17

Group Report: Degradation and Recovery in Socio-ecological Systems

A View from the Household/Farm Level

R.J. FERNANDEZ, Rapporteur

E.R.M. ARCHER, A.J. ASH, H. DOWLATABADI, P.H.Y. HIERNAUX,
J.F. REYNOLDS, C.H VOGEL, B.H. WALKER, and T. WIEGAND

INTRODUCTION

Desertification is a multidimensional problem, with many conceivable causes and a network of consequences encompassing a wide range of spatial and temporal scales. Because of its importance, it interests a broad variety of disciplines. Hence, it is not surprising that communication problems arise not only regarding the attribution of causes and choice of approaches, but also in its definition (see Reynolds and Stafford Smith, this volume). In this chapter we intend to move beyond these obstacles by proposing a framework based on a set of assumptions that, while general, are still specific enough to yield testable hypotheses. This framework is not intended to be a general model nor to instantly produce the best, definitive answers to all desertification questions. Rather, a framework is presented that we argue helps to move the debate on causal mechanisms of desertification forward. Our hope is that progress will stem from attempts to apply this framework to particular systems that are different from the ones most familiar to us.

We start by defining what we consider to be *land degradation* and *desertification*, and briefly touch on the issue of visualizing and communicating phenomena that cannot be represented by single variables or simple indexes. Secondly, we move to consider the problems encountered when trying to assign causality ("attribution" issues), focusing on the cognitive processes involved in our interactions with complex systems in general, and nature in particular. We conclude that being aware of our biases may be as important as having good technical expertise! Thirdly, we present our framework, which is based on two main propositions: The first is that the myriad of variables involved in land degradation (and the underlying processes

---

Global Desertification: Do Humans Cause Deserts?
Edited by J.F. Reynolds and D.M. Stafford Smith

they represent) can be classified into two, independent types, namely biophysical versus socioeconomic, and speed of change, i.e., relatively fast versus slow processes. The second proposition is that the supply of desired ecosystem goods and services is governed by a subset of a few of those variables, which include both biophysical and socioeconomic ones, and are always variables of relatively slow dynamics. The conceptual framework is illustrated with four examples of agricultural systems in Australia and Africa, showing the two main ways that systems can be driven to nearly irreversible degradation and how this can be prevented. Finally, we discuss research and policy implications of our framework. The two most important, "take-home" messages are:

- the need for prevention, an approach that we show is not only to be better but also more cost-effective than after-the-fact action (i.e., remediation). With the aid of the framework, we give examples highlighting the importance of improving resilience and building adaptive capacity via a simultaneous consideration of socioeconomic and biophysical processes.
- the importance of considering cross-scale linkages. While our analysis focuses on household and farm (HH/F) level, we must conclude that the interactions between this and other levels cannot be ignored and, indeed, are essential.

DEFINING, COMMUNICATING, AND EXPLAINING DEGRADATION

Defining Degradation

Degradation and restoration of an ecosystem are two sides of the same problem, involving both natural and social forces. Imagine a continuous axis representative of the biophysical state of a particular ecosystem (Figure 17.1). A situation within the range of natural variability and recovery is represented by a point, such as *a* near the origin (*O*); this is the *sustainable* segment (more generally, a sustainable region) of the landscape. Degradation can take several forms, all of them including the loss of some form of biological productivity (perhaps its current productivity, undoubtedly its long-term one), and its dominant mode would be represented by a movement of the system to the right-hand side on that axis. We can define a threshold of resilience to degradation to natural variability labeled *N.* Although this threshold would be defined empirically (e.g., in terms of spatial and temporal heterogeneity and trends), we assume that it is not arbitrarily defined, but set by the system's internal dynamics (cf. lower line in Figure 17.1). The next threshold is defined to include the resources that can be harnessed for restoration at a low level of intervention (*I*). This level may in some cases coincide with the HH/F level, but this cannot be generalized because land-tenure systems and other relevant parameters do vary. If these resources are not spent appropriately, the degradation away from the sustainable segment (region) continues, such as in *b*. With increased degradation, even greater resources must be brought into play to effect restoration (levels II, III, IV of degradation). To restore the system to an internally sustainable state for human use, these higher levels could successively draw on the community, the state, and international institutions for resources. Boundaries I–IV are somehow arbitrarily defined and, again, only weakly correlated with the availability of resources; for example, a farm owned by a large company would have far more resources and reach of action than a poor province or state.

