erosion; they were set up in a repeated block design to enable statistical comparisons. Local youth and undergraduate students monitored the experiments and collected runoff for measurement as needed. All these practices, products of the adaptive management process, build ownership by local decision makers in the research results and increase the likelihood that findings will be incorporated into actions.

Decision Making and Gender

Anecdotal evidence points toward gender-based biases in decision making. For example, INIAP reports that few women participate in training activities and community meetings, despite the fact that women in Bolivar are generally quite active in agriculture and other income-generating activities. Our survey data show that women are commonly excluded from participating in household decisions and are far less likely to participate in formal training than are men (table 5). Men are also more likely to market products and may, as a result, exercise economic power over women. Decisions about crop sales, chemical use, and household expenditures are predominantly made by men, although women in many households provide input into the decision process. In a similar vein, men are more likely to participate in meetings, elect authorities, and serve as authorities in community organizations. Because adaptive watershed management requires buy-in of stakeholders, particularly those making decisions, we needed to investigate the role of women in decision making and identify means of integrating them into the adaptive watershed process.

Gender roles are differentiated by watershed. Women in Illangama are more likely to haul water and firewood, participate in crop harvests, and care for livestock than women in Alumbre, suggesting that their participation in productive activities is greater. Women in Illangama, however, are much less likely to participate in household decision making such as chemical use on the farm, who participates in training, product sales, and the household budget. They are less engaged in marketing and unlikely to supply labor off the farm. While they are less likely than women from

Table 5. Participation in and responsibility for common activities by gender (%) (SANREM baseline survey of households).

	Alumbre		Illangama	
Activity	Women and men together	Women alone	Women and men together	Women alone
Carries water	15.9	73.2	13.0	83.3
Harvests crops	55.4	16.9	74.1	9.5
Cares for livestock	45.3	36.0	57.9	39.2
Sells products	11.8	29.0	21.2	12.1
Decides about				
Crop sales	19.9	19.9	25.5	13.6
Chemical use	6.6	15.2	0.0	12.8
General decisions	21.1	33.3	12.4	25.7
Expenditures	23.5	21.0	20.9	14.8
Who receives training	11.0	25.6	18.9	8.9
Participates in meetings	25.8	24.7	36.5	11.5
Elects authorities	28.1	25.0	47.9	8.2
Is a community authority	0.0	25.9	0.0	12.7

Note: N = 286.

the Alumbre watershed to serve as a community authority, they are equally likely to elect authorities and participate in meetings.

These observations, consistent with findings presented in table 2 about lower levels of education for women, paint a troubling picture of prospects for engaging women in participatory watershed management. Engaging women is important not only for equity but also to improve project efficiency and generate positive impacts. While we emphasize gender-based inequities, it is also important to note that a large minority of women are decision makers in relevant domains. Women make or participate in making general budgetary decisions in 54% of households in the Alumbre watershed and in 38% of households in the Illangama watershed. Women are heavily involved in decisions regarding crop sales and in marketing crops. Yet INIAP reports far lower levels of female participation in workshops regardless of the purpose. Special efforts have been designed to broaden participation: direct involvement of female professionals in the project, increased funding for female students, and aggressive efforts to stimulate participation by women in project activities.

Constraints to Livelihood Diversification

As we engaged farmers and other villagers in discussions, they quickly identified potential livelihood alternatives and asked for additional research to be conducted. Research was conducted on appropriate crop varieties, recommendations for fertilization, soil conservation measures, integrated pest management, and other areas. Existing crops were included in the research program, with a specific focus on alternative crops in the lower watershed. Stakeholders participated in all field-level research. Economic and social research also identified off-farm alternatives to raise incomes and increase local value added. Many activities are directly linked to agricultural production, so multipliers are likely to be large.

Discussions during the participatory assessment indicated that market access was an obstacle to increased incomes and retention of value added, particularly in the dairy market. Small-scale milk production is widespread in Illangama, and while most output is consumed in the household, sales of surplus milk and cheese in Guaranda and other markets is common. Producers rely on intermediaries, and information indicates that exercise of market power by intermediaries was slowing income growth in this market.

SANREM undertook a comprehensive analysis of the dairy marketing chain and identified factors constraining growth in the dairy market and livelihood diversification. Growth in dairy is constrained by low productivity; spatial dispersion, which increases costs of transport; and rudimentary cheese production facilities, which lead to waste and lower-quality products. These constraints help to limit possibilities for increased competition in transport and markets because volumes are low and, due to the nature of the product, margins are slim. The area around Illangama is served by a small number of cheese intermediaries who live in the communities of Patococha and Cuatro Esquinas, most of whom have a long family history in the business. Growth in dairy is also constrained by marketing institutions. Cost differentials between prices paid to producers and those received in the Guaranda market were high, but costs of transport are high and technologies are relatively primitive.

Adaptive Management Process and Transdisciplinary Articulation

Previous engagement with stakeholders is an important consideration in building confidence in the process. While the INIAP team had credibility in the domain of agricultural technology, this credibility was confined to the Illangama watershed and did not extend to areas of watershed modeling, environmental issues, and governance. Careful steps were taken to familiarize regional and local authorities with the research team and gradually build ownership in the process. The team also confronted an extremely narrow focus on the part of institutions and unwillingness to view problems as being interdependent. The transdisciplinary and trans-scale nature of the adaptive watershed management process contributed to problems of language and conflicts across decision domains that were difficult to overcome.

Parallel to establishment of the participatory research program, the team worked with provincial governments, which have substantial interest in the watershed approach. A key challenge, however, was to devolve this interest to localities: Changes in land uses, the main means by which environmental conditions can improve, depend on local actions. Beyond efforts at education and use of moral suasion, decisions made at the provincial level have only minimal impacts on land use at local levels. Further, each subwatershed comprises a number of local jurisdictions, and cross-locality cooperation has historically been minimal. Building mutual respect for joint interests and other bases for collaborative decision making became a focus.

The watershed modeling effort requires data of limited availability, including information on land use, soil properties, rainfall and climate, and stream flows. Data collection was designed to maximize community participation, and continued feedback among community members and the research team induces modifications. Less reliance on SWAT is one product of these interactions. Community data collection induced stakeholder interest and stimulated curiosity about data use. This interest further builds engagement in technical modeling.

A major goal is to integrate social sciences with engineering and agronomic research to strengthen the adaptive watershed management process. The watershed model requires information on the spatial distribution of land uses before and after a policy change or other intervention, and we used integrated transdisciplinary methods to "simulate" these changes in land use. This approach represents an important departure from previous efforts at adaptive watershed management. For instance, past efforts relied on deterministic and rather highly aggregated programming models to simulate household land-use decisions (Dario-Estrada and Posner 1999). These models calculate a maximized household objective function such as profits from use of household resources, subject to resource constraints such as the amount of land or labor available to the household. Modeling household decisions in such a fashion abstracts from social and cultural forces, the spatial distribution of transportation infrastructure, other factors affecting returns to specific activities in different locations, and household responses to risks, among others.

Our use of mixed and transparent research methods allows us to better understand the factors affecting land-use patterns and how policy change affects these patterns. This process requires close collaboration of researchers from multiple disciplines and also affords local farmers and other community members' opportunities to evaluate and suggest improvements to our land-use management plan. The qualitative inputs rely heavily on local knowledge of conditions in the watersheds, information on topography and land-use patterns, history of production practices and producer groups, and suitability of lands for different uses. We are also able to incorporate some non-quantifiable determinants of livelihoods and land use, such as the role of family history and experience, the importance of access to markets, and how social networks contribute to livelihood diversification.

The team also found, at the local level compared with the regional level, limited capacity to use project-related information, fewer resources to focus on efforts to influence land-use decisions, but, paradoxically, more interest in research to enhance income generation and improve livelihoods. This interest is a product of the dependency of watershed households on land-based incomes, some experience with farmer field days and other training events, and the immediacy of economic and environmental problems felt by the population. Limited local capacity requires the research team, particularly those presenting information from conceptual and analytical models, to tailor their interactions to generate interest and stimulate feedback from stakeholders. Capacity was particularly a problem in the lower watershed, where familiarity with INIAP was limited and decision making was less a part of community custom. In contrast to the lower watershed, in Illangama a history of interaction with INIAP led to ownership of research findings and incorporation of many of them into the watershed management plan.

Discussion

The watershed approach to natural resource management has been tried in several settings in the South American highlands with varying degrees of success. Watershed analyses require extensive digitized data and tools that are of limited availability in high mountain areas, and watershed management often requires the cooperation of competing and overlapping local and regional governments. Ethnic and social differences may inhibit participation, and stakeholder buy-in is a critical determinant of success. While watershed approaches to environmental problem solving show promise, a number of obstacles must be overcome during their implementation.

Engagement in research facilitates adaptive management in two ways: It enhances the quality of and builds confidence in research results, and it allows adjustments to research as findings are evaluated with local farmers and community members. For example, early participation in research prioritization induced us to devote more resources to research on soil conservation practices within existing crops; we had planned to look almost exclusively at new opportunities. Engagement also helped convince local authorities that the adaptive management process would require them to develop new capacities. In the past, they had thought of watershed management as focused exclusively on creation of land-use plans, but they now understand that, because of linkages between land use and economic activities, effective management would require them to become engaged in market regulation, in particular, the dairy market. Effective management requires a transfunctional approach to decision making in government.

Our model depends critically on participation of stakeholders as a means of gaining acceptance of the results and as a means of making the results more reflective of local realities. A track record of working in the upper Illangama watershed combined with the strong tradition of community decision making in the highly indigenous area enhanced engagement and ensured success. Early on, participation in assessment and goal formulation exercises led to substantial modifications of the research program. These changes helped make the research more relevant to stakeholder needs. While stakeholders in Illangama showed skepticism about many of the technical details, they were receptive and willing to learn. They eventually assumed ownership, which facilitated quick uptake of recommendations, creation of a community watershed plan, and active engagement in monitoring. Less familiarity with the research team and a more heterogeneous social structure slowed progress in Alumbre and required far more efforts to obtain stakeholder buy-in.

In both areas, economic, social, and geographic conditions limited livelihood options before engagement. Low incomes bounded the "economic space" necessary to permit investments in resource-conserving technologies, and knowledge about environmentally compatible alternatives was not widespread. Our research has created options and demonstrated to decision makers that environmental enhancement does not always imply short-term costs, for we helped to identify means of improving productivity, diversifying livelihoods, and introducing strategies to raise incomes while protecting the natural environment.

Social and physical heterogeneity in the watersheds makes the area a good test case for adaptive watershed management. This effort integrates several forms of social analysis with biophysical modeling to create a more nuanced picture of the relationships among policy and other interventions, land-use patterns, and environmental consequences. The eclectic approach also stimulates stakeholder engagement throughout the process, which increases the likelihood that recommendations are adopted.

Several benefits are apparent in approaching management from a watershed perspective. The watershed is a natural unit whose residents express a shared vision. Water quality and quantity, biodiversity, and other watershed-scale outcomes depend on joint decisions of residents. The effects of one's actions on others are immediately evident when a cross-scale perspective is introduced. This awareness stimulates uptake of recommendations.

Appendix: Livelihood Clusters in the Two Watersheds

Cluster analysis was used to uncover nine livelihood clusters across the two watersheds. Important differences in livelihood strategies were noted across the watershed.

Alumbre Clusters

Cluster 1: Agricultural activities and remittances dependent

This cluster has a relatively low level of household income, $2,590 a year, with most of it coming from agriculture but an important share from off-farm wages and migration. This group migrates seasonally to the coastal region to work during harvest. Households own an average of three head of cattle, which provide no measureable income; residents consume the milk products and use the animals to cope with risk. They mainly plant grains and legumes on an average of 5.9 hectares.

