Published March, 2010

SYMPOSIA

Should Enhanced Resilience Be an Objective of Natural Resource Management Research for Developing Countries?

Brian Walker,* Jeff Sayer, Neil L. Andrew, and Bruce Campbell

ABSTRACT

Productivity enhancement has traditionally been the main focus of agricultural research to alleviate poverty and enhance food security of poor farmers in the developing world. Recently, the harmful impact of climate change, economic volatility, and other external shocks on poor farmers has led to concern that resilience should feature alongside productivity as a major objective of research. The applicability of recent work on resilient social–ecological systems to the problems of poor farmers is reviewed, and proposals are made for issues that need to be addressed in determining when and how enhanced resilience might become an objective of research.

B. Walker, CSIRO Sustainable Ecosystems, Box 284, Canberra ACT 2601, Australia; J. Sayer, International Union for Conservation of Nature, 28 rue Mauverney, CH-1196 Gland, Switzerland; N.L. Andrew, The WorldFish Center, P.O. Box 500, Penang, Malaysia; B. Campbell, CGIAR Challenge Program on Climate Change, Agriculture and Food Security (CCAFS), Dep. of Agriculture and Ecology, Univ. of Copenhagen, Rolighedsvej 21, 1958 Frederiksberg C, Denmark. WorldFish Contribution no. 1936.
Received 2 Oct. 2009. *Corresponding author (brian.walker@csiro.au).

The Green Revolution was a product of conventional agricultural research applied to developing country situations. It focused on improving productivity and emphasized agricultural intensification, often using high inputs. The Green Revolution has been criticized on several fronts; for instance, that it failed to benefit farmers in low-potential areas and that it exposed its beneficiaries to risks associated with narrowly specialized agricultural systems. Farmers whose livelihoods were based on a broad range of products were thought to be less vulnerable than those dependent on a single crop and cropping system (Conway, 1997).

Recent initiatives to address poverty alleviation through agricultural research have responded to these criticisms by giving more attention to sustainability and, more recently, to resilience (von Braun et al., 2009). This has been motivated by the realization that poor farmers in developing countries are vulnerable to the external shocks that are likely to be caused by increased climatic variability, global economic volatility, civil disturbances, and disruption of supplies of agricultural inputs (FAO, 2008). There have been a number of recent publications on food security that have discussed the merits of agricultural systems that are more diverse and less dependent on external inputs (notably those derived from scarce fossil fuels). There has been a wave of interest

Published in Crop Sci. 50:S-10–S-19 (2010).
doi: 10.2135/cropsci2009.10.0565
Published online 27 Jan. 2010.

in shifting emphasis away from productivity enhancement and toward sustainability and resilience (McNeely and Scherr, 2003; IAASTD, 2009a, 2009b; UNEP, 2009).

Much of the interest in sustainability and resilience in agriculture comes from the industrialized world and is manifest in significant movements supporting organic agriculture and local self-sufficiency. There is a rich set of literature addressing these issues (McNeely and Scherr, 2003; Millennium Ecosystem Assessment, 2005; Pollan, 2006; Ronald and Adamchak, 2008). Recently, the logic of more diverse, locally sustainable agriculture has been applied to the developing world and the issue of increasing the resilience of poor developing world farmers has emerged as a significant concern. However, there is little empirical evidence to demonstrate how resilience may be enhanced. Green revolution technologies implicitly address resilience to climate variability, pest and disease outbreaks, and economic shocks through investments in improved water management, use of pesticides, and improved markets, capital accumulation, etc. There is an assumption that resilience might be better enhanced through promotion of extensive, low-input, highly biodiverse agricultural systems (UNEP, 2009), but the empirical evidence to support this hypothesis appears to be largely lacking. The objective of this paper is to explore the issues of when and how it might be appropriate to redirect investments toward enhanced resilience.

WHAT IS "RESILIENCE"?

Many definitions of resilience exist (Brand and Jax, 2007). For the purposes of this paper, we will use the definitions adopted by Walker et al. (2004), "the capacity to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks," and Cumming et al. (2005, p. 976), "the ability of the system to maintain its identity in the face of internal change and external shocks and disturbances."

These definitions imply that resilience is a desirable attribute. However, agricultural research for development is often addressing the needs of the extreme poor who are struggling to escape from agricultural systems that are highly resistant to change. In the context of poor developing country farmers, the need is clearly to change but to do so in ways that do not increase exposure to risks. The challenge is therefore to progress to more productive systems while at the same time retaining or increasing resilience to external shocks.

Walker et al. (2004) discuss a number of attributes of natural resource systems that influence resilience. The ones that are of most significance for agriculture are the following.

Thresholds and Tipping Points

An essential feature of resilience is the existence of limits, or thresholds, beyond which significant change will occur. If such change is of zero probability, then there is no fundamental problem for resource management. This is because such a system is always reversible within technology and resource constraints (as in Fig. 1a). If a mistake is made, or the managers change their minds, there is no fundamental obstacle in moving to another state of the system. In systems with nonlinear dynamics, however, the likelihood of alternate system regimes (alternate stable states) is high. A shift (intended or unintended) from one to the other can be irreversible or very hard to reverse.

Conventional natural resource management has tended to assume that ecosystems, agro-ecosystems, and social–ecological systems are predictable, controllable, and follow smooth trajectories (i.e., they don't exhibit discontinuous changes). Management has focused on average conditions and on particular time and space scales. It has mostly ignored extreme events, and it has assumed that getting the system into some particular state and then keeping it there will maximize the flow of benefits.

