

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.

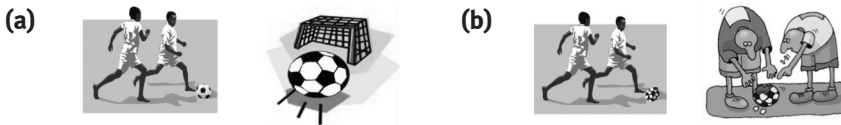


Figure 1. (a) Resilient system. (b) Nonresilient system.

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 regroupes 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

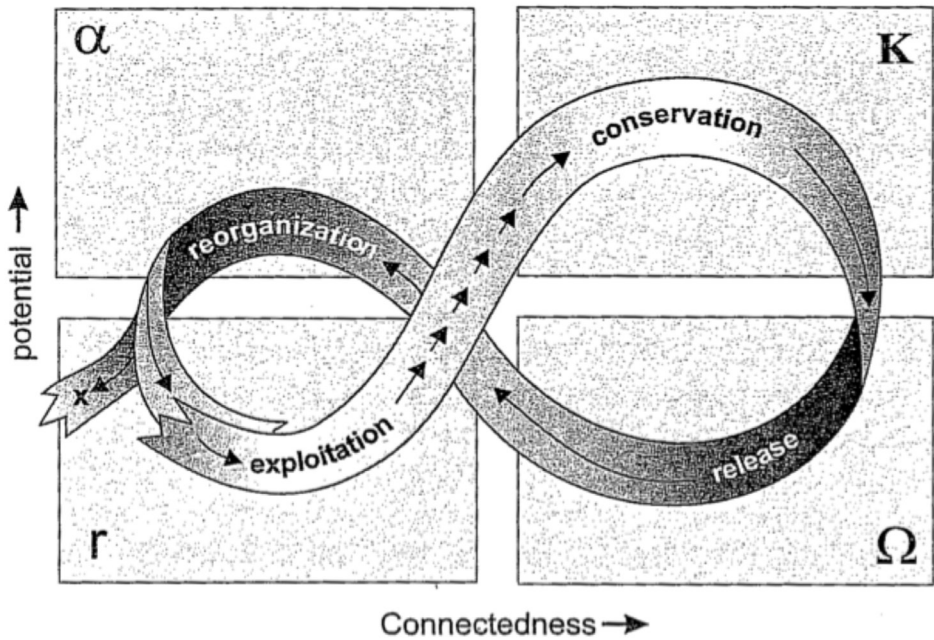


Figure 2. Holling's adaptive renewal cycle (from Holling and Gunderson 2002).

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 technologi-

cal 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-

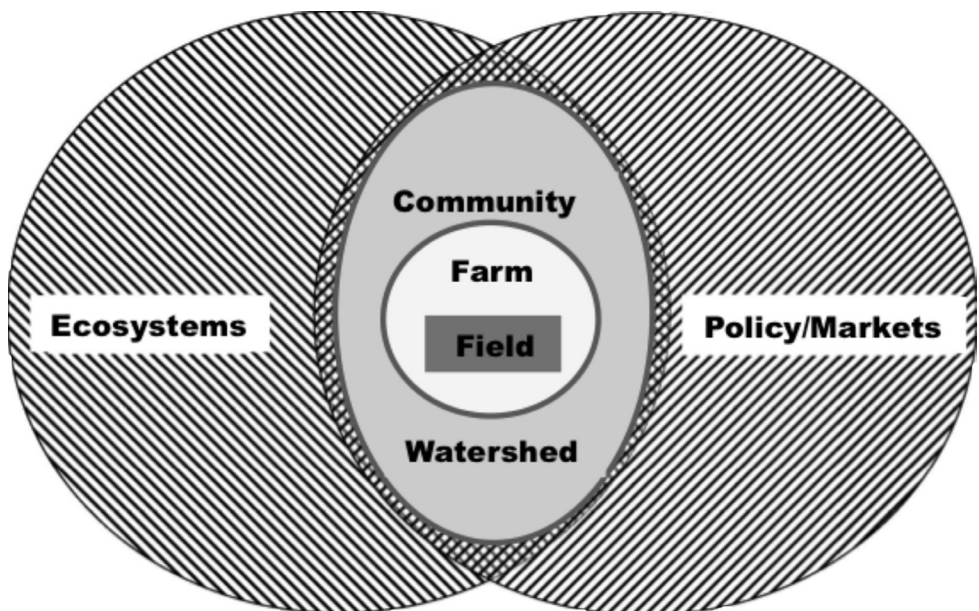


Figure 3. SANREM landscape systems framework.