Cluster 2: Off-farm agricultural wage dependent

This cluster has the lowest income, $1,450 a year, even though the farm area is close to the sample average (4.5 hectares). Residents' main income source is off-farm agricultural wages, and they spend more time working on other farms than on their own. They are sensitive to risky events, for their main source of income is linked to farming, and they have few assets to manage this risk. They primarily grow grains and legumes.

Cluster 3: Own-business dependent with more land

This cluster has the highest income in the region, $8,460 a year, and most of it comes from resident-owned businesses. Agriculture and off-farm activities are secondary sources. Residents hold small amounts of cattle as a resource in case of emergencies. They own the largest amounts of land (10.2 hectares on average) in the watershed.

Cluster 4: Agricultural activities and social-help dependent

This cluster is similar to Cluster 2 but with lower levels of income. This group diversifies its activities among several alternatives. Members depend on agricultural income, off-farm agricultural wage, and social help, each representing similar shares of total income. This group also participates in off-farm wage and migration, but income amounts from these sources are minor. Residents own very small extensions of land and few cattle.

Illangama Clusters

Cluster 1: Agriculture and off-farm wage dependent

Income is near the sample average of $3,520 a year. The main source of income is agriculture followed by off-farm wages and livestock income. This group has more livestock (eight head per household) than the sample average and produces raw cheese with traditional technology. Livestock activities account for a relatively low share of income but provide a constant source through the year. Average farms in this cluster are 3.9 hectares, and they produce pasture, potatoes, and minor crops.

Cluster 2: Strongly dependent on agriculture

This cluster has the lowest income in the upper watershed. Members depend on agricultural activities, off-farm agricultural wages, and very small shares of livestock income. Members of this group are sensitive to risky events because their incomes are so closely linked to agriculture. Households own an average of four head of cattle, which provide a modest but regular source of income. Farms in this cluster are small (1.8 hectares), and they are planted mainly in potatoes.

Cluster 3: Own-business dependent with less land

This group has the highest income in the watershed, about $8,650 per year. Half their income is from their own businesses, with farming and livestock activities as secondary sources. On average, households raise 11 head of cattle, producing raw cheese sold mainly to intermediaries. Average land holdings are 5.6 hectares, used for pasture and to grow potatoes and some legumes.

Cluster 4: Agriculture and migration dependent

This group is relatively poor, with an average income of $2,380 a year. Sources of income are agricultural activities and migration. Members migrate seasonally to Quito and other Andean cities. They reinvest migration income to grow potatoes and other minor crops. Migration represents almost half their income. They own small numbers of cattle and have extremely small land holdings (1.3 hectares), renting most of their cropland. They grow mainly potatoes.

Cluster 5: Agriculture dependent

This cluster has relatively low income, $2,660 a year, and depends mainly on agriculture (64%). Livestock, off-farm wages, and social help are secondary sources of income. Households own an average of four head of cattle and about 2.4 hectares. On these relatively small lands, they grow pasture and potatoes.

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Chapter 11

Community Organizing for Natural Resource Management: Strategies for Mitigating Farmer-Pastoralist Conflict through Decentralized Governance

Michael Bertelsen, Salmana Cissé, Keith M. Moore, and Abdoulaye Touré

Like many landscape systems around the world, the Inland Delta and hinterlands of the Niger River are transitioning to more intensified agriculture and animal husbandry. These dominant and interrelated farm household/enterprise systems must serve as the engines for sustainable economic development, providing food security and alleviating poverty. For centuries, subsistence agricultural communities of this region have been nested within an ecosystem characterized by open range, opportunistic grazing managed by transhumant (migrant) herders. Recently, however, increasing population pressure, changing political structures, declining and erratic rainfall, and degraded natural resources have forced both agricultural and pastoral communities to transform their production systems and the social relations on which they are based. Unfortunately, this transformation has brought about increasingly violent conflicts between farmers and pastoralists over natural resources, overlaid with ethnic differences.

The policies of the centralized colonial and post-colonial Malian state have not been adapted to growing market forces. Often they have perversely incited conflict by introducing projects, programs, and policies favoring one group of resource users over another. Across the Sahelian region of West Africa there is a growing consensus that central governments are poorly placed to make many of the decisions critical to their citizens' welfare.

At the Nouakchott (Mauritania) Conference in1984, sponsored by the Interstate Committee for the Fight against Desertification in the Sahel, West African governments for the first time formally recognized the need for local involvement in development projects. This conference was followed by two other Interstate Committee for the Fight against Desertification in the Sahel sponsored conferences, one in Ségou, Mali, in 1989 that further emphasized the need for decentralized natural resource management (NRM) governance; and the other in Praia, Cape Verde, in 1994 that highlighted the relationships between decentralization and land tenure. Subsequently, West African governments embarked on a policy of decentralization, devolving responsibility for governance to local administrative structures with far-reaching implications for the region. At the same time, multinational and bilateral donor agencies such as the World Bank and the United States Agency for International Development as well as nongovernmental organizations (NGOs) began promoting local civil society organizations as a core element in their new strategies for rural development and NRM. The advent of decentralization has provided the impetus for mobilizing rural civil society in the transition to more intensified farm household production systems and transforming the vicious cycle of poverty into a virtuous circle of poverty alleviation.

NRM is one of the powers decentralized to the community/watershed system level across West Africa, shifting governance and consensus building to those nearest and most knowledgeable to address these issues. However, this has placed a significant burden on newly emerging local NRM decision-making institutions. Frequently illiterate and without specialized knowledge or skills, local officials are poorly equipped or trained to deal with NRM issues. Also, members of the rural councils are fully occupied in becoming acquainted with the large number of additional duties and responsibilities they have assumed under decentralization. A consistent, effective approach to building and reinforcing the social and human capital necessary to facilitate local NRM decision making is needed.

Decentralization has changed the dynamics of NRM, but it has not yet yielded a methodology for effective local governance in the Sahel. In response to this insufficiency, the Sustainable Agriculture and Natural Resource Management (SANREM) Collaborative Research Support Program (CRSP) West Africa project (Phase II, 1999–2004) designed and implemented a program to develop and test an approach to address issues surrounding decentralization, conflict, and NRM in the Niger Delta of Mali. The driving force behind the approach was the need to find long-term institutional structures to manage complicated natural resource management problems. Typically, transhumant Peul herders have found their cattle trails increasingly encroached on by settled Marka farmers who find their crops trampled by wandering cattle as the dry season approaches.

Although in dealing with conflict over natural resources, it is important to implement short-term conflict resolution/management strategies, the SANREM approach also focuses on long-term consensus building and provision of social infrastructure as a platform for change and improved agricultural and natural resource decision making. The same tools being used to resolve conflict and develop a set of organizational skills (human capital investment) for consensus building and local governance are being used simultaneously to establish a new form of social infrastructure (social capital investment) to bridge relationships, build trust among local communities, and link these communities with scientific research services to identify and introduce technologies that increase the productive capacity of the natural resource base. The working development hypothesis of SANREM in Mali has been as follows: When a local population is provided with (1) methods for natural resource and conflict management, and (2) an institutional vehicle for inter-village, inter-ethnic dialogue, the population can then become proactive in addressing major agricultural productivity and natural resource management issues.

Local Institutional Environment

The proposed social infrastructure was designed to build linkages within the local institutional environment and bridges to external organizations and stakeholders. Two bases of institutional power at the community/watershed system level in rural Mali have vied for control of resource mobilization for development and environmental conservation: state power through the *chef de arrondissement (sous-prefet)*, who can bring to bear the police force; and customary power through village and other resource chiefs, who control the immediate allocation of resources for household livelihoods.

The resources of the state in north central Mali have been mobilized by an array of technical extension services that have attempted to assure environmental protection by threat of law and regulation of surplus extraction through development initiatives. For instance, the Office

Riz (the rice marketing cooperative) has been a major state initiative, reformulated from time to time, to enhance the productive power of the peasantry in rice production. This effort has been implemented by organizing farmers into village rice-growing associations. The livestock service monitors cattle health and the movement of herds within the zone. The forestry service polices the cutting of wood for fuel and timber to assure that overharvesting does not occur, frequently levying fines and collecting fees for woodcutting. The Centre Régional de Recherche Agronomique (CRRA)/Mopti is charged with developing new and adapted technologies to increase productivity.

Rural civil society has been restricted for the most part to the village level. Village associations are common among men and have often provided a point of contact for state development efforts. Women's associations have been largely neglected until recently. The Herders' Association of Nérékoro was established as a local organization to protect the interests of migrant herders who have local bases within the region but little or no administrative representation.

Since the end of the Traoré regime in 1991, the establishment of rural communes (local government units) has brought government closer to the population while ostensibly empowering the people to improve their livelihoods. Supporting this movement, NGOs have provided an alternative source of incentives for self-improvement, stimulating new initiatives and developing organizational skills. The communal elections in June 1999 brought to power the first elected officials who actually lived and worked in the rural communes of Mali. Despite their names being drawn from national party lists, their local roots and residence have increased the tendency for them to be more responsive to local concerns. Time will tell whether these elected officials will be truly responsive to the expressed concerns of the populations they serve.

Any process that involves multiple stakeholders should address how benefits can be optimized for the group as a whole. Stakeholder involvement implies not only participation but also recognition that not all participants have the same goals or the same power to achieve them. Successful negotiation of a shared vision involves pooling of earlier knowledge and reasoning processes and is predicated on a collective need or desire for results by and for the group. Confronting the reality of opposing stakeholder interests is necessary if the sense of ownership in a shared vision is to be created and the plan embedded in the social consciousness.

The SANREM CRSP West Africa project captured this holistic element by building on landscape concepts drawn from watershed management and complementing the metaphor with a new term: lifescape. Landscapes are constructed realities. In the global lexicon of SANREM Phase II, working at the landscape/lifescape scale meant going beyond what has come to be known as *gestion de terroir*, or village-based development in the West African Sahel. Indeed, the scale at which livestock management operates requires movement across ecosystems in a seasonal adaptation to fulfill resource needs. As scale increases across the nested landscapes, a wider range of stakeholders, often having no direct interest in specific local communities or production systems, becomes involved. SANREM Phase II research focused on understanding the complicated biophysical and social processes within and across community/watershed systems.

For small groups, it is easy to gather in one location and quickly take these steps at one or two meetings. However, this is not possible in the context of decentralized administrative units because the population of each community can range from 2,000 to 15,000 individuals. In this case, a standardized methodology is necessary to aggregate local (*terroir*/village) participation into commune-wide participation. An adaptive management approach was necessary to learn how to expand the networks of the community/watershed system and determine the most feasible mechanisms for aggregating village priorities and concerns. Local knowledge and practice, in fact, provide one of the most reliable ways to identify mechanisms for this adaptation and aggregation.

SANREM West Africa Approach

The SANREM West Africa approach to improving natural resource and conflict management at the commune level comprises five steps:

1. Ascertain local perceptions and priority needs.
2. Build commune consensus and establish local management capacity through a natural resource management advisory council (NRMAC).
3. Build institutional capacity for impact, including training of NRMAC members in literacy, numeracy, and governance; and training in natural resource management and conflict management.
4. Complement local knowledge with biophysical and socioeconomic research and development that lead to improved technologies and decision-making tools.
5. Monitor and evaluate.

These steps are summarized below.