However, many social–ecological systems exhibit threshold-type changes. If these thresholds are exceeded, changes in feedbacks will cause them to shift toward a different state. Examples occur in agricultural, forestry, and fisheries systems, which do not recover after being changed by human or natural disturbances beyond some critical level. They may "break down" and remain in different, low-production states, even after human use is withdrawn.

Resilience is a feature of social and ecological systems and governance is clearly an important determinant of resilience. The resilience of governance systems is determined largely by the attributes of networks, trust, human capital, leadership, etc. (Walker et al., 2004). A particular feature of threshold changes and recovery—hysteresis—is illustrated in Fig. 1.

The likelihood of alternate stable states is what makes the concept of resilience so important. The bigger the difference between the levels of the two states, and the bigger the hysteresis effect (i.e., the more the controlling variable needs to be reversed before the state of the system "flips" back), the greater is the significance of that particular aspect of resilience.

Specified and General Resilience

Resilience is often seen as specific to an external driver of change; for instance, of a particular fish stock to fishing intensity, or of crop production to a drought (Carpenter et al., 2001). However, increased resilience to specific disturbances may cause the system to lose resilience to others. The "highly optimized tolerance" theory (Doyle and Carlson, 2000) shows how systems that become very robust to frequent kinds of disturbance *necessarily* become fragile in relation to infrequent kinds.

An important question is whether it is only the resilience of agricultural production (for example) that is of concern, or the resilience of broader attributes of livelihoods. Some specialized agricultural technologies or production systems may be less resilient to external challenges than the diverse production systems they replace. For instance, encouraging millions of small farmers in Africa to adopt hybrid seeds only available from a few distant producers and requiring high fertilizer inputs may greatly increase their incomes, but render them highly vulnerable to any external disruptions to the supply of agricultural inputs.

"General resilience" does not consider any particular kind of shock, or any particular aspect of the system that might be affected, and is, therefore, used both normatively and positively, implying that the general capacity to deal with shocks is deemed to be a good thing. The capacity of people and institutions to learn and adapt, and to self-organize and reorganize is critical to building resilience (Folke et al., 2003; Walker et al., 2004; Berkes and Seixas, 2005; Kooiman et al., 2005; Folke, 2006; Mahon et al., 2008). This capacity to respond to surprises is especially important in enabling managers to adapt (McLain and Lee, 1996). Building the capacity to adapt is therefore a key element of enhancing resilience. The concept of generalized resilience implies that the attributes that enable a system to cope with one kind of shock (e.g., a tsunami) are similar to those needed to respond to a different kind of shock (the global financial crisis).

Enhancing Resilience vs. Transformation

When a society is trapped in an undesirable system regime and recovery to its former state, or movement to some new configuration of the system, is not possible, the only option is to transform into a different kind of system: a system defined by new state variables. It means introducing new components and new ways of making a living, and often changes in the scales at which the system functions. This is the general problem that agricultural research for development is confronting.

Many production systems do not meet the needs of local communities. And some existing agricultural systems will not be viable under changed climate conditions; simple incremental adaptation will not suffice. These systems will need to be transformed into new kinds of agro-ecosystems. Such a transformational change may require that totally new germplasm, crops, farming systems, institutions, and policies are all put into place in a short space of time.

Resilience and transformability are both necessary attributes of systems. Building resilience to cope with external change is the appropriate action in some circumstances. In others cases, incremental adaptations to a changing environment may amount to "digging the hole deeper." The question facing policymakers will increasingly become: "Which parts of our (locality, region, or country), or which components or sectors, need enhanced resilience (to ensure their present, preferred states can continue), and which parts need to be transformed?" This is a fundamental societal choice and the legitimacy of the decision-making process is critical.

Changing to Persist

Resilience requires that a system can change and should not be equated with resisting change. Keeping a system in some particular state may reduce its resilience. Allowing a system to change is necessary for maintaining the

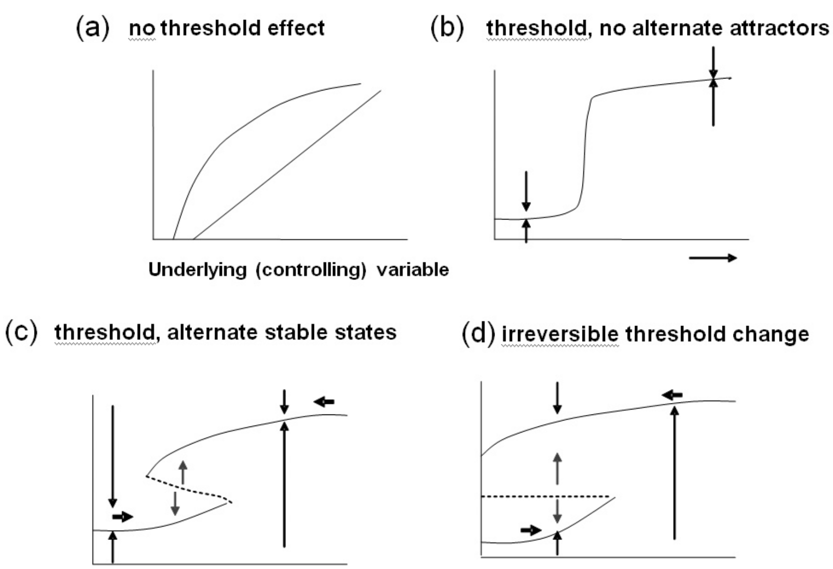

Figure 1. The four possible responses of the equilibrium state of a system (here denoted by the state of a capital stock) to changes in an underlying, controlling variable. The equilibrium state is the amount of the capital stock that the system will eventually reach if the controlling variable is held constant at any particular level. (a) and (b) represent systems with no alternate equilibrium states; the response is smoothly changing in (a) and a step change in (b). The lateral arrows in (c) and (d) represent the direction of change. (c) and (d) involve hysteretic responses, where the return path is different from the development path, resulting in two possible stable (equilibrium) states for the same level of the controlling variable. (From Walker et al., 2009a).