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 (Pirrot 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 chil-

dren. 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, for-

ests, 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 produc-

tion, 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 translocating 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 concep-

tual 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

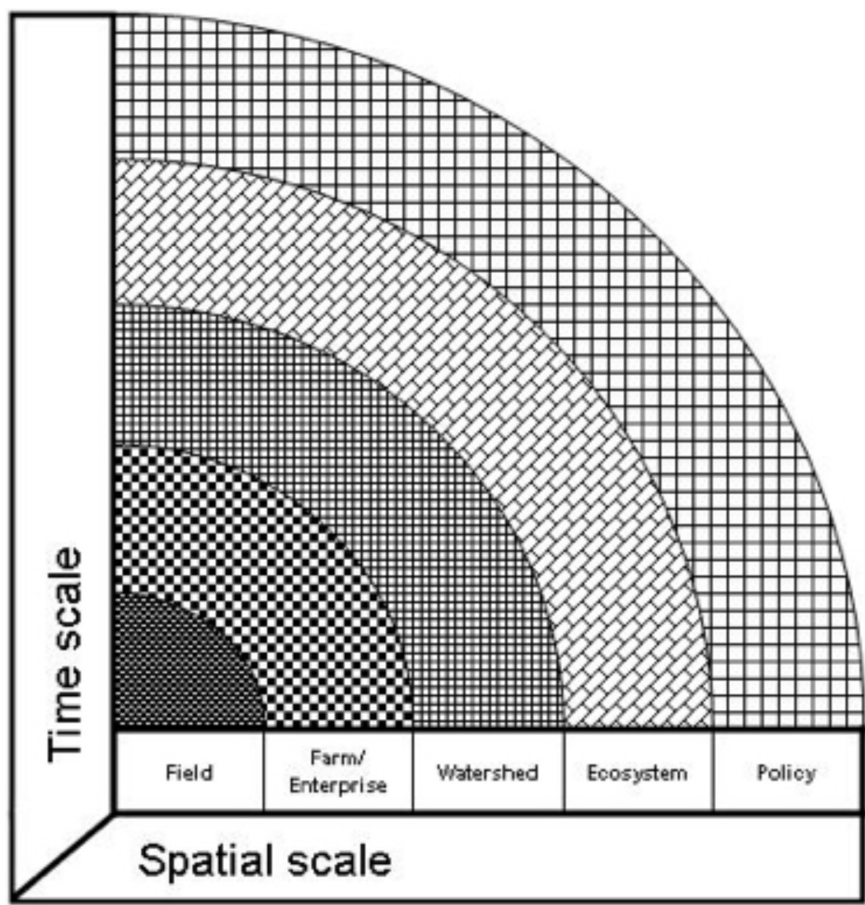


Figure 4. Scalar dimensions of SANREM landscape systems.

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.