Step 1. Ascertain local perceptions and priority needs

Implementation of the SANREM process is predicated on the interests of local partners and local government. Further, local perceptions of the constraints and potentials of the region's nested landscape systems must be understood. Generally, perceptions vary over time, within communities, and among stakeholders: farmers, pastoralists, village associations, NGOs, and technical service providers. The best way to initially reveal and document these perceptions is with a rapid participatory survey at a multivillage level, such as the participatory landscape/lifescape appraisal (PLLA), developed by the SANREM CRSP as an improvement on the standard rapid rural appraisal.

The PLLA is based on the proposition that any successful NRM project must be grounded in a balanced, thorough appreciation for the biophysical and socioeconomic milieu of the target community (Earl and Kodio 2005). The PLLA forms multidisciplinary teams of researchers and local stakeholders to examine the natural resource base and the socioeconomic realities of the community. Participatory techniques identify key biophysical and socioeconomic constraints and opportunities. Groups and individuals from all strata of the local population become involved, and a representative picture of the commune becomes apparent during the course of the weeklong exercise. Particular attention is paid to institutions and customs that provide an interface across systems, for management decisions affecting both landscape and lifescape are made through them. The PLLA also provides the opportunity to inform the local population about the nature of the SANREM interventions and helps to form realistic expectations within the community about what collaboration may mean in the future.

The PLLA in the commune of Madiama in February 1999 identified three major NRM constraints: the poor and degrading condition of soil fertility, pasture, and water points for livestock. These constraints formed the basis for prioritizing the activities that became the work plans and research programs prepared by the partners, including representatives from the local population.

Step 2. Build commune consensus and establish local management capacity through a natural resource management advisory council

In September 1999, a SANREM CRSP–sponsored delegation of national agricultural researchers, the newly elected mayor of the commune, and representatives of the local Office Riz and a World Bank NRM project visited all 10 villages in the commune of Madiama (Moore et al. 2005). In each village, the chief and a group of his counselors were informed about the objectives, value, and role of participation in village NRM user groups and a commune-level NRMAC. The members of the delegation explained that the primary purpose of the NRMAC was to provide a forum for reflection on NRM to improve communal resource management. Village NRM user groups would provide an essential link for communicating technological innovations developed by researchers. The NRMAC would provide a network through which researchers could learn about commune priorities, technology, and information needs and a local platform to prevent, mitigate, and resolve NRM conflicts and to develop a plan for natural resource management.

Each chief selected five delegates to represent the village in a commune-wide general assembly. According to the relative importance of the activity to village livelihoods, either two herders, two farmers, or one of each was selected. Two or three more villagers were selected to represent women, hunters, and crafts/forest gatherers. Two of 10 villages initially declined to participate, but one of them later sent four representatives to the assembly. Each of the nine participating villages and the local irrigation management committee sent three to five representatives to the general assembly in October 1999.

The mayor of the commune opened the assembly with the 45 village representatives, including seven women, and another 25 participants, including representatives from research, NGOs, development projects, locally based government services, the commune council, and the *sous-prefet*. The anticipated objectives, role, and structure of the NRMAC were again described. Translations were provided in the two local languages, Peular and Bambara. Participants were divided into four discussion groups: organizational and administrative issues; dryland farming, rice farming, and fishing issues; livestock, hunting, gathering, and craft issues; and the role of women. The groups were enjoined to debate the concerns and priorities of the commune with respect to each topic. After the groups reported their conclusions at the plenary session, all research, technical service, NGO, and elected officials withdrew, and elections were held to form the NRMAC. Twelve men and two women were elected; four more women were added later for gender balance. The village that had originally declined to participate for political reasons sent a representative to join the committee after it had been established.

NRMAC roles include the following:

- collaborating in drawing up each year's work plan, choosing farmers and pastoralists to participate in field tests, monitoring and evaluating results of field tests and progress toward fulfilling work plan objectives, and disseminating awareness of these activities and any recommendations resulting from them
- working with farmers, pastoralists, local chiefs, and other stakeholders to avoid and manage disputes over natural resources
- acting as a liaison between the local population and the commune's mayor and other government authorities regarding natural resource issues
- providing training and acting as mentors for the development of holistic and conflict management strategies in the commune's villages

Great care was taken to ensure that all social strata in the commune were equitably represented on the advisory committee, particularly in terms of socio-professional groups, ethnicity, and gender. Because perceived constraints and solutions vary considerably, any excluded group will not attach much legitimacy to decisions or advice coming from the committees. In Madiama, representatives were elected to the commune-level NRMAC from representatives of each village user group. Each village committee had at least one representative. One-third of the commune-level committee members were women. Although SANREM encourages diversity, the village committees are less diverse than the commune committee because the villages themselves are less heterogeneous in terms of ethnicity, socio-professional groups, and in their views of gender roles.

The NRMAC can function well only if village chiefs, the mayor, and other authorities are fully informed, provide support, and understand that their own role in the local hierarchy will remain secure and undiminished by collaboration. In Madiama, the NRMAC established good relations with the mayor, who regularly participated in meetings, often officially opening and closing them. The *chef d'arrondissement* also attended. Both were outspoken in encouraging committee activities.

NRMAC sustainability is an important issue. Sustainability in this context is dependent on the participants acquiring the training and skills necessary to maintain adaptive capacity in the management of everyday problems and on the capacity to access and interact with local providers of technical services. The emergence of complex adaptive systems in a commune means that new and difficult challenges will arise in the future. The NRMAC has been designed to build social capital within Madiama to meet these challenges, whether through the solidarity of horizontal bonds between villages and ethnic groups or through bridges connecting the community to service providers.

Legitimacy of the Natural Resource Management Advisory Council

Four factors contribute to the legitimacy of the NRMAC as a viable community organization. They are all based on the foundation of the participatory approach developed between researchers and the community for establishing and operating the committee. The first involves gaining formal recognition of the committee as a legal entity. The second is the establishment of relationships with stakeholders and partners in the association's environment. The third is serving a valued purpose for the community. The fourth is the re-election of committee members after their first term had been served.

Formal recognition of the association. To become legally recognized, the NRMAC was required to conform to national laws concerning associations. With the assistance of a local NGO, CARE/Djenné, the general assembly drafted, discussed, and passed bylaws that were approved by the judicial authorities. The NRMAC then formally petitioned the *prefet* of the Cercle of Djenné for legal recognition. Initially, the *prefet* refused the request because the domain of the NRMAC activities fell within the range of authorities devolved to the commune council. Therefore, the NRMAC requested that the mayor, who had assisted in the process of association development, send the *prefet* a letter in support of formal recognition. The mayor obliged and, on receipt of that letter, the *prefet* approved the request. The NRMAC was formally registered as an association by the Cercle of Djenné in October 2001.

Relations with other associations, technical services, and villages. Partnerships have been developed to provide a framework for productive relationships. These partnerships are either formal ones, conforming to the standards of national civil society, or informal ones, based on shared understandings of customary practice at the village level.

The first step in developing formal agreements of cooperation/collaboration was the signing of a protocol with CARE/Djenné, the NGO providing the NRMAC with institutional development training and assistance. Once formally recognized as a registered civil society organization, the NRMAC also signed a partnership agreement with the commune council. This document, perhaps the most significant of the NRMAC's formal protocols, provides a framework for the NRMAC to influence NRM decisions within the commune, to be consulted concerning decisions of the commune council, to be recognized throughout the commune as a significant player in the resolution of conflicts linked to natural resources, and to actively participate in the economic development of the commune. (The NRMAC proactively explored other formal partnerships. To develop collaborative relations, the NRMAC invited representatives of the technical services for the Cercle of Djenné to a meeting. Subsequently, a relationship with the Service Locale de la Réglementation et du Contrôle, which is charged with protecting the forestry resources of the Cercle, was established.)

The second type of partnership builds collaborative relationships with customary authorities and villagers. Although not formally documented, these relationships were formed while conducting activities involving the village chief. This kind of partnership began with the establishment of village NRM user groups under the direction of the village chiefs. By sending representatives to the general assembly to elect the NRMAC, the chiefs in effect confirmed the legitimacy of the NRMAC. The reticence of certain chiefs to designate village members to participate in the initial general assembly of the association bears witness to the validating role that chiefs play. This form of legitimacy is fragile and arbitrary in nature. Unlike formal, documented recognition, it may be withdrawn at any moment. (Frequent communication with all partners is essential for effective organizational functioning. However, this communication is more than a matter of transferring information; it involves continually renewing understandings between the NRMAC and the village chiefs. NRMAC members have regularly kept the village chiefs informed of their activities, the training programs in which they participate, and the research activities they monitor.)

Valued purpose. Unless the NRMAC serves the community, community members have difficulty understanding why the association should be of any concern to them. Based on the priority concerns of villagers, the NRMAC's mission has been to promote the management of natural resources in the commune by introducing and adapting technologies to local conditions so that the people can improve their livelihoods. An essential element in this mission involves the management of conflicts generated in the use of natural resources by various community members. By providing such services, e.g., protecting and planting trees, resolving conflicts, and introducing new technologies, the NRMAC legitimizes itself in the eyes of local leaders and villagers.

Reelection of committee members. This legitimacy was validated with the reelection of the NRMAC. Announcement of the process for reelecting the members was circulated through the commune, in each village, and on rural radio. As when it was first constituted, the process started at the village level. The chiefs assembled the village NRM user groups, and five representatives from each of the 10 villages were sent to a general assembly at the commune seat of Madiama. At this assembly, presided over by the mayor and the sub-prefect, the NRMAC president and executive bureau presented an activity and financial report of their accomplishments during the past three years. After a question and answer session, all the NRMAC members resigned. Following an open debate and consideration of their experience and training, all members of the committee were reelected by acclamation, thereby renewing their mandate. As an additional outcome of the debate, a commission of peers including a representative from the commune council, the village chiefs, and other customary or religious leaders, the CRRA/Mopti, and NGOs working in the area will monitor this new term of office.

Step 3. Build institutional capacity for impact

While formal training was important, learning by doing was crucial for the development of effective skills. Early in its development the NRMAC visited each village to develop a list of NRM priorities. These lists, along with the committee's consolidation of them, were presented to CRRA/Mopti researchers at a meeting in February 2000. A discussion ensued during which the committee prioritized two biophysical themes: improved soil fertility in croplands and improved pasture management for researcher assistance. The committee also emphasized the importance of reinforcing its organizational capacities. These priorities formed the basis for the initial research and outreach relationship. All training activities were developed and extended in a training-of-trainers format. In addition, key leaders of the NRMAC have profited from national and international study tours.

Formal training of NRMAC members and their local technical assistance partners covered three domains. Holistic management (HM) workshops focused on applying holistic principles to evaluate on-farm research trials, establish wetlands management, and develop a grazing system for open rangelands. Conflict management workshops focused on building consensus, managing power and change, and adapting this training to the management of wetlands and open rangeland grazing. Institutional reinforcement based on an institutional analysis of organizational strengths and weaknesses led to training in the following: functional literacy; democratic governance; financial management and accounting; strategic planning; NRM texts, codes, and laws; decentralization codes and laws; and lobbying.

Training in natural resource and conflict management

Holistic management as an approach to natural resource management was first conceived in southern Africa and has been applied around the world. It helps to foster skills necessary to maintain adaptive management dialogue among stakeholders. HM involves diagnostic tools to evaluate resources, rotational grazing strategies to optimize livestock feeding and pasture management, and visioning techniques to channel dialogue toward consensus. HM training and implementation in Madiama initially concentrated on the contentious issue of *bourgou* management and moved on to help the NRMAC with more common dryland pasture issues, introducing timed rotational grazing strategies. (*Echinoloa stagnina* or *bourgou* in French is a wetland grass that grows with the rising river waters during the rainy season. It is prized as a very nutritious animal feed.)