resilience of the system's current configuration. Change is also needed to shift the system to an alternate regime if that is desired; for example, in the crop–livestock systems in western Niger, from a low and declining state of soil fertility and crop production to a higher, self-maintaining state (Fernandez et al., 2002). Change is also needed to transform systems to different configurations when that is necessary (e.g., from a low-production livestock system to a new way of making a living).

Resilient systems are learning systems. Ecosystems adapt through exposure to shocks; for example, by the reorganization of species assemblages following a disturbance. Social systems learn in multiple ways. Policy and management actions need to enable and foster learning. Learning requires providing safe spaces for experimentation, and rewarding novelty and experiments, rather than having them prevented and penalized. This same need is explicitly recognized in the "safe arenas" concept in the field of transition theory and practice (Kemp et al., 2007).

Estimating or Measuring Resilience

How does one know if the resilience of the system is increasing or decreasing? For a well-defined threshold, such as water table depth and salinity, it may be possible to measure whether or not the state of the system (water table depth) is getting closer to the threshold and, therefore, whether resilience is declining. For others, such as a shift from a clean, high-diversity river system to one dominated by algal blooms and with low biodiversity, the position of the threshold may not be known, and managers will need to monitor changes in the attributes that likely determine the threshold, such as flow rates, inflow levels of pollutants, abundance and diversity of fish and zooplankton species, and use these as indicators of changes in resilience.

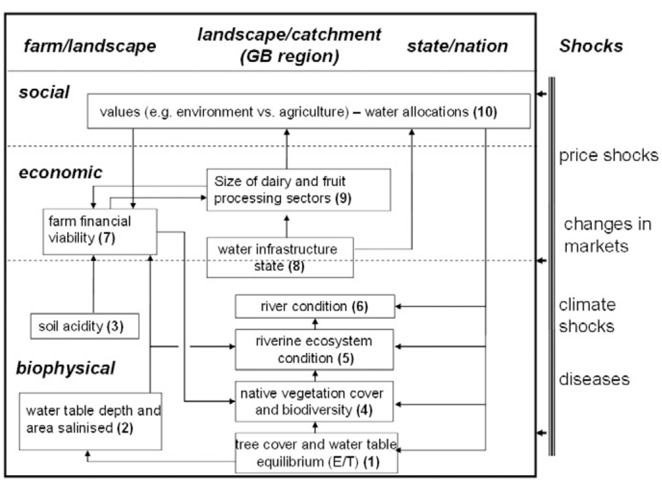

Figure 2. Ten interacting thresholds in the Goulburn-Broken Catchment (GB region) in South East Australia, at three scales and in three domains. The kind and magnitude of a shock will determine which threshold is most likely to be crossed, and the subsequent cascading effect through the system. Crossing one particular threshold may either increase or decrease the likelihood of another being crossed. (From Walker et al., 2009b).

If a threshold is known to exist, then it is important to learn about it. This is a difficult area for both science and management, but two approaches are worth considering. The first is development of a typology of thresholds with respect to the systems they are likely to occur in. A start has been made on developing a database for a very general framework (Walker and Meyers, 2004), but it calls for a wide research effort. A second, very pragmatic, approach is that in use by the Kruger National Park in South Africa. It involves identifying "thresholds of potential concern" (TPCs) based on available information and knowledge of related systems. The list is regularly revised and the top few TPCs are used to guide both research and management (Biggs and Rogers, 2003).

CONSEQUENCES OF A RESILIENCE PERSPECTIVE FOR NATURAL RESOURCE MANAGEMENT

A number of recurring principles that are important in understanding resilience can be identified from comparisons of resilience among social–ecological systems (Walker et al., 2006):

1. Allow systems to vary and to probe the boundaries of resilience.

Attempts to resist change reduce resilience. A common objective of policies aimed at optimizing some particular product or outcome is to identify an "optimal" state of the system, and then to somehow try to keep it in that particular state. Keeping a system in one particular state leads to changes that make the system less resilient. For instance, preventing fire in an attempt to keep a forest in its present state leads eventually to the loss of species that are fire tolerant. They are outcompeted by species that do not have to channel resources into thick bark, resistant cell structures, dormant stem buds that enable them to resist or recover from fire. The longer fire is prevented, the more flammable material accumulates and the more vulnerable the forest becomes to fire. To keep a forest resilient to fire, it is necessary to periodically allow the forest to burn. To keep a community, an organization, or a society resilient, it has to be exposed to subcritical levels of the kinds of disturbances to which it needs to be resilient.