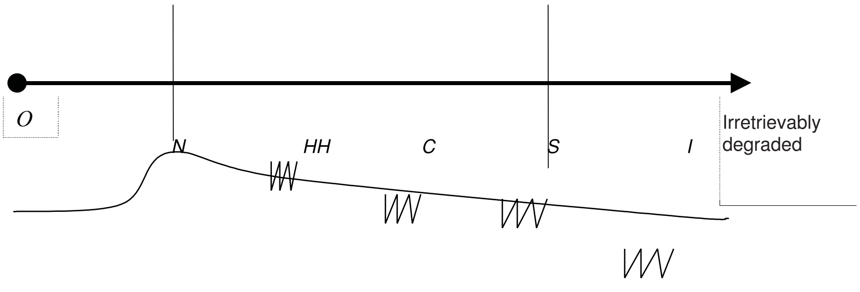


Figure 17.1 The straight, horizontal line represents a continuous axis — from the origin (*O*) to an irretrievably degraded state — of the biophysical state of a particular ecosystem. Using the ball-in-the-cup metaphor for systems dynamics, the system may move along this axis, where its "resistance" (the zigzag symbols) represent buffering actions without which the system will continue a trend to a degraded state. See text for details.

Land degradation is therefore envisioned to be a process that is started by inappropriate human use and/or by infrequent natural events, such as long-term drought. These two types of causes interact, producing either degraded landscapes in the worst case scenario or sustainable landscapes in a desirable scenario. After any trigger moves the system beyond its natural boundary *N*, some external action is required in order to prevent further degradation under persisting human use. These actions are represented by the zigzag, "resistance" symbols in Figure 17.1. Restoring the system to its original state requires even more resources. If degradation has proceeded far away from the initial biophysical conditions (e.g., crossing threshold IV in Figure 17.1), the required economic resources may be unavailable even at the higher level of intervention, meaning that the system has reached what most people would call a *desertified* condition. However, there is not a fundamental, qualitative difference between the stepwise process of degradation just described and its more or less "final" point, which as noted earlier we consider contingent on the existence of affordable technologies and means of restoration. This does *not* imply that dryland ecosystems can be abandoned on their own because they can almost always be restored later. This would not only be irresponsible and dangerous (what if the appropriate technical 'fix' never becomes available?), but predictably more expensive than preserving the land in its more productive state in the first place.

In short, *we define land degradation as a decrease of biological productivity under current human use that (1) reduces potential options for foreseeable uses in the future and (2) is not reversible to a specified level in the temporal scale relevant to the decision-makers with the current resources available to them.* Desertification will occur whenever land degradation has passed the point beyond which restoration is no longer practical (Figure 17.1) and may indeed be improbable at the temporal scales relevant to humans. As with any type of change, degradation has to be assessed or compared to some baseline and it is case-specific.

Desertification may be occurring if future productivity is reduced by human activities even if the current productivity is not reduced. One example is the degradation that occurs if natural vegetation is replaced by a large area of an homogeneous crop that grows with high external input, e.g., irrigation in Inner Mongolia (see Jiang, this volume). While in the short term this land use will lead to an increased biological productivity, it may result in a reduced productivity in the long term (e.g., due to salinization of the soil).

As compared to definitions of desertification (see Reynolds and Stafford Smith, this volume), the framework proposed here highlights the difference between the biophysical process of degradation (the movement to the right along the axis in Figure 17.1) and the capacity of the socioeconomic system to deal with these changes. These elements are also encompassed within the "desertification syndromes" of Downing and Lüdeke (this volume). In addition, our definition and framework attribute desertification to current practices of human use, explicitly connecting them with the concept of sustainability. Finally, it stresses that "reversibility" is not totally independent from the scale of analysis and is contingent on the physical, technological, and institutional/political resources available. The necessary resources for restoration are different along the deterioration axis, and therefore different intervention levels will be needed. The development of a desertification map according to this framework will necessarily include multiple drawings (or layers) or the use of isolines (one for each level of intervention required to reverse the problem).

Representing Degradation

The number of possible symptoms or "indicators" of desertification is high (a minimum list is provided in Table V in Reynolds 2001). Examples include high soil bulk density, high rate of soil erosion, low transpiration to evapotranspiration ratio, low plant cover, reduced litter accumulation, and low agricultural yields (e.g., meat production). However, the processes involved in degradation are complex and it is doubtful that a single biophysical or economic indicator can unambiguously represent degradation. Portraying such complexity does not necessarily obstruct communication — it may actually improve it! In a recent study on how to better communicate environmental information to decision makers and the public, Schiller et al. (2001) concluded that information was most positively received when it contained broad ecological conditions assessed through the use of combined indicators.