Training in conflict management

This training provides techniques for resolving differences within the contexts of scarcity, diversity, and unequal power distributions (Goebel et al. 2005). The training is well adapted to conflict avoidance and management where natural resources are concerned. NRMAC members have been very pleased with conflict management training and assert that it has had the most impact of all early SANREM interventions; indeed, fewer conflicts were reported by community members. Clashes have been avoided or managed using the techniques learned during the training. Conflict management tools used successfully helped legitimize the NRMAC and the SANREM program, particularly when combined with agricultural and NRM research and interventions planned in collaboration with the NRMAC and jointly implemented with local partners.

Training in literacy, governance, and financial management

To be effective, NRMAC members require significant training in organizational leadership, democratic procedures, literacy, and financial management. The value of literacy and numeracy training is that it gives the NRMAC the capacity and confidence to act autonomously: gathering information, writing plans, managing a budget, and contacting government authorities. Training is essential in the processes of decentralization and democratization.

Institutional strengthening was provided to the committee by the Djenné office of CARE/Mali through formal workshops, informal exchanges, monitoring and technical assistance, and study tours. The institutional reinforcement training program was initiated with an institutional diagnosis that identified the strengths and weaknesses of the organization. Focusing on the identified weaknesses, a plan for institutional development was elaborated. Thus, the formal training program applied functional literacy methodologies, focused on the principles of democratic governance, and assured comprehension of national texts, laws, and codes for NRM and decentralization. Subsequent training addressed financial management and accounting, strategic planning, and lobbying. These workshops were designed to create a framework of exchange and dialogue between the NRMAC and the other actors implicated directly or indirectly in NRM. The NRMAC also benefited from the support of CARE in conducting inter-village negotiations to establish agreements for wetlands management. Institutional coaching also included assistance in developing statutes and rules of procedure, formal registration of the organization, financial management, the mobilization of the external resources, and the development of linkages with other local service providers and NGOs.

Since the initial workshops, the lessons learned at these training sessions have been routinely communicated at the village level, at first under the supervision of the SANREM trainers. However, responsibility for this communication has increasingly shifted to NRMAC members. To date, NRMAC trainers have designed and implemented five workshops at the village level and hosted a workshop for commune level representatives across the Cercle of Djenné. These events created a framework for exchange and dialogue among the NRMAC and other local leaders.

Step 4. Complementing local knowledge with biophysical and socioeconomic research and development that lead to improved technologies and decision-making tools

SANREM's science-based tools include biophysical and socioeconomic models that can be used to generalize the experience of one commune to other, broader geographical areas.

Biophysical modeling

In Madiama, SANREM has applied CropSyst, a cropping systems model that predicts the influence of climatic conditions as well as soil and management practices on productivity and sustainability at the field system level (Badini et al. 2005). CropSyst serves three purposes:

- to simulate results with variables such as yield, soil fertility and erosion over 20 years, allowing for long-term evaluation and comparison of current and alternative farming and NRM technologies without long-term field tests
- to identify crops and technologies best suited for ecosystems in the region
- to provide a basis for dialogue with NRMAC, local farmers, and herders

The biophysical models require rainfall data, obtained from official meteorological statistics and supplemented with rain gauges placed by the project and monitored by local stakeholders.

The models also use soil data collected by a cost-effective alternative to classic intensive soil surveys that combines computer-based remote sensing analysis and geographic information system technologies with limited field assessment and ground-truthing to classify and map soil types, vegetative cover, and agricultural land uses.

The dialogue with local resource users builds on the farmers' and herders' own considerable knowledge of the land and on prescriptions regarding crops and NRM techniques suggested by the modeling. Researchers correlate their scientific soil training with conventional soil concepts that farmers have devised, and they enter into discussion with farmers using the local terminology. Through this dialogue, researchers use the model to confront the local reality, and farmers gain access to the researchers' knowledge of model-identified alternatives and the benefits they can bring.

Socioeconomic modeling

SANREM researchers also developed a social accounting matrix (SAM) for the commune of Madiama. The SAM is a modified input-output model that shows the flow of income and expenditures among production activities and among socioeconomic groups and the community/watershed level. It is a flexible, powerful tool that can be used to analyze market systems in diverse social and cultural settings from villages up through states and regions. Given its flexibility, the SAM can also be developed to address specific topics such as environmental issues (Miller et al. 1985) or migration (Adelman et al. 1988) and may also complement expanded policy analysis built on computable general equilibrium modeling efforts (Taylor et al. 1999).

The SAM is organized as an accounting matrix of modeler-selected endogenous and exogenous sectors' inflows and outflows. It is based on the assumption that production activities are endogenous and demand-driven. Endogenous accounts are those for which changes in the level of expenditure directly follow any changes in income. The endogenous accounts typically include the following: production activities (the input-output submatrix), factors such as labor, and institutions such as households and firms. Exogenous accounts are those determined outside the community level. Typically these consist of policy and markets.

Four types of farm household systems were identified according socio-professional status by community leaders as being most important for understanding the commune: farmers, whose income is mainly from crops; agro-pastoralists, who have a significant amount of livestock as well as crops; sedentary pastoralists, who grow crops but regard livestock raising as their primary occupation; and transhumants, who move their livestock seasonally to grasslands within or outside the commune along traditional routes. Major findings illustrated how benefits from increased production in any activity are passed on through repeated cycles of spending and income to benefit other production activities and the incomes of the other household types. In Madiama, it was found that an increase in production in any sector, including livestock, benefits transhumants far less than the other three socio-professional groups. Thus interventions must take particular care to target transhumants specifically, or they will tend to fall farther behind economically, a situation that could contribute to greater conflict. The Madiama SAM results are relevant to neighboring communes with similar socioeconomic groups and natural resource bases (Brewster et al. 2004).

Step 5. Monitor and evaluate

The broad-based SANREM strategy requires an equally broad-based monitoring and evaluation process to assess progress and to identify and correct problems. Much of the monitoring and evaluation process is participatory, with indicators and measurements identified and followed by the local participants. However, to take advantage of local learning and apply it horizontally across communes and vertically to the regional level, the universal language of science must be employed. While local definitions of resources, indicators, and results are indispensable for local applications, on their own they may not be widely applicable. The fundamental strategy that SANREM uses to apply results to contexts beyond the commune is to ensure that biophysical and socioeconomic researchers work with those variables and categories that local populations understand and are familiar with. This choice of variables and categories is the responsibility of the researchers so as not to overburden local participants with data gathering they do not understand or for which they have no practical use.

Services Provided

The NRMAC has served as an interface for the commune with government services. However, during its first three years of existence, the committee initiated additional activities.

Monitoring Research Trials

Improved soil fertility

During the first year, researchers worked with user groups in three target villages. These groups chose collaborating farmers for the field tests. In the second year, the NRMAC made certain that each of the village NRM user groups participated. Trial sites in each village allowed for this participation. However, not all farmer collaborators managed their plots conscientiously. The NRMAC learned from this experience and more closely monitored the quality of farmer participation in subsequent years. These trials provided a focus for addressing issues of increasing soil fertility within the commune.

Pasture improvement

Given the complexity of coordinating the management of communal pasturelands, pasture improvement research began more slowly by building rapport and establishing common objectives within the community at both the commune and village levels. Two open-range rotational grazing sites and ensilage trials based on *Cassia tora* to optimize forage resources for women were ultimately established (El Hadj et al. 2005; Abaye et al. 2005).

Information Exchange

A considerable amount of information filters through the NRMAC. This privileged position allows the NRMAC to learn about new techniques and technologies, codes, and laws concerning decentralization and NRM; and to develop skills in the management of community affairs, including conflict prevention. The primary method of information exchange is through direct contact. The committee holds business meetings on the last Sunday of each month and less routinely conducts training workshops at the village level. The mayor or his representative routinely participates as an ex officio member. The village representative on the committee reports the information and/or issues discussed in these meetings to the village chief and to some extent the village NRM user groups. NRMAC members are not equally proficient at reporting back to their villages, due in part to their educational levels but also to a reticence or lack of confidence in their own information transfer roles. Consequently, the overall quality of these communications has suffered. Nevertheless, village chiefs report being well informed about NRMAC activities.

NRMAC members have been trained as trainers and have appropriated this training to develop their own training modules, often in a local theater format, a mechanism that disassociates the individual from the message. This training has been conducted in four villages. The NRMAC has also conducted four information and awareness-building programs on the local radio station, with three rebroadcasts to date. Five committee members, including two women, led each program, with a total of 10 committee members participating. These programs have described the NRMAC mission, a campaign to protect the balanzan (*Acacia albida*), local agreements for the promotion of wetlands regeneration, and issues of decentralized administration.

Forestry Services

Early in the life of the NRMAC, the mayor called on it to assist him in the promotion of a national campaign to protect the *Acacia albida.* Drawing on the network of village NRM user groups, the NRMAC was able to disseminate the message quickly. This action resulted in a reported decrease in damage to this nitrogen-fixing tree.

The NRMAC also led a reforestation effort, purchasing and planting trees. Six villages had sufficient water at the time of planting to assure tree establishment and consequently requested a total of 149 trees of three species (neem, baobab, and néré), which were planted. The village NRM user groups were responsible for planting and watering until these trees were fully established. The head of the Service de la Conservation de la Nature (forestry service) was impressed with the user groups' independent action and assured them that future support would be available.

Agreement Development

The NRMAC has initiated dialogues with selected villages to develop agreements for the regeneration of seasonal wetlands in the commune of Madiama. Stakeholder negotiations were initiated in four villages, but due to a lack of consensus in one of the villages, only three were retained for the wetlands regeneration program. Negotiations were also begun with neighboring villages and stakeholders to establish local agreements governing the sustainable exploitation of these basins. (The objective of these agreements is to minimize conflicts between wetland users, improve the management of pastures, and develop the financial resources to maintain them. The agreements define the parameters of collaboration as well as the roles and responsibilities of each party. Two multivillage agreements have been drafted, but no progress in implementation has been made.)

Conflict Resolution

Violent conflict in the commune of Madiama decreased over the three years following the initiation of SANREM activities (Moore and Cissé 2005). Although their claims were difficult to verify objectively, community members attributed this at least in part to the awareness building of the NRMAC. The local population deeply appreciated its ability to resolve conflicts locally, that is, without recourse to government authorities.

On two occasions, the NRMAC was called on to intervene in local conflicts. The first occasion involved the early entry of cattle into the commune. This incident was the result of a need for water and did not actually involve cattle entering unharvested fields. However, other herders in the commune were not happy about this breach of the agreement concerning the date of entry, for their herds were forced to remain outside the commune. After informing the mayor of the unauthorized entry into the commune, the other herders were ready to call the *gendarmerie* of the Cercle.

However, NRMAC members spoke with the principals in the conflict and negotiated a resolution, thereby avoiding involvement with the authorities.

The second incident involved a fight between a Peul and a Marka in the village of Promani. When one of them was seriously wounded, the village chief called the *gendarmerie*, and the aggressor was taken to jail in Djenné. Only after this incident was the NRMAC called in. Although at this point there was still considerable animosity between the two combatants' families, the NRMAC was able to negotiate an *entente* between them and persuaded the family of the wounded participant to withdraw the charges against his assailant, resulting in his release from jail.

Resource Mobilization

The NRMAC has benefited from both technical and financial assistance through the SANREM CRSP project. However, the committee recognizes that it must be able to generate its own resources if it is to maintain a meaningful role in the community.