2. Multiple scales and cross-scale effects.

It is not possible to understand or manage a social–ecological system by focusing only on the scale of primary interest. All systems are structured and function at multiple interconnected scales, and cross-scale effects strongly determine the overall trajectory of the system as a whole—the concept of "panarchy" (see Holling et al., 2002). Resource managers tend to operate at a single scale—for instance, the farm or the forest—but building resilience at one scale can reduce resilience at other scales. In developing policy or management proposals, one needs to consider the broader context and the effects of changes at finer and greater scales. The so-called "Dutch disease" is a well-documented example of how macroeconomic changes driven by development based on oil and gas exploitation can have harmful impacts on other sectors of the economy (Wunder, 2003, 2008; Wunder and Sunderlin, 2004). There are numerous examples of mining, infrastructure, and agro-industrial developments having positive impacts on the economy at national scales, but having harmful impacts on the livelihoods of certain sectors of the population.

3. Multiple thresholds across scales and domains.

In addition to cross-scale effects there are cross-domain effects—interactions between the ecological, social, and economic domains. They are made especially difficult by the fact that the three domains function at different scales in both time and space. Threshold effects can occur at each scale and in each domain. As an example, Fig. 2 depicts 10 known or strongly suspected thresholds in the Goulburn-Broken Catchment, in South East Australia, at three spatial scales and in the three domains. The kind of shock the region experiences will determine which of the thresholds might be crossed. Crossing a particular threshold may then initiate a cascading effect in crossing other thresholds; and it may also lessen the likelihood of crossing certain others.

4. Controlling variables.

Comparisons of resilience in several regions/systems suggest that, at any one scale, there are only three to five critical variables that determine the dynamics of the system (Walker et al., 2006). Identifying these critical variables is fundamental to management. The Kruger National Park approach of iteratively identifying a priority list of "thresholds of potential concern" is an interesting application (Biggs and Rogers, 2003).

5. Pursuing narrowly defined efficiency reduces resilience.

Efficiency is taken to be "good" in virtually all policy developments. Where it really does only eliminate waste or redundancy, this is justified. But in many cases what is apparently redundant is actually "response diversity," in resilience terms (Elmqvist et al., 2003). A farming system with many annual and perennial crops is more resilient to external fluctuations in weather, markets, input supplies, etc., than is a single, high-production commodity crop system. The pursuit of economic efficiency needs to be accompanied by analysis of unintended resilience consequences.

OPPORTUNITIES AND CHALLENGES

We consider that the following seven challenges and opportunities will need to be addressed in understanding resilience of developing country agro-ecosystems.

1. Defining the system and providing context.

A critical first step in any resilience assessment is to define the system of concern. We need to be clear about the resilience "of what" and have an understanding of resilience "to what." What are the variables of concern? What is the normal disturbance regime of the system? What shocks, pressures, or internal changes is the system subject to? Even if the main focus is on the natural system, the social aspects of management responses strongly influence the dynamics of the linked social–ecological system. How we define the identity of a social–ecological system is important from both a technical and political point of view. Defining the identity of the system addresses not only the "of what," "to what," but, as well, the "for whom" questions (Carpenter et al., 2001; Lebel et al., 2006; Nadasdy, 2007). It requires perceiving and understanding the system as a linked system with strong interactions between the social and ecological domains, often across scales.

The Resilience Alliance Workbooks (http://www.resalliance.org/index.php?id=3874&sr=1&type=pop [verified 26 Dec. 2009]) provide a list of questions to guide such assessments. For many applications a simpler list might be developed, but some analysis is necessary to clarify the controlling variables of the system, to prioritize issues both within and external to the system, and to identify a constituency and set of rights and institutions that "fit" the system (Young, 2002; Andrew et al., 2007; McClanahan et al., 2008; Evans and Andrew, 2009). There is a long history of developing and testing ecological and social methods for developing country contexts that would constitute the tools for the differential diagnosis of agro-ecosystems. Such methods are critical in the developing world because, in most instances, long-term resource-rich analyses of systems are neither possible nor desirable. Integration and adaptation of rapid participatory methods for resilience analysis is an area that needs further research effort.

Difficulties in defining "the system" can often be resolved by explicitly defining the spatial and time scales over which resilience is of concern. Fast variables at one scale are often slower variables at, and hence controlled by, the scale above. A closely related idea is the notion of layered interventions. It calls for identifying the set of important barriers to advancing human wellbeing, and how and in what order to deal with them. It is not good enough to deal with only some of them. A single remaining barrier can prevent progress. Reducing or removing these barriers is equivalent to addressing the limiting factors to general resilience, and also transformability. It is necessary to encompass the whole system of problems to identify the key leverage points for change. Partial solutions do not work.

2. Thresholds and the importance of integrated natural resource management.

Thresholds in the behavior of complex systems are difficult to recognize and are most often "seen" after they have been crossed. In the institutionally weak, data-sparse world in which researchers operate in developing country contexts, this is the norm. Resilience management that seeks to keep a production system away from thresholds needs to know something about where those thresholds might be (see Estimating or Measuring Resilience, above). The "rule of hand" [see Point 4, Controlling variables, above] suggests that there are three to five critical, controlling (often slowly changing) variables that determine the dynamics of the system at a given scale. Special attention should be paid to thresholds in these controlling variables that lead to changes in system behavior. Trying to identify controlling feedbacks is a useful way to approach the problem.

A threshold may be crossed as the result of an external shock (a tsunami or a civil war) or the cumulative effects of internal stresses (chopping down too many trees or catching too many fish). Although many systems will at some point exhibit threshold changes in dynamics, it would be wrong to focus research and management attention only on identifying thresholds. Production systems can be made less vulnerable to the threat of external shocks without knowing when they will occur (building general resilience). Management within this domain has been well articulated as integrated natural resource management (Sayer and Campbell, 2001). As outlined earlier, integrated natural resource management shares many of the principles and concepts with resilience thinking and most of the field methods and analytical tools will be the same.