Key indicators of land degradation are depicted in Figure 17.2 in the form of a snowflake diagram. Three aspects of the diagram are noteworthy. First, axes are scaled to represent the hierarchy of thresholds as concentric circles (as labeled in Figure 17.1). Second, by plotting the value of the indicators representing the state of a given location, we can quickly visualize proximity to a degraded state as well as focus attention on where specifically to apply efforts to restore the system. Third, a wide range of indicators can be plotted together to describe the state of a human-modified landscape, such as biophysical states of an ecosystem and relevant socioeconomic aspects. Useful as it is, two items are missing from Figure 17.2. The first is *variability*. In reality, thresholds should be represented by fuzzy rather than solid lines in order to better represent spatial heterogeneity and temporal fluctuations. Second, and most important, is the inability to properly represent the *interactive* effects between variables. The framework presented below deals with interacting factors in a more formal way.

While interactions are extremely important, their temporal dynamics create further complications. Variables usually operate at different rates and speeds, which are not easy to capture. Hierarchy theory postulates that not all variables are equally important, and that the drivers of a process are more likely to be find amongst the slower and mid-frequency ones — not among the fastest-changing ones (Allen and Starr 1982; see also Carpenter and

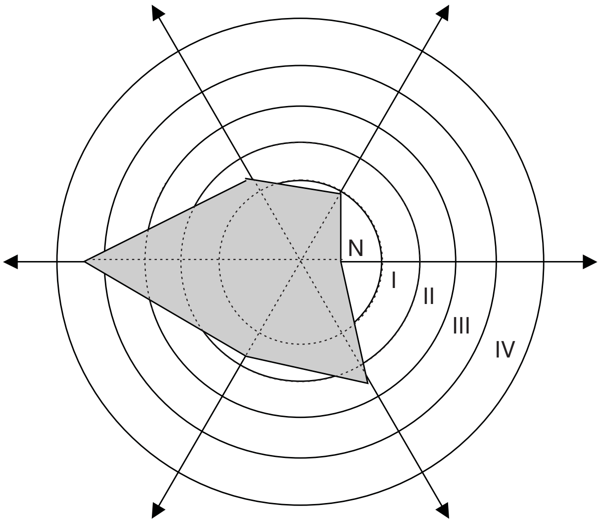


Figure 17.2 A "snowflake" diagram portrayal of the multivariate nature of land degradation. Each of the radii represents one relevant state variable, with the centre point representing its extreme nondegraded value. Circles indicate deterioration thresholds following Figure 17.1. This example represents the state of a system using 6 variables: two of them are within the threshold of natural variability but the rest require external resources (at different levels of intervention) to be restored. The shaded area quantifies the degree of overall system deterioration.

Turner 2001). Thus, we argue that the desertification debate will be clarified by distinguishing between two very different types of variables:

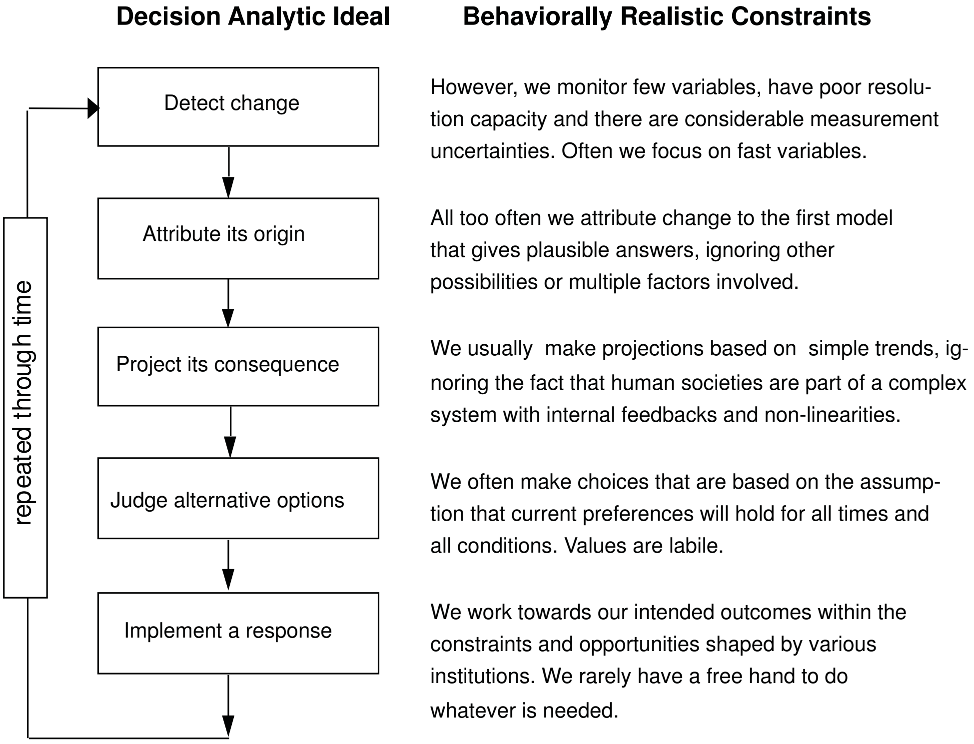
- variables that represent ecosystem goods and services (e.g., amount of protein in forage per unit area and unit time); and
- variables that represent the ability of the system to sustain those processes of interest to humans, i.e., the production of goods and services (e.g., soil with high water infiltration characteristics — instead of high run-off — thereby enhancing forage production).

Both types of variables "indicate" the ability of the system to provide welfare to the people: the first type its *current* ability, the second type its *sustainable, long-term* ability. Variables in the first group are often too sensitive to short-term events to be of use. Thus, we postulate that only those variables in the second group, which usually have slower dynamics, should be used to characterize the state of an ecosystem, i.e., its position along the axes of Figures 17.1 and 17.2. While the above discussion focuses more on biophysical variables, socioeconomic variables are equally useful and essential, particularly when classified using this same hierarchical, frequency-based scheme (see below the section on The Framework in DEGRADATION IN LINKED SOCIO-ECOLOGICAL SYSTEMS).

Biases in the Attribution of Causes

Our approach to land degradation emphasizes the close linkage between ecosystems and human activities. In such socio-ecological systems, humans derive goods and services via interactions with their environment (Costanza et al. 1997). Poor management of these interactions will lead to systems that fail, necessitating a change in ecology, society, or both. Desertification is an extreme case of such a failure, i.e., the collapse of a system. Regardless whether acting as individuals, as part of a household or farm, or in organizations at any level, human actions are prompted at least in part by their perceptions. Figure 17.3 is used to compare an idealized "decision-analytic" representation of human activities (at any level) with one that points out real-world constraints that impede its application.

Our ability to detect change especially identifying those critical slow variables that define the overall dynamics of any complex system is not reassuring. More often than not we focus on extreme events while ignoring slow trends. Thus, it should not surprise us that at the farm level, a rural population will normally focus on events surrounding a current dry spell, which has led to a generalized crop failure (perhaps even accompanied by dust storms reaching nearby cities), while not even noticing, for example, that the surface soil structure has been deteriorating over several decades due to poor management practices. This surface soil structure (*sensu* above section) is the slow changing variable that will ultimately result in the loss of a crop. In fact, if the soils were in excellent shape (as per first section under CASE STUDIES,



However, we monitor few variables, have poor resolution capacity and there are considerable measurement uncertainties. Often we focus on fast variables.

All too often we attribute change to the first model that gives plausible answers, ignoring other possibilities or multiple factors involved.

We usually make projections based on simple trends, ignoring the fact that human societies are part of a complex system with internal feedbacks and non-linearities.

We often make choices that are based on the assumption that current preferences will hold for all times and all conditions. Values are labile.

We work towards our intended outcomes within the constraints and opportunities shaped by various institutions. We rarely have a free hand to do whatever is needed.

Figure 17.3 Interacting with nature: A comparison of an idealistic and a behaviorally realistic depiction.

below), the effect of the current drought on crop production would likely not have been as severe.

The second box in Figure 17.3, which attributes the origins of change, must consider the multiple viewpoints of the relevant stakeholders involved. For example, a soil scientist would likely identify soil processes as the underlying causes of degradation at the farm level while a meteorologist might target unusual weather patterns. In either case, the identification of a single "cause" of the problem (and only one because the analysis stops there; see Figure 17.3, right column) is part of the problem since it necessarily narrows the scope of any future actions. Of course, the views of different stakeholders are inevitably biased. A farmer is much less likely to attribute land degradation to any current farming practice than to some "external" factor, such us declining rainfall. A local agricultural official is less likely to attribute land degradation to the lack of proper extension activities in his/her jurisdiction than to federal taxation policies or declining market prices.