Internal

NRMAC membership cards have been designed and printed at the expense of the association to provide a credible presentation and to generate funds through a one-time membership fee. By mid-2003, more than 250 people had paid the 500 FCFA fee. (FCFA is the name for the West African [francophone] financial community currency. Five hundred francs CFA is worth about $1.00.)

External

Learning of an opportunity to request funding from the philanthropic organization Fondation de France, the NRMAC considered proposing income-generating activities, including animal vaccinations, soap production by women, and techniques for seed multiplication. However, it was concluded that the NRM mission would be best served through assistance in developing a communication strategy for the association. With help from CARE/Djenné, the NRMAC submitted a proposal that was later revised and resubmitted. Fondation de France approved the proposal, and the consultancy has been completed.

Summary

The NRMAC has begun to mature as an organization in the service of civil society in Madiama. Founded in both modern legal traditions and customary practice, the NRMAC is on the cutting edge of the transformation in rural civil society in Mali during this era of decentralization. It has provided space for dialogue between villages and ethnic groups and is building the confidence to address sensitive issues involving resource allocation.

NRMAC members see communication as key to viability as a civil society organization. Linkages with CRRA/Mopti researchers, other service providers, NGOs, the village chiefs, and the commune council place the NRMAC in the center of an important network of NRM decision makers. With its members trained not only in the management of their organization but also in how to provide leadership for other community groups at the village and commune levels, the committee has taken a leadership role in disseminating information concerning new technologies, innovative approaches to community-based NRM, decentralization, tree planting, and other issues of natural resource conservation. Members have dealt with conflict situations and facilitated their resolution. They have also initiated but not consummated the establishment of multi-village resource management agreements. Overall, from the villages to the commune council, community members have been satisfied with NRMAC performance and have renewed its mandate.

Conclusions

Skills in conflict resolution have led to increased confidence in relationships across ethnic groups and village clans. Although this has not yet led to a broad-based local consensus on resource use, the building blocks for an autonomous civil society are emerging. (Previously social capital was never explicitly mobilized due to the ignorance or contempt of the administration or the rigidity of its rules and procedures. It can now be seen to have possibilities. For example, all the village chiefs of the commune of Madiama questioned concerning their perception of the creation of the rural communes [decentralization] noted that it had led to the breaking of relations with the commandant [*sous-prefet*], that is, with the administration [Touré 2003]. Those same village chiefs also noted the positive contributions of the NRMAC to commune life.) For consensus to occur, two conditions are needed: a fully committed national decentralization policy involving protection for minority rights, and new bridging organizations between traditional village hierarchies and local government. Through a sector-specific (NRM) initiative in Madiama, disparate groups have initiated dialogue on critical decision-making issues. This analysis demonstrates the importance of building on established social relationships and combining them with linkages across groups for community-based NRM. In this way, viable negotiated solutions can be achieved and a new social contract realized.

The policy of decentralization in Mali has created the opportunity for civil society to emerge as a component of rural community systems. However, further changes at the national level supportive of independent civil society organizations are necessary for rural civil society to prosper. Decentralization has created the opportunity to build existing bonds at the village level into a network of relations creating a modern tool at the commune level. However, national leaders and administrators must devolve more authority to match the responsibilities that have been decentralized. At the same time, maintaining an independent judiciary is critical as minority groups assert their rights in a context of shifting local power relations.

Organization at the multi-village commune level in the Sahel is essential. We believe that donor and NGO emphasis on building village-level associations, while successful in mobilizing local resources for development, is insufficient because the scale is too small to offset the costs of extended replication and village social capital is too insular for these associations to have a transformative effect on rural social structures and dynamics. For rural civil society to grow, linkages among villages must be developed and citizen networks established. In particular, we recommend the reinforcement of all commune-wide associations that increase the number of ties between agriculturalists and pastoralists. We must qualify this in regard to the development of women's role in rural society. While women are often constrained by tradition to remain in the village, women's village associations are serving to mobilize them in their struggle for improved quality of life. These opportunities for women to formally associate should be encouraged.

Finally, a word of caution: Creating opportunities for empowerment of local populations takes place in historically specific conditions where power and the "weapons of the weak" are well entrenched. Development agents trying to encourage the growth of modern civil society should take into account our lessons learned:

1. Including all stakeholders is a necessary but problematic task.
2. There is no single model for building social capital; linkages are historically contingent.
3. Project and partner personnel need to be well trained in participatory approaches.
4. Power relations and stakeholder interests need to be carefully taken into account.
5. Development agents must foster synergy between public and private sectors.
6. Conditions of dependence on external resources should be avoided.

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Chapter 12

Systems Integration and Innovation

Keith M. Moore

This transdisciplinary book has been designed as a foundation for a second Green Revolution driven by smallholders and their development facilitators. It can be summarized in six messages grouped under three themes. The first theme is food security, poverty, and environmental degradation as linked problems. These problems and their solutions are emergent from the complex adaptive systems of which they are a part. The Sustainable Agriculture and Natural Resource Management (SANREM) landscape systems framework provides a way to organize this complexity to learn from it and identify viable management options. Thus, the first two messages are as follows:

- Each SANREM landscape system is a scientifically documented coherent whole with its own terminology, dynamics, and drivers.
- Individual systems do not function in isolation; the cross-scale effects of one system on another may lead to abrupt shifts in individual and overall system impacts.

The second theme is problem management as an adaptive learning process. Adaptive management provides development practitioners with a learning-by-doing methodology. The second two messages are as follows:

- Adaptive management is a knowledge- and management-intensive learning process.
- The learning experience is not just a matter of one-time adoption but an iterative process of decision making, action, and evaluation.

The third theme is successful adaptive management as a team effort. It is not an individual activity, nor can it be implemented in a simple top-down fashion. Producers, conservation and development agents, and market and policy actors are all tightly interwoven in the complex adaptive systems they are trying to manage. Coordinated behaviors are necessary for successful management and effective learning. The last two messages are as follows:

- Effective management of complex adaptive systems requires the leadership and collaboration of multiple stakeholders across system levels from the field and farm household to the government and markets.
- Successful comanagement of complex adaptive systems involves institutionalized mechanisms for multi-stakeholder communication and governance.

Adaptive Management

The chapters in this book teach us that adaptive management is a way of life. It constitutes a matter of day-to-day routines: listening, observing, and documenting results as the growing season advances. These routines are punctuated periodically with the reevaluation of goals and objectives, and subsequently, modification or reinforcement of behaviors and practices. Adaptive management must operate at multiple system levels, providing options and alternatives adapted to decision-maker circumstances.

Listening to these various authors, we learn that adaptive management begins with problem definition, goal setting, and planning. Problems are frequently defined with respect to soil quality, but their resolution requires higher system-level responses. Several authors mention the importance of conservation agriculture strategies to reduce or eliminate the disruption of natural soil processes, maintain soil cover, and rotate crops. Adopting conservation agricultural practices involves a series of adaptations across system levels.

Adaptation implies making changes in the way we do things. A certain amount of risk and uncertainty is to be expected. As Wyeth (chapter 3) points out, risk is a critical element shaping farmer assessments of their production possibilities. These risks need to be shared and a consciousness developed that we are in a process of learning together how to reduce or mitigate them. Buck and Scherr (chapter 8) emphasize the collaborative dimension of adaptive management as critical to the successful development of local innovations systems. Improvements in the production system at the farm level are mirrored in improvements across the rural economy. The lessons learned contribute to transdisciplinary and locally adapted knowledge bases or, as Alwang et al. (chapter 10) suggest, with an eye to operational implementation—"transfunctional" knowledge. This holistic, transdisciplinary knowledge founded on a base of solid scientific research at various system levels is needed to change the farm household livelihood opportunity sets. Making that knowledge useful in the daily lives of rural communities requires adaptation from the behavioral practices of those livelihoods.

Complex Adaptive Systems

If this book had been written by a single author, the transitions from chapter to chapter would have been smoother. However, there would have been a tendency to maintain the same tone, language, and terminology. Consequently, recognition of different perspectives across systems, scales, and disciplinary approaches would have been lost. Each system has its own terminology and key concepts that provide its scientific insights. Through reading these chapters one comes to recognize the differences between the mindsets of the scientists working within each system. Nevertheless, there is a great similarity of messages from one system level to another. The authors approach the integration of various system levels diversely, but all recognize the significance of cross-scale interactions and effects, demonstrating the necessity of the landscape systems approach for sustainable agriculture and natural resource management. Given the diversity of factors involved at various system levels, recognizing the site and time specificity of a management problem is critical to the identification of potentially viable adaptive management options. Specific technological interventions will be embedded in the broader socio-ecological context, requiring both an understanding of watershed and ecosystem dynamics and a supportive local community and government environment. Let us review the basic system drivers, components, and principles of the complex adaptive landscape systems and their cross-scale interactions; then consider a set of tools and techniques for their adaptive management.

Boundaries of Nested Landscape Systems

Field systems (Mueller et al., chapter 2) are the primary units of managed space in which the biophysical components of the productive process come together: soil, water, microorganisms, and energy. Through a series of bio-geochemical processes, microorganisms cycle carbon, nutrients, water, and energy through the soil, creating the soil organic matter that preserves those same components for the nourishment of plant and animal life. In their turn, the fruits of the plant life are harvested and exported to other system levels.

Farm household/enterprise systems (Wyeth, chapter 3) are the interface between field systems and input and output markets, ecosystem services, and policies. These farm systems are managed by primary producers who organize the land, labor, and capital resources shaping their production possibilities. The focal point for production and innovation decision making is found within this system level. Smallholder choices are also shaped by risks and opportunities for sustained and culturally meaningful livelihoods. While the degree to which decision making operates in a unified fashion varies culturally and historically, some form of kinship unity and reciprocity operates and is mediated by local norms and practices regarding age and gender.

The watershed system (Walker and Mostaghimi, chapter 4) is defined by the land that drains to a particular point or outlet. While the corresponding governance boundaries may not exactly coincide, community watersheds aggregate and unify the biophysical and socioeconomic dynamics of the field and farm systems and pose questions of collective, community-based governance and decision making. Water is the critical element driving this system and linking it across systems. Variability in system dynamics is a function of rainfall events and the soil and topographical features shaping the water's consequent infiltration, percolation, and evaporation or transpiration. Management relies as much on successful negotiation of stakeholder priorities as on the coordinated implementation of specific field system practices.

Ecosystems (Haas et al., chapter 6) are defined similarly to field systems in that energy, nutrient and water cycles are the underlying features. However, ecosystems as discussed here are delimited by the foraging range of the particular species of interest—in this case, humans in communities. With increasing globalization these boundaries are expanding with the associated system threats. Management focuses on those cycles that provide communities with food, water, fiber, and fuel; regulate polluting practices; and offer aesthetic and spiritual nourishment while constantly attending to the foundation of soil formation and nutrient cycling.

The policy-market system (Shively and Birur, chapter 7) is driven by incentive and constraint signals in the form of prices. These signals communicate the choices and tradeoffs to consider in securing livelihoods and in conducting productive activities. Institutions at the local, national, and international levels establish the rules and norms for legitimate behavior shaping those incentives and constraints. Policymakers negotiate the rules established by these institutions. The resulting compromises may hamper or facilitate the communication of market signals as a function of market competition, information, and knowledge transfer. Innovative behaviors can be enhanced through careful designation of incentives and constraints.