3. Values.

As emphasized earlier, resilience per se is neither good nor bad; it is a property of the current configuration of a system. It is critical not to conflate understanding of the resilience of some system configuration (value-free) with judgments about its desirability (value-based). The challenge is to strengthen the capacity of society to *manage* resilience; to enhance it where appropriate or to erode it and help transform systems that are in undesirable states. The overall goal has to be to preserve the flow of economic, social, and environmental benefits to society as a whole.

Value judgments will always be needed and those judgments should be made by legitimate decision makers (Lebel et al., 2006; Nadasdy, 2007). Depending on one's priorities and values, the current state of a system may or may not be desirable. Many undesirable social–ecological system configurations are highly resilient; for instance, forestry operations by military regimes and illegal fishing in the seas of developing countries.

"Resilience of whom?" (Lebel et al., 2006) is an ethical question and, except in the most egregious cases, legitimate but opposing perspectives may be held. In his critique of resilience thinking, Nadasdy (2007, p. 216) makes a further point: "the more one has invested (ecologically, socially, or economically) in existing social–ecological relations and institutions, the more one is likely to view resilience as 'good'. Those who are marginalized or excluded are less likely to view a collapse of existing social/institutional structures as an unmitigated disaster. Indeed, they may even embrace the kind of radical socio-ecological change brought about by a system shift. The valorisation of resilience, then, represents a decision—at least implicitly—to endorse the socio-ecological status quo." In essence, Nadasdy makes the case for resilience as a value-free proposition for analysis. We note, however, that the poorest and weakest are likely to fare worse in the transition.

4. Reconciling "sustainable development" and "resilience".

Sustainable development is a societal goal that the world has adopted. Some definitions emphasize stability and control—of the environment, society, or the economy—using institutions of governance. Since a resilience perspective is counter to this (it assumes that responses of ecosystems to human use have limited predictability and control), it might be seen as opposed to conventional sustainable development. In some ways it is, where sustainable development invokes goals of equilibrium and optimization as embodied in metrics such as maximum sustainable yield. However, as posited by Lebel et al. (2006), resilience should rather be regarded as a necessary system property for sustainability in the face of change and uncertainty, furthering our endeavor to achieve sustainable development rather than challenging it. They assert that strengthening the capacity of societies to manage resilience is critical to effectively pursuing sustainable development.

It is useful to distinguish between "resilience," the system property, "resilience based-management," and "resilience-based development"—that is, designing a development strategy that leads to the maintenance or enhancement of resilience. We deal with this last aspect of resilience in the following point.

5. Development pathways and path dependence.

Some development pathways will likely lead to greater resilience than others. For instance, one might argue that the Millennium Ecosystem Assessment "Adapting Mosaic" scenario would be more resilient than the "Global Orchestration" scenario (Millennium Ecosystem Assessment, 2005), and that, if so, there should be more attention to research that would favor this scenario. Similarly the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) provides analysis that supports agricultural development pathways that are locally adapted and less reliant on outside inputs of technology or agro-chemicals (the latter derived from declining fossil fuels) (IAASTD, 2009a, 2009b). A resilience approach suggests that there should be more research focused on these multiple precision agricultural models rather than on conventional specialized models centered on a very small number of crops and valuing economies of scale, standardization, and specialization.

6. Transformation.

"Transformational change" is much needed to meet the food security challenges of the developing world. In reality, transformation is a tricky ethical arena (Olsson et al., 2005, 2008; Kristjanson et al., 2009). The questions facing managers (broadly defined) with respect to the transformation of production systems include:

- Which parts of the (locality, region, country), or which components or sectors, need enhanced resilience to ensure that their present states can continue, and which parts need to be transformed?
- If a production system is to be transformed, who decides what the changes will be? Trying to determine the "best" new system can lead into the same kind of trap the social–ecological system is currently in, and it may be better to allow for a learning approach within a range of acceptable new trajectories; that is, decide on where NOT to go, avoid those pathways, and allow self-organization within the range of acceptable futures.
- Transformation will favor some people over others—Who will lose and who will be the winners? What process will ensure the legitimacy of the decisions that lead to such redistributions of wealth and influence? Do scientists have any legitimate role in this process?
- The transformation process may be chaotic and unpredictable, throwing up new actors seeking advantage, creating new, visionary leaders that catalyze societal change in good ways, causing unexpected ecological phase shifts, etc. What responsibility do agents of change have for transformations that make things worse in the fight against poverty?
- Can managers capitalize on windows of opportunity to create the sense of urgency needed to overcome resistance to change (Olsson et al., 2005, 2008)?
- Transformations of production systems will prompt discussions about the tradeoffs between different sorts of landscapes. The currency used in such discussions will likely be in terms of ecosystem services (including biodiversity conservation). Very quickly this will lead to issues of ecosystem valuation and the problems of nonmonetary valuation of, for example, rivers and forests.

7. Governance—partnerships, networks, and forums.

Exclusive, centralized forms of management have failed to deliver sustainable and equitable use of natural resources in the developing world (Berkes, 2003; Charles, 2001; Varjopuro et al., 2008). Inclusion of a diverse, but appropriate set of stakeholders will include better problem definition and ownership, a more diverse knowledge base for decision making, greater legitimacy, and, therefore, better compliance and commitment to agreed courses of action, and conflict resolution (Jentoft, 2000; Bryan, 2004). Recent work on so-called boundary processes—individuals and organizations—has been identified in the success (or lack of success) in many developing country situations. Their success in enabling cross-scale and cross-institution communication and cooperation depends in all cases on their being identified by all players as accountable and trusted (Guston, 2001; Carr and Wilkinson, 2005; McNie, 2007; Kristjanson et al., 2009).