Human perceptions, in terms of correctly identifying or recognizing the key elements giving rise to systems dynamics, are also flawed. Sterman (1987a, b; 1989a, b) has used a number of elegant experiments to demonstrate the extent and consequences of such cognitive failings in humans. Consequently, we must be vigilant in addressing misunderstandings and devising alternative approaches, which will not only help at the household and farm (HH/F) level but also with higher-level decision-makers. Toward that end, Robbins et al. (this volume) highlight the importance of "mental models" in communication. The way in which we detect and respond to environmental change shapes how we interact within the socio-ecological system that constitutes that environment. The capacity of humans to detect changes in time, attribute them correctly, and take appropriate measures is very likely to affect the longevity and vitality of socio-ecological systems. We are handicapped for many of these roles, and we need to be aware of it.

DEGRADATION IN LINKED SOCIO-ECOLOGICAL SYSTEMS

The Framework

This section is based on an approach being developed for the analysis of resilience in regional-scale socio-ecological systems (Walker et al., in preparation). It is not detailed enough to be considered a model, and we are not proposing it as the final approach to the desertification problem. It is a *framework* based on a set of assumptions that, we believe, are sound and not too general as to be vague. These assumptions can be tailored to suit the socioeconomic circumstances of (and yield falsifiable predictions for) particular systems. We have explained above how biophysical degradation is best described by a set of deteriorating slow-moving variables that can drive the system across thresholds. As successive thresholds are crossed, it becomes increasingly difficult to return to the original system state. The main novelties of the proposed framework are the concepts of slow variables being the most critical in determining system dynamics, and the existence of thresholds that can be applied not only to biophysical variables but also to socioeconomic ones. We will explain the framework in steps, highlighting its main assumptions.

1. *The level of supply of ecosystem goods and services is related to the state of the ecosystem*. Where ecosystems exhibit threshold effects and multi-stable states (as in Figure 17.1; cf also Holmgren and Scheffer 2001) their long-term supply of goods and services depends not so much on the particular combination of the state variables, but more on which state the ecosystem is in (i.e., within which region of the phase-space it operates). This can be exemplified by the case of a rangeland that is prone to shrub encroachment and in which the important ecosystem service is the supply of grass for livestock production (e.g., Walker et al. 1981). Livestock production depends on the amount of grass, which in turn depends on the amount of shrub, woody cover (W). Above some critical threshold (W_t) of W, insufficient fuel (grass biomass) can accumulate, even in the absence of grazing, to carry a fire that will control shrubs. Allowing W to increase beyond W_t results in a change in state. In terms of sustainability, it means that the system has moved into a new, undesirable trajectory. For other ecosystem services and their associated governing variables, the relationships might be more gradual, or might be abrupt shifts (bifurcation points between alternate stable states). In either case, there are no a priori reasons to expect these relationships to be linear (Holling et al. 2002).
2. *Human welfare is dependent on relatively fast variables that in turn are controlled by slower variables*. Human welfare (as, e.g., derived from livestock production in a savanna) is dependent on the annual amount of grass production (a "fast" variable) that in turn depends on the amount of woody biomass. Woody biomass is a "slow" variable because it gradually increases under conditions of heavy grazing and absence of fire. In a cropping system (see the Sahel example below) the "fast " ecosystem service variable is millet or sorghum yield, which in turn relies on soil fertility, the "slowly" changing. As long as fertility remains high, crop production is sustainable at acceptable levels. We will see next that, in addition to being slow, there are relatively few controlling variables and that they can be of both ecological (biophysical) and socioeconomic type.
3. *There are only a few relevant slow variables that determine the state of a socio-ecological system.* Analyses of several different ecosystem types show that the number of crucial variables that govern the trajectories of the desired ecosystem services is likely to be somewhere between three and five (Gunderson and Holling 2002). These variables are invariably "slow" ones, in that they are relatively slower than the variables that are of immediate concern to human welfare. Also, since both biophysical and socioeconomic drivers of the system must be included, the minimum number of slow variables is two. While most of the examples we present here involve only two axes — one representing a biophysical variable and the other a socioeconomic variable — this is done solely for the sake of simplicity and graphical representation. In reality, the relevant phase-space is a multivariate one (as in the snowflake diagram of Figure 17.2).