References

- Alcorn, J. B., Bamba, J., Masiun, S., Natalia, I., and Royo, A. 2003. Keeping ecological resilience afloat in cross-scale turbulence: An indigenous social movement navigates change in Indonesia. *In* Navigating Social-Ecological Systems, eds. Berkes, F., J. Colding, and C. Folke. Cambridge, UK: Cambridge University Press.
- Anderies, J.M., M.A. Janssen, and E. Ostrom. 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and Society* 9:18. <http://www.ecologyandsociety.org/vol9/iss1/art18/>
- Aquino, G., and E.A. Henrichs. 1979. Brown planthopper populations on resistant varieties treated with a resurgence-causing insecticide. *International Rice Research Newsletter* 4:12.
- Berkes, F., J. Colding, and C. Folke. 2003. *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge, UK: Cambridge University Press.
- Boehm H.D.V., and F. Siegert. 2001. Ecological impact of the one million hectare rice project in Central Kalimantan, Indonesia, using remote sensing and GIS. *In* Proceedings from the 22nd Asian Conference on Remote Sensing, November 5-9, 2001, Singapore, 439-444.
- Booth, A., ed. 1992. *The Oil Boom and After: Indonesian Economic Policy and Performance in the Soeharto Era*. Oxford, UK: Oxford University Press.
- Booth, A. 2000. Poverty and inequality in the Soeharto era: An assessment. *Bulletin of Indonesian Economic Studies* 36:73-104.
- Chancellor, T., E. Tiongco, J. Holt, S. Villareal, and P. Teng. The influence of varietal resistance and synchrony on tungro incidence in irrigated rice ecosystems in the Philippines. Presented at the International Workshop on Tungro Disease Management, November 9-11, 1998. Los Baños, Philippines: International Rice Research Institute.
- Colfer, C. 2005. *The Complex Forest: Communities, Uncertainty, and Collaborative Management*. Washington, DC: Resources for the Future.
- Collinson, M., ed. 2000. *A History of Farming Systems Research*. Oxon, UK: FAO and CABI Publishing.
- CropLife International. 2005. Crop Protection Stewardship Activities of the Plant Science Industry: A Stocktaking Report. http://www.croplife.org/library/documents/Stewardship/crop_protection_stewardship_activities_of_the_plant_science_industry_-_Oct_2005.pdf
- FAO STAT. 2007. Paddy Rice Production in Indonesia, 1961-2006 (in kilo tons). Rome: FAO. <http://faostat.fao.org/site/340/DesktopDefault.aspx?PageID=340>
- Geertz, Clifford. 1963. *Agricultural Involution*. Berkeley: University of California Press.
- Hagmann, J.R., E. Chuma, K. Murwira, M. Connolly, and P. Ficarella. 2002. Success factors in integrated natural resource management R&D: Lessons from practice. *Conservation Ecology* 5(2):29. <http://www.consecol.org/vol5/iss2/art29/>
- Harwood, R., and A. Kassam. 2003. *Research Towards Integrated Natural Resource Management: Examples of Research Problems, Approaches and Partnerships in Action in the CGIAR*. Rome: FAO.
- Henley, D. 2005. Agrarian change and diversity in light of Brookfield, Boserup and Malthus: Historical illustrations from Sulawesi, Indonesia. *Asia Pacific Viewpoint* 46(2):153-172.
- Hill, H. 2000. Indonesia: The strange and sudden death of a tiger economy. *Oxford Development Studies* 28(2):117-39.
- Hill, R. 1998. Stasis and change in forty years of Southeast Asian Agriculture. *Singapore Journal of Tropical Geography* 19(1):1-25.