A resilience approach clearly anticipates or leads many of these trends, and so the types and modalities of research required to support resource management are also changing. Creation of new knowledge will remain a cornerstone activity, but increasingly the role of research may be to understand the processes and necessary conditions for transformational change. Research may more explicitly seek to build general resilience. Concrete examples of these new modalities may include:

- Supporting the creation of national and regional forums to take leadership of management change and to set the research agenda. In fisheries, for example, the African Union's New Partnership for Africa's Development (NEPAD) has articulated the AU-NEPAD Action Plan for the Development of African Fisheries and Aquaculture, which has become a key component of NEPAD's Comprehensive African Agriculture Program.
- Facilitate learning networks that encourage local institutions to become learning organizations to build resilience. For example, in the Greater Mekong region, the Wetlands Alliance (www.wetlandsalliance.org [verified 26 Dec. 2009]), a network of >30 organizations, works with "dialog partners" to address institutional aspects of poverty through capacity building for wetlands management.
- The current interest in landscape and ecosystem approaches to fisheries, forest, and agro-ecological system problems are implicitly driven by considerations of resilience. They seek a more balanced and sustainable approach to productivity enhancement and address the flows of multiple benefits.

An overall conclusion in regard to governance in developing world social–ecological systems is the need for decentralization and devolution of power. Centralized control leads to frequent inappropriate actions through application of one-size-fits-all policies, and because it involves long feedback times it does not match the speed at which decisions need to be made. The model of polycentricity and distributive governance (e.g., Marshall, 2009) is more in line with developing country needs.

CONCLUSIONS

There are few examples of resilience thinking being formally incorporated into the natural resource management programs of developing countries. A comparison of resilience in some 15 social–ecological systems around the world led to the identification of 10 guidelines that might be applied in the agricultural and natural resources management programs of these countries (Anderies et al., 2006). Several of these have profound implications for the way in which scientists approach agricultural and natural resources research. They also have profound implications for the management of natural resources in the developing world, and we advocate their wider adoption. They are:

- · Neither ecosystems nor social systems can be managed in isolation. Their strong interactions and multiple feedbacks must be taken into account.
- · Managers must intervene at multiple scales, understand how the focal scale interacts with other scales, what is happening in the levels above and below, and what effects cross-scale processes are likely to exert.
- · Slow variables need to be understood. Identifying the key controlling variables with threshold effects that determine alternate system regimes is important. There are typically no more than a few such key variables that are important at any one scale.
- · Manage for diversity. Simplifying production, ecological, or social systems for increased efficiency carries with it a reduction in response diversity, so that the system becomes more vulnerable to stresses and shocks.
- · Accept that maintaining resilience incurs costs. There may be a tradeoff between short-term benefits from high efficiency under narrowly constrained circumstances and the long-term performance of a more resilient regime with reduced costs of crisis management.
- · Make strategic interventions. Focus on identifying the key points for intervention in the social–ecological system that can avoid undesirable pathways and alternate regimes. Successful intervention requires investment in adaptive capacity.
- · Understand underlying mental models. Successful outcomes depend on expanding and connecting the mental models that exist across the stakeholder groups so as to increase their mutual understanding and thereby the social system's capacity to act.
- · Embrace adaptive governance. Introduce flexible, dynamic institutional and governance structures so that key intervention points can be addressed at the appropriate scales and times.
- · Recognize windows for transformation. If a system has already moved onto an undesirable trajectory that is unacceptable and efforts to move off it are failing, there comes a point at which adaptation is no longer ecologically, socially, or economically feasible. When transformation is the only option, the sooner it is recognized and acted on, the lower the transition costs and the higher the likelihood of success.
- · Recognize that vulnerability cannot be eliminated. Strategies that enhance robustness to particular types of shocks necessarily give rise to new vulnerabilities in other domains.

Our overall conclusion is that the primary goal in international agricultural research is to shift people out of their highly resilient condition of poverty into a more productive condition as defined by a broad set of livelihood attributes without making them vulnerable to external shocks such as those caused by climate variability, economic volatility, pandemics, etc. In some circumstances, resilience may hinder escape from a poverty trap to a more desirable state. Where resilience is an obstacle to change, then transformation has to be actively sought. This means moving to a different kind of system, defined by different variables, with a different way of making a living. Enhancing transformability is a major need in the developing world. The literature on resilience could enhance the ability of science to bring solutions to the needs of the rural poor without exposing them to some of the risks that may result from overly simple solutions focusing solely on yield increases and efficiency. We therefore advocate the broader adoption of systems approaches to agricultural research. Such approaches must be based on a thorough understanding of the context within which farming, fishing, and forestry take place, a process of continuous experimentation and learning that involves producers working alongside scientists and the integration of many knowledge systems. It requires that scientists take into account the broad set of attributes of the system that ultimately determine the livelihoods of the rural poor (Sayer and Campbell, 2004).

ACKNOWLEDGMENTS

This paper is based on a background paper prepared for a workshop at the Science Forum 2009 of the Consultative Group on International Agricultural Research (CGIAR). We are grateful to the panelists and speakers in the workshop for their insights: Patrick Caron, William Clarke, Sir Gordon Conway, Dennis Garitty, Line Gordon, Hannah Jaenicke, Peter Mollinga, Richard Munang, Meine van Noordwijk, Thomas Rosswall, Marten Scheffer, and Mark Smith. We also thank the numerous participants who engaged in the lively discussion.