Cross-Scale Interactions

Cross-scale interactions are remarkably common, and their impacts need to be considered as an integral component of adaptive management decision making. Field practices that open the soil and leave it exposed to wind and water erosion can lead to losses of pollutants and sediment, which affect aquatic biodiversity, water availability, and drinking water quality throughout the watershed. Field practices, in turn, may be affected by input or crop price-support subsidies, which promote monocropping or excessive application of fertilizer or pesticides. On the other hand, policy and/or price supports may create conditions for local innovation. Input subsidies can stimulate positive adaptation and growth in the small-farm sector.

Governance systems that shape and enforce policies at the local and national levels can improve or constrain effective management of field, farm, watershed, ecosystem, and policy/market systems. Collaboration and co-learning at the community level can have a significant effect on innovations that improve productivity and/or conservation within field systems and livelihood outcomes at the farm household level.

Functioning input and output markets shape the conditions under which farm households manage their resources. Cross-scale effects are not fixed; these complex interactions require analysis and modeling where possible. For example, policies supporting biofuel development may reduce net greenhouse gas emissions compared with fossil fuel, but they may simultaneously increase greenhouse gas emission through deforestation and conversion of grasslands to biofuels production. While biofuel support policies may increase farm incomes for some, others may be left food insecure when food crops are used to produce biofuels. Off-farm employment opportunities affect the availability of labor for productive activities on the farm. Trade policies condition practices at the field level, such as whether to plant cacao or maize. Credit availability provides increased potential for investing in more profitable farming technology or for overusing chemical inputs.

Long-term sustainability depends on practices of multiple smallholders across the landscape. For instance, the "tyranny of small decisions" can lead to either increased forest cover, reducing stream water temperatures and improving rainwater infiltration and groundwater supplies; or forest clearing can yield fresh fields for agricultural production and improved farm incomes. In either case, land tenure arrangements may or may not support a suitable environment for developing carbon-trading schemes for carbon sequestration. Further, overspraying pesticides may induce pesticide resistance and consequent harvest losses, which at a sufficient scale may lead to famine. Various combinations of these management options can facilitate or inhibit wildlife buffers, habitat, and migration corridors that provide field systems with a source of pollination and beneficial insects for pest control. A careful balance needs to be collectively maintained.

Principles and Tools for Adaptive Management at the System Level

The essence of adaptive management is for all stakeholders to assume their stewardship responsibilities at the system level in which they reside and to support others within their respective systems. Just as each system has its own distinctive characteristics and dynamics, each has its priority concerns too.

At the field level, regenerative practices should enhance soil organic matter, assure clean and abundant water supplies, protect biodiversity, particularly of soil resources, and reduce dependence on external energy inputs.

Smallholder innovation can be enhanced by focusing on those practices that have both short- and long-term benefits, are supported by viable input and output markets and policies, accommodate and reduce risk, and are supported by patient, collaborative, and inclusive efforts of external agents.

Those sharing landscapes at the community level should develop cordial relations and positive synergy among themselves for watershed management to be successfully organized and implemented through an inclusive process that allows them to identify common problems and their likely causes, agree on reasonable goals and determine the levels of action required to achieve them, evaluate solutions in terms of their effectiveness in meeting common goals, interaction with other resources, economic feasibility, and site suitability, implement agreed-on solutions, and monitor results and evaluate the effectiveness of solutions.

At the ecosystem level a broader perspective is required for sustainability that focuses on long-term and large-scale consequences, maintains local diversity and recycles local materials, and works with the natural environment.

These actions can be enhanced through maintaining a policy/market environment that generates smallholder production incentives signaled by market prices, establishes norms and rules of behavior favoring those incentives, establishes norms and rules of behavior discouraging resource degradation, secures enforceable property rights, and facilitates the development and introduction of innovative technologies.

Complex adaptive system management is both knowledge and practice intensive. It is also locally specific. The following list of tools, technologies, and practices is indicative of the types of options stakeholders should consider and, if agreed, test and evaluate. The items are grouped by system but, as one can see, because of their cross-scale nature many would be easily categorized otherwise.

Partial list of tools, technologies, and practices for adaptive management

Field

Mulch
Cover crops
Hedgerows
Compost and other organic amendments
Reduced tillage
Conservation agriculture
Fallowing
Water conservation
Drip irrigation
Treadle pump
Reduced external inputs and contaminants
Integrated pest management
Crop rotations/crop diversity
Intercropping
Promotion of soil biodiversity

Farm

Integrated crops and livestock
Controlled grazing
Credit (micro and alternatives)
Adaptation of tasks to available labor

Community

Bringing stakeholder groups together
Being inclusive and cognizant of differences
Facilitating respectful social interaction
Finding common ground and language
Building congenial and trusting relationships
Acting transparently and accountably
Establishing platforms and networks for communication and action

Watershed

Soil and hydrologic data collection
Group goal setting and problem solving
Use of geographic information systems
Watershed modeling

Ecosystem

Understanding local ecosystem
Planting trees
Agroforestry
Wildlife corridors and riparian buffers
Biocontrol of pests
Sustainable harvesting (of trees and wildlife)
Non-timber forest products
Designation of natural parks and reserves
Payments for ecosystem services

Policy/Market

Removing or initiating input subsidies
Encouraging perennial crops
Promoting resource conserving practices
Introducing risk-reducing innovations
Strengthening local institutions
Supporting secure property rights
Improving smallholder market linkages
Coordinating national agencies
Building human, social, and physical assets

Building Transdisciplinary Teams

One of the primary points of this book is that we must work together. No one discipline, institution, farmer, entrepreneur, or government agency has everything needed to manage the emergent properties of these complex adaptive systems. In fact, one of the lessons of the systems approach is that the whole is truly greater than the sum of its parts.

Establishing Institutional Arrangements

Innovation for adaptive management involves the mobilization of individual actors and groups across the landscape. Care must be taken in bringing these individual actors and groups together. This care is double faceted. Bringing people together across the landscape and with non-local stakeholders involves organizational skills (Buck and Scherr, chapter 8) as well as basic etiquette and civility (Flora and Thiboumery, chapter 5). On one level, the landscape may include individuals and groups who have never even met. They may very well have different customs, norms, and language, and come from different social classes or status levels. Furthermore, their knowledge and frames of reference are likely to differ significantly. While fostering technological change in complex adaptive systems is enriched with knowledge across a wide range of local and scientific perspectives, it also requires the skills of facilitating communication between and among local and technical knowledge producers and users. Mutual respect must be established for both local and scientific knowledge and its caretakers.

Being cordial and open to learning from one another is not enough. Knowledge and information need to be proactively shared among those faced with similar sets of opportunities and constraints. Building networks of these individuals and groups strengthens the social learning process and assures that knowledge development is adapted to local settings. The sharing of experiences and information helps to create lasting relationships on which adaptive management practices can be built. Taking action on those understandings requires more formalized platforms or forums for discussion, debate, learning, negotiation, and decision making. Platforms help to gather the relevant actors to focus on specific issues or problems for which action needs to be taken. They provide a framework for linking with and bringing in non-local stakeholders such as policymakers, entrepreneurs, government agencies, or other scientists or advisors. Through these platforms awareness can be built, goals specified, resources negotiated, and joint actions taken.

While activities that develop social relationships are critical for building social capital and mobilizing other community or non-local resources, human capital development is also required. Adaptive management of complex adaptive systems is knowledge intensive, involving new and often more complex skills. This is not a matter simply of social learning but of training in and development of new technical and management skills among the local partners. One of the most critical elements is the realm of leadership training and development.

Creating Leadership

There is a real need for leadership. Leaders come in many forms depending on the specific knowledge and skills to be mobilized at a particular moment. The key leader is the overall facilitator for adaptive management of the landscape. This leader may be from a government or non-governmental agency or from a farmers' organization, that is, someone with the power to bring diverse groups together in the first instance. Whatever the source of leadership, leaders should be perceived as neutral, adept in promoting experiential learning—to guide without leading—and able to motivate others, putting them at ease during the process of problem identification or when negotiating a solution compatible with all stakeholder concerns. Skills of the facilitator should be supplemented with knowledge of group management, learning processes, and facilitation tools (see Buck and Scherr, chapter 8).

But leadership involves a variety of stakeholders and scientific subject matter specialists (research and extension). Adaptive management is an ongoing process; local champions are critical to maintaining the momentum that leads to the success of adaptive management projects. A constant supply of leaders is needed. At any one time, there may be a series of tasks to be accomplished. As time goes on, the endurance of some leaders will fade, and others will have to carry on. Consequently, there is a constant demand for new leaders and leadership training.

Fostering Communication for Learning and Innovation

Communication, learning, and innovation don't just happen; they must be cultivated. While extension agents are often tasked with the responsibility for communicating, they are not the only ones involved in promoting and communicating. As Buck and Scherr (chapter 8) note concerning the management of complex adaptive systems, the "boundaries between generators and users of knowledge are blurred." Consequently, all stakeholders need to be communicators. It is the role of the facilitator(s) to ensure that the connections are made among this diversity of partners. Networks provide the framework within which routine information exchange can flourish. Community knowledge exchange is vital to planning and feedback for timely and relevant decision making. Establishing a shared framework or vision about landscape functions is both an end and a means.

Communication needs to be directed. Communication should be encouraged and transformed into creative problem solving. Once the foundation for communication is established (Flora and Thiboumery, chapter 5), social learning can occur. Facilitators should engage groups in conscious, self-directed learning and problem solving. Although experiential or inquiry-based learning is most apparent in the evaluation phase of adaptive management, it begins with the process of problem identification and goal setting, and it continues throughout implementation. This learning should encourage active engagement, motivating community members to exhibit responsibility and independence as well as develop creativity and problem-solving skills. However, it should not be presumed that community interaction will be without conflict. Shaping landscapes is a process of negotiation.

Communication is not simply a matter of words. Maps, photographs, and other visual aids facilitate the development of the spatial literacy necessary for the discussion of complex landscape issues. Geographic information systems, along with watershed and other models, increase the precision and value of information for decision making. However, these methods are not always easily understood by local decision makers. Communicating across disciplinary boundaries and introducing cross-scale information to local authorities can be challenging. Often, systems thinking is not apparent to single-issue stakeholders. Simple tools and/or models need to be used for transmitting scientific messages and findings.

Enrolling All Stakeholders in the Process

Inclusion of all voices is also required. However, empowering the poor is a challenge. There are difficulties in enrolling women and minorities in project or group activities (Flora and Thiboumery, chapter 5; Bell, chapter 9; Bertelsen et al., chapter 11). Lower-status individuals are often ignored, with meetings scheduled when they are otherwise occupied or located where they cannot attend. The costs of ignoring any stakeholders can compromise successful implementation. Both the weak and the strong can subvert collective endeavors. The poorest, women, and other minorities will require special efforts, but so too will powerful elites, government officers, and critical partners along the input and output value chains.

Implementation

The three case studies indicate a generic model for the implementation of adaptive management for complex adaptive systems. The process begins with problem diagnosis and moves on to building consensus around how to solve it. Innovation systems grow out of these locally expressed needs. Two of the case studies focus on community/watershed-level management and the other on household-level decision making as it affects higher levels of management. Clearly more resources were expended in the Bangladeshi development project, and a broader dispersion of impacts consequently occurred. Nevertheless, both development and research projects can provide the conditions for social learning and adaptive management. Each case study identifies the problem to be resolved concerning soil or water management, yet each one puts considerable emphasis on institutional and governance relations to accomplish the identified production and conservation goals. Issues of governance appear to emerge with the implementation of improved practices.