- Holling, C.S. 1974. Stability and resilience in ecological systems. *Annual Review of Ecology and Systematics* 4:1-24.
- Holling, C.S. 1986. The resilience of terrestrial ecosystems: Local surprise and global change. In *Sustainable Development of the Biosphere*, ed. W.C. Clark and R.E. Munn, 292-317. Cambridge, UK: Cambridge University Press.
- Holling, C. 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. *Ecological Monographs* 62(4):447-502.
- Holling, C.S. and L. Gunderson. 2002. Resilience and adaptive cycles. In *Panarchy: Understanding Transformations in Human and Natural Systems*, ed. L. Gunderson and C. Holling, 25-62. Washington, DC: Island Press.
- Kartasubrata, J. 1993. Indonesia. In *Sustainable Agriculture and the Environment in the Humid Tropics*. Committee on Sustainable Agriculture and the Environment in the Humid Tropics. Board on Agriculture and Board on Science and Technology for Sustainable Development, National Research Council. Washington, DC: National Academy Press.
- Kinzig, A.P., S. Carpenter, M. Dove, G. Heal, S. Levin, et al. 2000. Nature and Society: An Imperative for Integrated Environmental Research. <http://lsweb.la.asu.edu/kinzig/NSFReport.pdf>
- Lewis, P. 2007. Growing Apart: Oil, Politics and Economic Change in Indonesia and Nigeria. Ann Arbor, MI: University of Michigan Press.
- Maltby, E., M. Holdgate, M. Acreman, and A. Weir. 1999. Ecosystem management, questions for science and society. Royal Holloway Institute for Environmental Research, Royal Holloway, University of London, Egham.
- Page, S., F. Seigert, J. Reiley, H. Boehm, A. Jaya, and S. Limin. The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature* 420(6911):61-65.
- Pirot, J., P. Meynell, D. Elder, eds. *Ecosystem Management: Lessons from Around the World*. International Union for Conservation of Nature. 2000.
- Prawiro, R. 1998. *Indonesia's Struggle for Economic Development: Pragmatism in Action*. Oxford, England: Oxford University Press.
- Röling, N., and J. Jiggins. 1998. The Ecological Knowledge System. In *Facilitating Sustainable Agriculture: Participatory Learning and Adaptive Management in Times of Environmental Uncertainty*, ed. N.G. Röling and M.A.E. Wagemakers. Cambridge, UK: Cambridge University Press.
- Röling, N., and E. van de Fliert. 1998. Introducing Integrated Pest Management in Rice in Indonesia: a Pioneering Attempt to Facilitate Large-Scale Change. In *Facilitating Sustainable Agriculture: Participatory Learning and Adaptive Management in Times of Environmental Uncertainty*, ed. N.G. Röling and M.A.E. Wagemakers. Cambridge, UK: Cambridge University Press.
- Rudel, T. 2005. *Tropical Forests: Regional Paths of Destruction and Regeneration in the Late Twentieth Century*. Columbia, NY: Columbia University Press.
- Ruf, F. 2001. L'avenir des cultures pérennes en Indonésie. Cacao et girofle après la tempête monétaire. *Revue Tiers Monde* 41(162):431-452.
- Salafsky, N., R. Margoluis, and K.H. Redford. 2001. *Adaptive Management: A Tool for Conservation Practitioners*. Washington, DC: Biodiversity Support Program.
- Sandbukt, O. 1995. *Management of Tropical Forests: Towards an Integrated Perspective*. Oslo, Norway: Centre for Development and the Environment, University of Oslo.
- Santoso, A. 1993. The working of rural cooperatives (KUD) in Malang, 1970-84. In *Balanced Development: East Java in the New Order*, ed. H. Dick, J.J. Fox, and J. Mackie, 214-229. Singapore: Oxford University Press.
- Sayer, J. and B. Campbell. 2004. *The Science of Sustainable Development: Local Livelihoods and the Global Environment*. Cambridge, UK: Cambridge University Press.
- Settle, W., H. Ariawan, E.T. Astuti, W. Cahyana, A.L. Hakim, D. Hindayana, and A.S. Lestari. 1996. Managing tropical rice pests through conservation of generalist natural enemies and alternative prey. *Ecology* 77:1,975-1,988.

- Sunderlin, W. and P. Resosudarmo. 1999. The effect of population and migration on forest cover in Indonesia. *Journal of Environment and Development* 8(2):152-169.
- Theirs, P. 1997. Successful pesticide reduction policies: Learning from Indonesia. *Society and Natural Resources*, 10:319-328.
- UNDP. 2001. Rice self-sufficiency: Indonesia, sharing innovative experiences. *Agriculture and Rural Development in the South* 5(1). <http://tcdc.undp.org/Sie/experiences/vol5/Rice%20self.pdf>
- van de Fliert, E., and Y.T. Winarto. 1996. From technological packages to ecological principles. *LEISA Magazine* 9:16-18.
- Walker, B., S. Carpenter, J. Anderies, N. Abel, G.S. Cumming, M. Janssen, L. Lebel, J. Norberg, G.D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems: A working hypothesis for a participatory approach. *Conservation Ecology* 6(1):14. <http://www.consecol.org/vol6/iss1/art14/>
- Young, M. 2003. Food production and environmental security in Indonesia. *In Development and Security in Southeast Asia*, ed. D. Dewitt and C. Hernandez, 137-162. Burlington, VT: Ashgate Publishing.