REFERENCES

Anderies, J.M., B.H. Walker, and A.P. Kinzig. 2006. Fifteen weddings and a funeral: Case studies and resilience-based management. Ecol. Soc. 11(1): Article 21.

Andrew, N., C. Béné, S.J. Hall, E.H. Allison, S. Heck, and B.D. Ratner. 2007. Diagnosis and management of small-scale fisheries in developing countries. Fish Fish. 8:227–240.

Berkes, F. 2003. Alternatives to conventional management: Lessons from small-scale fisheries. Environments 31:1–14.

Berkes, F., and C.S. Seixas. 2005. Building resilience in lagoon social–ecological systems: A local-level perspective. Ecosystems 8:967–974.

Biggs, H.C., and K.H. Rogers. 2003. An adaptive system to link science, monitoring, and management in practice. p. 59–80. *In* J.H. Du Toit et al. (ed.) The Kruger experience. Island Press, Washington, DC.

Brand, F.S., and K. Jax. 2007. Focusing the meaning(s) of resilience: Resilience as a descriptive concept and a boundary object. Ecol. Soc. 12(1): Article 23.

Bryan, T.A. 2004. Tragedy averted: The promise of collaboration. Soc. Nat. Resour. 17:881–896.

Carpenter, S.J., B. Walker, J.M. Anderies, and N. Abel. 2001. From metaphor to measurement: Resilience of what to what? Ecosystems 4:765–781.

Carr, A.J.L., and R.L. Wilkinson. 2005. Beyond participation:

Boundary organizations as a new space for farmers and scientists to interact. Soc. Nat. Resour. 18:255–265.

Charles, A.T. 2001. Sustainable fishery systems. Blackwell Sci., London.

Conway, G. 1997. The doubly green revolution. Cornell Univ. Press, Ithaca, NY.

Cumming, G.S., G. Barnes, S. Perz, M. Schmink, K.E. Sieving, J. Southworth, M. Binford, R.D. Holt, C. Stickler, and T. Van Holt. 2005. An exploratory framework for the empirical measurement of resilience. Ecosystems 8:975–987.

Doyle, J., and J. Carlson. 2000. Power laws, highly optimized tolerance, and generalized source coding. Phys. Rev. Lett. 84:5656–5659.

Elmqvist, T., C. Folke, M. Nystrom, G. Peterson, J. Bengston, B. Walker, and J. Norberg. 2003. Response diversity, ecosystem change and resilience. Front. Ecol. Environ. 1:488–494.

Evans, L., and N. Andrew. 2009. Diagnosis and the management constituency of small-scale fisheries. The WorldFish Ctr. Working Pap. 1941. Available at http://www.worldfishcenter.org/resource_centre/WF_2416.pdf (verified 23 Dec. 2009). The WorldFish Ctr., Penang, Malaysia.

FAO. 2008. The state of food and agriculture 2008. Available at http://www.fao.org/docrep/011/i0100e/i0100e00.htm (verified 23 Dec. 2009). Food and Agric. Organ. of the United Nations, Rome.

Fernandez, R.F., E.R.M. Archer, A.J. Ash, H. Dowlatabadi, P.H.Y. Hiernaux, J.F. Reynolds, C.H. Vogel, B.H. Walker, and T.W. Iegand. 2002. Degradation and recovery in socio-ecological systems: A view from the household/farm level. p. 297–323. *In* J.F. Reynolds and D.M. Stafford Smith (ed.) Global desertification. Do humans cause deserts? Dahlem Univ Press., Berlin.

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. Global Environ. Change 16:253–267.

Folke, C., J. Colding, and F. Berkes. 2003. Synthesis: Building resilience and adaptive capacity in social–ecological systems. p. 352–387. *In* F. Berkes et al. (ed.) Navigating social–ecological systems: Building resilience for complexity and change. Cambridge Univ. Press, Cambridge, UK.

Guston, D.H. 2001. Boundary organizations in environmental policy and science: An introduction. Sci. Technol. Hum. Values 26:399–408.

Holling, C.S., L.H. Gunderson, and G.D. Peterson. 2002. Sustainability and panarchies. p. 63–102. *In* L.H. Gunderson and C.S. Holling (ed.) Panarchy: Understanding transformations in human and natural systems. Island Press, Washington, DC.

IAASTD. 2009a. A synthesis of the Global and Sub-global IAASTD reports. Available at http://www.agassessment.org/index.cfm?Page=IAASTD%20Reports&ItemID=2713 (verified 23 Dec. 2009). Island Press, Washington, DC.

IAASTD. 2009b. Towards multifunctional agriculture for social, environmental and economic sustainability. Policy issue brief. Available at http://www.agassessment.org/index.cfm?Page=IAASTD%20Reports&ItemID=2713 (verified 23 Dec. 2009). Island Press, Washington, DC.

Jentoft, S. 2000. Legitimacy and disappointment in fisheries management. Mar. Pollut. 24:141–148.

Kemp, R., D. Loorbach, and J. Rotmans. 2007. Transition management as a model for managing processes of co-evolution towards sustainable development. Int. J. Sust. Devel. World Ecol. 14:1–15.

Kooiman, J., M. Bavinck, S. Jentoft, and R. Pullin (ed.) 2005. Fish for life: Interactive governance for fisheries. Amsterdam Univ. Press, Amsterdam.