Problem Diagnosis

For researchers and development professionals alike, problem diagnosis begins with a review of local development experiences and priorities, an exploration of current findings and best practices relevant to potential behavioral changes, and collection of secondary data on the targeted area. Before trying to narrow problem diagnosis, it is important to gauge the context within which production or conservation improvements are expected. In Ecuador, Alwang et al. (chapter 10) began by conducting discussions with local officials integrating science and local knowledge to describe and evaluate economic, social, and environmental problems in the watershed. Bell (chapter 9) reviewed the lessons learned from previous projects in Bangladesh (no local participation, lack of local government/elite participation). Further, given the focus on poverty and the environment, the Management of Aquatic Ecosystems through Community Husbandry (MACH) project addressed revival of local fisheries but recognized the importance of focusing on the ecosystem as a whole. Incorporating existing institutional arrangements was critical to designing a sustainable supporting environment for adaptive management. Bertelsen et al. (chapter 11) framed their relationship with the local community in the new policy context of Malian government decentralization. The formation of the Natural Resource Management Advisory Committee (NRMAC) mobilized new leaders in the interstices between traditional and modern institutions and set the research and development agenda.

Dialogue with those directly involved in production processes is critical to understanding current management practices and to developing the rapport needed to build teams of local and nonlocal participants. Alwang et al. (chapter 10) note the importance of sustained contacts (through previous projects) between outside research agencies and local producers for building the confidence to collaborate effectively. Bertelsen et al. (chapter 11) applied the participatory landscape/lifescape appraisal methodology to provide a mechanism not only to learn about local biophysical, socioeconomic, and institutional conditions but also to build the collective team effort combining representatives from several local institutions with other community members. Workshops were used by the MACH project to bring stakeholders together and collectively identify key problems to be addressed. The interaction among stakeholders and the recording of their collective perceptions and priorities is a critical first step in building local involvement. Not only do outside agency representatives come to an increased understanding of the problems and potential solutions, but the exchange that develops among locals who seldom speak with one another provides the critical learning experience.

Consensus, Goal Setting, and Planning

Both Bertelsen et al. (chapter 11) and Bell (chapter 9) discuss action-plan development as a multistage process involving stakeholders discussing and developing alternatives in small groups before consolidating them in plenary sessions. Consensus building is actively sought at the primary-level village user groups (chapter 11) and resource user groups (chapter 9) who report to larger groups that involve local government partners and elites. The purpose of these groups is not only to set goals and plan collective interventions and research programs but also to institutionalize a process that shares information and lessons learned. As new needs become apparent, these relationships are in place to take new actions.

Having conducted earlier discussions with knowledgeable local agents, Alwang et al. (chapter 10) describe a process by which scientific information is introduced from the start into a participatory process of problem evaluation, goal setting, and planning. As a consequence, the scientific models were reformulated with improved local data, analysis, and evaluation. The approaches of both Bertelsen et al. and Alwang et al. frame the primary issue of decision making at the farm household level as it shapes the options for livelihood diversification and a diversity of household strategies.

Institutional Relations for Sustained Adaptive Management

In Bangladesh, the MACH project was organized around comanagement of the water-based ecosystem and involved many community-based organizations and their local councils. The research-developed NRMAC in Mali was more limited in scope and focused on community level conflict management and adaptation of technologies. However, each assured that an institutionalized platform for debate and action was being established. Alwang et al. (chapter 10) used a series of workshops to develop a platform for discussion of watershed issues within the two Ecuadorian communities in which they were working. In all cases, links with existing government and local institutions were made. Full participation of all stakeholders (the poor householders, local elites, government officials, and development agents) was critical to long-term success. This participation assures the legitimacy of the collective efforts. It also provides locals with the conditions and opportunities to become leaders. Local champions are an essential feature of sustainable local efforts.

Capacity building is critical to ensuring that local organizations and government units can develop and maintain an active role in adaptive management. Capacity building has two dimensions. In the first, institutional skills and behaviors are needed to assure that these organizations are well governed and effectively managed. Bell (chapter 9) and Bertelsen et al. (chapter 11) describe considerable efforts to accomplish this. Skills are needed in proper governance practices, literacy and accounting practices as well as more advanced business management skills. Learning for institutional development is time consuming and requires that all relations be adequately cultivated. Communication must continually move back and forth from user groups to local leaders.

Capacity to incorporate scientific and technical knowledge is the second dimension. Alwang et al. (chapter 10) and Bertelsen et al. (chapter 11) emphasized the active engagement of farmers and local officials in field research on new technologies and practices that may be put to use in adaptive management programs. Alwang et al. (chapter 10) found that initial skepticism over the value of models led to increased precision of models as stakeholders became more familiar with them. However, it was often necessary to use simpler techniques such as maps to communicate the results of these models in a form useable by local leaders. Involving farmers and local officials in the conduct of scientific studies and analyses led to improved understanding of cause-and-effect relationships and of the alternatives that were generated for potential implementation by all stakeholders. While training was useful for transmitting much of this new information, it was the learning-by-doing approach that assured the commitment of local leaders.

Take Risks, Monitor, and Adjust

All of these cases identified and implemented innovative practices. Mistakes were made, or lessons were learned, leading to management adaptations. By setting in place user groups and their supporting institutional infrastructure, a framework for learning (monitoring and adapting) evolved. Maintaining inclusive practices was emphasized in Bangladesh. The resource management organizations needed to retain a majority of poor resource users throughout the process. The NRMAC in Mali routinely brought issues of minority herders to the table, and pasture management became a key research focus.

Reviewing implementation, evaluating outcomes, and updating plans is an ongoing process. Models were helpful in facilitating this task to the extent that local leaders were involved in initial model adaptations (earlier learning). Models reflect cross-scale linkages and other decision-making domains. The NRMAC learned in its second year to manage research trials with farmers, identifying those cooperators most likely to fulfill their obligations and provide feedback across the community. The local review and evaluation of quantitative data in the Ecuadorian watersheds was complemented by qualitative data provided by locals concerning idiosyncratic local conditions or operational issues of implementation. This feedback, in turn, increased the analytic precision and research value to both researchers and local participants.

End of an Iteration

Writing this book was a collective effort in adaptive management; some likened it to herding cats. The various authors, trained as disciplinary scientists, acted and reacted as components of complex adaptive systems, elaborating their systems and crossing scales as these chapters of complexity emerged. Building on their diverse array of experiences from around the world, we negotiated each of their contributions in providing this collective product. However, this book is not designed for specialists; it is designed for transdisciplinary adaptive management facilitators.

The purpose of this book is to inform development practitioners about the range of expertise available for addressing the wide range of adaptive management options. In this iteration we attempted to provide the basic knowledge, terminology, understandings, and tools at each system level to improve the capacity of smallholders to better manage their assets. Chapters from the book can be used individually as needed to address a specific problem or collectively to help guide the coordination of team efforts. There is no single answer. Successful and sustainable solutions must be negotiated to deal with each specific time and place and must be agreed to by the range of current stakeholders.

A second Green Revolution is on the horizon, this one for smallholders. As we learn through the application of these system concepts and adaptive management principles, we can continue to communicate and adaptively revise our notions of how best to move forward.

Contributors

Jeffrey Alwang has been a faculty member in the Department of Agricultural and Applied Economics at Virginia Tech since 1989. He has served as an advisor to several developing countries, including El Salvador (2008–2009), Paraguay (2006), and the government of Zimbabwe and the World Bank (1997–1998). His teaching focuses on economic development and poverty reduction in rural areas. His research addresses issues in economic development and the economics of poverty with a focus on policies to attain poverty-reducing economic development in rural areas. He has conducted research in Central and South America, Africa, the Caribbean, and the Middle East. Alwang earned his master's degree in agricultural economics from Pennsylvania State University and his PhD in agricultural economics from Cornell University.

Robert Andrade completed his undergraduate studies at the Catholic University of Quito, Ecuador. In August 2008 he received a master's degree in agricultural and applied economics at Virginia Tech. His master's thesis examines livelihood strategies in Chimbo, Ecuador, and forms a major part of the book chapter. Andrade works with the National Agricultural Research Institute (INIAP) in Ecuador and has participated in both the Integrated Pest Management (IPM) and the Sustainable Agriculture and Natural Resource Management (SANREM) Collaborative Research Support Programs (CRSPs).

Victor Barrera has been a lead scientist at INIAP for more than 20 years. He leads a team on project design, implementation, and evaluation that provides technical support to key research teams at the institute. He has worked on integrated management of agricultural pests, natural resource management, agricultural marketing, gender, and community development among other projects. He received a master's degree in production systems from the Catholic University of Chile and is currently finishing his PhD in planning and project management from the Polytechnic University of Madrid.

Michael Bertelsen received his graduate degrees in agricultural economics from the University of Wisconsin-River Falls (master's) and Virginia Tech (PhD). During a professional career of nearly 30 years, he has taught land economics and agricultural policy at the University of Wyoming, served as a research economist with the United Fruit Company in Honduras, and worked as a long- and short-term consultant in the general area of agricultural and natural resource economics in more than 25 developing countries in Africa, Latin America, and Asia. He joined the Office of International Research, Education, and Development at Virginia Tech in 1995 and currently serves as its associate director as well as associate dean for international programs in the College of Agriculture and Life Sciences.

Dileep Birur is a PhD student in the Department of Agricultural Economics at Purdue University. He holds a master's degree in agricultural economics from the University of Idaho, a master's in agricultural economics from CCS Haryana Agricultural University in India, and a bachelor's in agricultural marketing from the University of Agricultural Sciences, Bangalore, India. His research interests are international trade and the environment, mainly focusing on bioenergy, land use and land cover change, greenhouse gas emissions, poverty, policy, and development. He has worked as a research associate in the Division of Agricultural Economics, Indian Agricultural Research Institute, New Delhi, and as graduate research and teaching assistant at the University of Idaho and Purdue University.

Louise Buck received a master's degree in natural resources planning and rural sociology at Colorado State University and a PhD in natural resources and development sociology at Cornell University. With more than 25 years of experience in the design, analysis, and management of integrated natural resources and rural development programs, she specializes in linking the capacities of universities and research centers with those of field-based development initiatives to improve the science and practice of natural resource management. Buck designed and developed a sequence of agroforestry and rural development projects in East Africa linking the World Agroforestry Center with the humanitarian organization CARE and other nongovernmental groups to demonstrate community benefits from trees in agricultural systems. At the Center for International Forestry Research and Cornell, she worked with organizations in Indonesia and Madagascar to advance the science and practice of community-based forest management. Currently she works jointly for Ecoagriculture Partners and the Department of Natural Resources at Cornell to foster innovation in integrated landscape management.

Salmana Cissé received his PhD in sociology from Université Paris VII. With more than three decades of research and development experience in the region of the inner delta of the Niger (Mali) and across West Africa, Cissé is a widely reputed expert in agro-silvo-pastoral livelihoods and production practices with a special interest in the land-tenure dimensions of rural production systems. As a consultant for the World Bank and multiple bilateral development agencies, he has managed and evaluated development projects and programs for national and international development agencies across Mali. Cissé is currently director of the Regional Agricultural Research Center for the national Institut de L'Économie Rurale in Mopti, Mali.

Denise Finney received a master's degree in horticultural science from North Carolina State University. She has more than 10 years of experience working with communities on agricultural development and research projects, primarily in Latin America and southern Africa. Finney served as project director for the SANREM CRSP at North Carolina State from 2005 to 2007.