Kristjanson, P., R.S. Reid, N. Dickson, W.C. Clark, D. Romney, R. Puskur, S. MacMillan, and D. Grace. 2009. Linking international agricultural research knowledge with action for sustainable development. Proc. Natl. Acad. Sci. USA 106:5047–5052.

Lebel, L., J.M. Anderies, B. Campbell, C. Folke, S. Hatfield-Dodds, T.P. Hughes, and J. Wilson. 2006. Governance and the capacity to manage resilience in regional social–ecological systems. Ecol. Soc. 11: Article 19.

Mahon, R., P. McConney, and R.N. Roy. 2008. Governing fisheries as complex adaptive systems. Mar. Pollut. 32:104–112.

Marshall, G.R. 2009. Polycentricity, reciprocity, and farmer adoption of conservation practices under community-based governance. Ecol. Econ. 68:1507–1520.

McClanahan, T.R., J.C. Castilla, A.T. White, and O. Defeo. 2008. Healing small-scale fisheries by facilitating complex socio-ecological systems. Rev. Fish Biol. Fish. 19:33–47.

McLain, R.J., and R.G. Lee. 1996. Adaptive management: Promises and pitfalls. Environ. Manage. 20:437–448.

McNeely, J.A., and S.J. Scherr. 2003. Ecoagriculture: Strategies for feeding the world and conserving wild biodiversity. Island Press, Washington, DC.

McNie, E.C. 2007. Reconciling the supply of scientific information with user demands: An analysis of the problem and review of the literature. Environ. Sci. Pollut. 10:17–38.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being. Vol. 2: Scenarios. Available at http://www.millenniumassessment.org/en/Scenarios.aspx (verified 4 Jan. 2009). Island Press, Washington, DC.

Nadasdy, P. 2007. Adaptive co-management and the gospel of resilience. p. 208–226. *In* D. Armitage et al. (ed.) Adaptive co-management: Collaboration, learning and multi-level governance. Univ. of British Columbia Press, Vancouver, Canada.

Olsson, P., S. Carpenter, L. Gunderson, P. Ryan, L. Lebel, C. Folke, and C.S. Holling. 2005. Shooting the rapids: Navigating transitions to adaptive ecosystem governance. Ecol. Soc. 11: Article 18.

Olsson, P., C. Folke, and T.P. Hughes. 2008. Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. Proc. Natl. Acad. Sci. USA 105:9489–9494.

Pollan, M. 2006. The omnivore's dilemma. Penguin Books, New York.

Ronald, P.C., and R.W. Adamchak. 2008. Tomorrow's table: Organic farming, genetics and the future of food. Oxford Univ. Press, New York.

Sayer, J.A., and B. Campbell. 2001. Research to integrate productivity enhancement, environmental protection and human development. Conserv. Ecol. 5: Article 32.

Sayer, J.A., and B. Campbell. 2004. The science of sustainable development; local livelihoods and the global environment. Cambridge Univ. Press, Cambridge, UK.

UNEP. 2009. The environmental food crisis—The environment's role in averting future food crises. A UNEP rapid response assessment. Available at http://new.unep.org/pdf/FoodCrisis_lores.pdf (verified 23 Dec. 2009). United Nations Environ. Progr., Nairobi.

Varjopuro, R., T. Gray, J. Hatchard, F. Rauschmayer, and H. Wittmer. 2008. Introduction: Interaction between environment and fisheries and the role of stakeholder participation. Mar. Pollut. 32:158–168.

von Braun, J., D. Byerlee, C. Chartres, T. Lumpkin, N. Olembo, and J. Waage. 2009. Towards a strategy and results framework for the CGIAR: Draft report by the Strategy Team 21 October 2009. Available at http://www.cgiar.org/exco/exco17/exco17_srf&mps.pdf (verified 4 Jan. 2009).

Walker, B., L. Gunderson, A. Kinzig, C. Folke, S. Carpenter, and L. Schultz. 2006. A handful of heuristics and some propositions for understanding resilience in social–ecological systems. Ecol. Soc. 11(1): Article 13.

Walker, B., and J.A. Meyers. 2004. Thresholds in ecological and social–ecological systems: A developing database. Ecol. Soc. 9(2): Article 3.

Walker, B., L. Pearson, M. Harris, K.-G. Maler, C.-Z. Li, R. Biggs, and T. Baynes. 2009a. Incorporating resilience in the assessment of inclusive wealth: An example from South East Australia. Environ. Resour. Econ. doi: 10.1007/s10640-009-9311-7.

Walker, B.H., N. Abel, J.M. Anderies, and P. Ryan. 2009b. Resilience, adaptability, and transformability in the Goulburn-Broken Catchment, Australia. Ecol. Soc. 14(1): Article 12.

Walker, B.H., C.S. Holling, S.C. Carpenter, and A.P. Kinzig. 2004. Resilience, adaptability and transformability. Ecol. Soc. 9(2): Article 5.

Wunder, S. 2003. Oil wealth and the fate of the forest: A comparative study of eight tropical countries. Routledge, Taylor & Francis Group, New York.

Wunder, S. 2008. Oil wealth and the fate of the forest: Linking resource booms, macroeconomics, and the environment. Routledge, London.

Wunder, S., and W.D. Sunderlin. 2004. Oil, macroeconomics, and forests: Assessing the linkages. World Bank Res. Observ. 19:231–257.

Young, R.O. 2002. The institutional dimensions of environmental change: Fit, interplay, and scale. MIT Press, London.