Cornelia Butler Flora received a master's degree in rural sociology and a PhD in development sociology from Cornell University. She has worked internationally, primarily in Latin America, for more than 40 years as a program advisor for the Ford Foundation, consultant for the World Bank and United Nations projects, and as part of collaborative research projects in Latin America. She has been director of the Population Research Laboratory and Distinguished Professor of Sociology at Kansas State University, head of the Department of Sociology at Virginia Tech, and is currently Charles F. Curtiss Distinguished Professor of Sociology, Agriculture and Life Sciences at Iowa State University. She served for 15 years as director of the U.S. Department of Agriculture's Cooperative State Research, Education, and Extension Service North Central Regional Center for Rural Development at Iowa State University. She is a Fellow of the American Association for the Advancement of Science and a past president of the Rural Sociological Society, the Community Development Society, and the Agriculture and Human Values Society.

Emmanuel A. Frimpong is an assistant professor of fisheries science at Virginia Tech. He received a bachelor's degree in natural resources management at the University of Science and Technology, Ghana, a master's in aquaculture and fisheries at the University of Arkansas, and an interdisciplinary PhD in fisheries and aquatic sciences and natural resources policy at Purdue University. His research focuses on the effects of landscape disturbances on streams and their watersheds, and development of cost-effective methods for conservation of fisheries in these systems. He has worked in Midwestern U.S. agricultural landscapes and is currently a principal investigator on an AquaFish CRSP project in Ghana, studying pond aquaculture effluent influences on receiving streams and best management practices.

Carola A. Haas received her bachelor's degree in biological sciences at Wellesley College and her PhD in ecology and evolutionary biology at Cornell University. Her research focuses on how native populations of wild birds, amphibians, and reptiles may best be maintained on land used for production agriculture and forestry or other human uses. She is particularly interested in dispersal behavior. She has conducted much of her research on private land through the cooperation and kindness of farmers and foresters in North America and Asia. She leads the Southern Appalachian Silviculture and Biodiversity project, now in its 15th year. As a postdoctoral Fellow with the NSF/ Japan Society for the Promotion of Science, Haas worked in Japan for two years in affiliation with Yamanashi University and the Wild Bird Society of Japan. She has served on the faculty in the Department of Fisheries and Wildlife Sciences at Virginia Tech since 1993.

Sarah Hamilton is an anthropologist and professor and director of the program in international development at the Josef Korbel School of International Studies at the University of Denver. Her research focuses on economic, social, and environmental impacts of agricultural market participation by small-scale farmers; rural livelihood security; and the gendered dimensions of international agricultural development and environmental sustainability efforts. Previously she served as the director of Women in Development program at Virginia Tech. Hamilton received her master's degree and PhD in anthropology from the University of Kentucky.

Paul Hepperly, Fulbright Scholar and research director at the Rodale Institute, has played a leading role in efforts to provide organic solutions to global climate change, nutrient-dense food, famine prevention, and poverty reduction through research, education, and information outreach. His expertise extends to both organic and conventional agriculture. As a researcher/manager, he has worked in Central and South America, the Caribbean, Europe, India, and Africa. He has contributed to more than 180 publications on diverse subjects related to agronomy and pathology, carbon sequestration, and research program management. He manages long-term agricultural trials that promote farming, safe food, and pure water. He holds PhD, master's, and bachelor's degrees in plant pathology, agronomy, and psychology, respectively, from the University of Illinois. He was honored with the Rachel Carson Council Sense of Science Award in 2005 and a Fulbright Scholarship in 2007. His lifetime goal is to increase science and public awareness of biologically based farming systems.

Sarah M. Karpanty is an assistant professor in the Department of Fisheries and Wildlife Sciences at Virginia Tech. Her research includes studies of both wildlife behavioral ecology and the restoration of tropical native forests. Karpanty has worked in Madagascar since 1997 on predator-prey ecology in fragmented rainforest landscapes and community-based native tree restoration. She has been consulting with USAID in Madagascar since 2005 to explore the potential for passive versus active restoration of degraded rainforests in eastern Madagascar. She has been asked to participate in the development of a national strategic plan for forest restoration in Madagascar and has begun work with the Malagasy Department of Water and Forests, USAID, Conservation International, World Wildlife Fund (WWF), and the University of Antananarivo, Madagascar. Since 2004, Karpanty has been studying shorebirds to identify the factors that might regulate threatened and endangered species during migratory stopovers and the impact of human development on the Atlantic Coast of the United States.

Keith M. Moore received a master's degree in rural development at the Institute of Social Studies in The Hague, Netherlands, and a PhD in rural sociology at the University of Wisconsin-

Madison. He has more than 25 years of experience in the design, implementation, and analysis of agricultural and natural resource-based projects and policies. His activities have included managing research and technology transfer programs, building community-level social infrastructure, diagnosing institutional and technical constraints, designing information systems, and facilitating stakeholder communication. Moore taught at Oklahoma State University and the Institute of Technology in Malaysia, and conducted research in North and West Africa, Eastern and Western Europe, Southeast Asia, and the United States. He is currently associate program director for the SANREM CRSP at Virginia Tech, where he has worked since 1994 coordinating multidisciplinary research teams with project sites in Africa, Asia, and Latin America.

Saied Mostaghimi is the H.E. and Elizabeth F. Alphin Professor and department head of biological systems engineering at Virginia Tech. He has been widely recognized for his research, outreach, and educational programs in watershed management, in particular, soil erosion and non-point source (NPS) pollution assessment and prevention. Mostaghimi has published more than 350 technical works on watershed management, integrating modeling and monitoring for assessing the impacts of land-use activities on water quality, NPS pollution control, and impact of land-use activities on the quality of surface and groundwater. He has conducted sponsored projects and provided consulting services on NPS pollution control around the world. He is a Fellow of the American Society of Agricultural and Biological Engineers and currently serves on the executive board of the Chesapeake Bay Scientific and Technical Advisory committee, which has significantly contributed to the Bay cleanup program. Mostaghimi received his master's degree and PhD. in agricultural engineering from the University of Illinois.

J. Paul Mueller received a master's degree in agronomy from the University of Delaware and a PhD in grassland agronomy from Pennsylvania State University. He has been involved with international programs and projects beginning with a six-month study leave in 1985-86 to research intensive grazing management and pasture ecology in New Zealand. In 1993, as one of three co-investigators, he was awarded a five-year University Development Linkage Project grant from USAID to North Carolina State, Universidad de Costa Rica, and Universidad Nacional de Costa Rica. He initiated ongoing research with scientists in Cuba working on agroecological projects including organic production systems that integrate crops and animals. As a visiting scientist with the Food and Agriculture Organization of the United Nations, he conducted case studies in Costa Rica, El Salvador, Honduras, and Tanzania. He is currently a co-principal investigator on a U.S. Department of Agriculture International Science Education grant focused on organic agriculture in Uruguay; and serves as interim assistant dean for international programs for the College of Agriculture and Life Science at North Carolina State.

George W. Norton has been a faculty member at Virginia Tech since 1980. He was a visiting scientist at the Economic Research Service, U.S. Department of Agriculture (1999-2000), visiting associate professor at Cornell University (1987-88), and held adjunct appointments as a research fellow (1988-91) and a senior fellow (1991-94) at the International Service for National Agricultural Research. His teaching focuses on the economics of agricultural development and trade. His research addresses issues in agricultural development and production economics with a focus on evaluating economic impacts of agricultural research and integrated pest management. He chairs the Technical Committee for the IPM CRSP and has conducted research in Asia, Africa, Latin America, the Caribbean, and the Middle East. Norton earned his master's degree and PhD in agricultural economics from the University of Minnesota.

Sara J. Scherr is an agricultural and natural resource economist whose career has focused on agricultural and forest policy in tropical developing countries. She is founder and president of

Ecoagriculture Partners, a nongovernmental organization supporting agricultural communities to increase production and incomes, and to enhance wild biodiversity and ecosystem services. She is a member of the United Nations Environment Program Advisory Panel on Food Security and the board of directors of The Katoomba Group and REBRAF-USA. She recently served on the board of the World Agroforestry Centre and was a member of the United Nations Millennium Project Task Force on Hunger. Scherr's former positions include director of ecosystem services for Forest Trends, adjunct professor at the University of Maryland, co-leader of the Consultative Group on International Agricultural Research Gender Program, senior research Fellow at the International Food Policy Research Institute, and a principal researcher at the World Agroforestry Centre. She has been honored as a Fulbright Scholar and a Rockefeller Social Science Fellow. Scherr received her master's degree and PhD in international economics and development at Cornell University.

Devona Bell Sherwood has more than 15 years of professional experience in project management with a focus on ecosystem restoration, natural resource management, conservation, and rural economic development—needs assessments, project design and management, monitoring and evaluation, capacity building, and strategic planning. She holds a master's degree from North Carolina State University in natural resource policy and administration with an emphasis on multidisciplinary, collaborative, innovative, and alternative approaches to resolving conflict between sustainable environmental management and human pressures on natural resources. She is currently a senior project manager for the Everglades Partners Joint Venture, working on implementation of various elements of the South Florida and Everglades Ecosystem Restoration Program for the U.S. Army Corps of Engineers. Previously, Bell Sherwood was a program officer for Winrock International's Forestry & Natural Resource Management unit, working on the participatory natural resource management program that offers integrated strategies for sustainable resource management and livelihoods.

Gerald Shively conducts research on a range of topics related to poverty, economic development, and the environment in developing regions of the world. He is a professor of agricultural economics at Purdue University and an adjunct professor in the Department of Economics and Resource Management at the Norwegian University of Life Sciences. He serves on the executive committee of the Purdue Climate Change Research Center and is co-editor in chief of *Agricultural Economics*, the journal of the International Association of Agricultural Economists. He holds a PhD in agricultural and applied economics from the University of Wisconsin-Madison and bachelor's and master's degrees in economics from Boston University.

Arion Thiboumery will complete his doctorate at Iowa State University in December 2009 in sustainable agriculture, rural sociology, and meat science. His work has focused extensively on knowledge networks, adaptive management, and group organizing in the food system. To this effect, he coordinates the Small Meat Processors Working Group in Iowa and co-coordinates the national Niche Meat Processor Assistance Network, an extension community of practice. Operating at different scales, both groups bring together diverse stakeholders and assistance providers to more effectively, and in a coordinated fashion, support small-scale meat processing infrastructure development to promote sustainable rural development and new agricultural opportunities.

Abdoulaye Touré earned his Diplôme d'Ingénieur des Sciences Appliquées in agriculture at the Institut Polytechnique Rural in Katibougou, Mali. His work has included managing community-based rural development projects as well as democracy- and institution-building programs across Mali. Touré is currently regional coordinator for CARE in Mopti, Mali, focused primarily on the management of local conflicts.

Sharyl Walker holds bachelor's and master's degrees in agricultural engineering from Virginia Tech and a PhD in agricultural engineering from the University of Illinois at Urbana-Champaign. She has worked with a variety of local planning groups to address water-quality issues at the watershed scale and has taught college-level courses on water quality and watershed management. Walker currently serves as a conservation engineer with the Natural Resources Conservation Service of the U.S. Department of Agriculture.

Peter Wyeth has a bachelor's degree in economics from London University and a PhD in agricultural economics from the University of California-Berkeley. He was reared in several Asian countries and has spent most of his career in development work, particularly in Africa (Kenya, Lesotho, Cameroon, Mali, and Malawi, among others) but also in Asia (Afghanistan) and Latin America (Chile and Guatemala). His areas of special interest have been marketing and export diversification (especially in agricultural products), economic analysis of sustainable farming practices, agricultural policy, and monitoring and evaluation of development programs. He has taught economics at the University of Nairobi and economics and business at Washington State University. He worked for some years in the International Programs Research and Development unit at Washington State, from which he retired at the end of 2007. He continues to work in economic development at the university and to teach international business courses in the Distance Degree Program.

Index

Page numbers in italics refer to figures and tables.
Authors' names are in boldface.

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