The relationship between biophysical and socioeconomic variables are illustrated in Figure 17.4, with the important biophysical (B) slow variable governing sustainability (the ability of people to continue deriving utility from the system) represented by the horizontal axis, and the important slow socioeconomic variable (S), represented by the vertical axis. In our

This is a color figure.

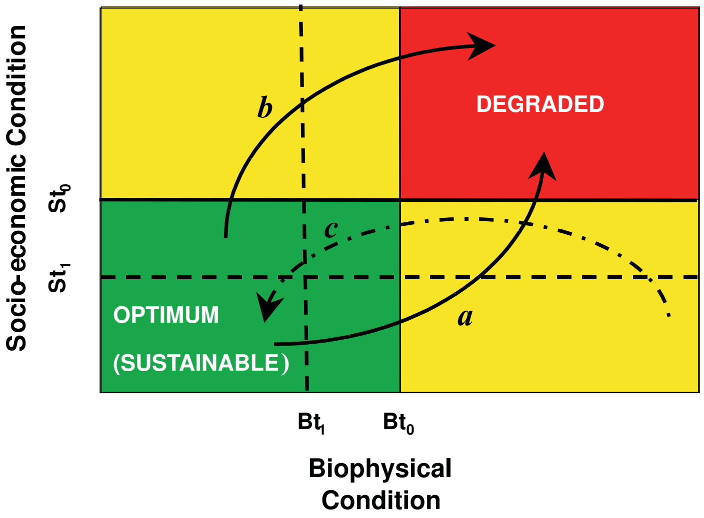


Figure 17.4 Conceptual representation of degradation framework, showing two possible states of system. The *B*-axis represents a "fast" biophysical variable and the *S*-axis is a "slow" socioeconomic variable. The sustainable region is shown in green, unsustainable in yellow, and permanently-degraded in red. Trajectories explained in the text.

rangeland example, axis *B* could be the woody-to-grass biomass ratio. Axis *S* could be called in general " social capital," but for the purposes of illustration we will define it in this case as the debt-to-income ratio, although we know that actually there is a limited number of other, interacting variables involved.

In the same way that we have drawn biophysical thresholds between different states of the system as vertical lines, in this diagram we can define socioeconomic thresholds as horizontal lines. For the objective of sustainable ecosystem services, all desirable trajectories keep the system in the phase-plane below these two threshold levels. Thus, the lower left corner in our diagram represents a "green," nondegraded zone that is sustainable. As in Figure 17.1, there is not just one threshold for each variable but several, each defining a different resilience area corresponding to a different severities of deterioration, i.e., degree of departure from the most desirable state.

Once the appropriate pair of thresholds has been defined, there are two main ways in which the system can be drawn into the "red" zone (Figure 17.4). The biophysical threshold (*Bt*) can be exceeded regardless of the level of *S* through lack of ecological understanding or through short-term profit seeking. Once beyond this threshold, the system cannot recover through natural reorganization, and it requires external inputs to do so. As in Figure 17.1, the further away from the threshold the system moves, the greater the external inputs needed to get it back. In our example, if it remains beyond the threshold, natural dynamics leads the system to a woody thicket state, and under such conditions the income levels resulting from the reduced grass production will decline, and the system will inevitably trend to the red quadrant (arrow *a,* Figure 17.4). On the other hand, if the system moves into the region that is still below *Bt* but above *St*, the farmer is forced to graze too heavily (to service the debt) and the system will then inevitably also cross *Bt* into the undesired red quadrant (arrow *b,* Figure 17.4).

Determinants of Resilience

This section summarizes three important principles that complete the framework just introduced:

1. *The resilience of the system is depicted* not *by its position in the plane, which usually changes from year to year, but by the area of the "green" zone* at the lower left quadrant of Figure 17.4. As stated previously, the safe, sustainable condition of a system is not a particular combination of selected state variables but rather a state (cf. point 1 above). In accordance with our definition of land degradation (INTRODUCTION), what different analysts consider resilient would depend on the resources (physical, technical, human, and political ones) available for restoration.
2. *The positions of the thresholds determining the actual boundaries of resilience are not* fixed. History (weather and management) determines the actual boundaries of resilience and may cause them to fluctuate in response to extreme events. But a threshold in relation with a slow variable should not change fast in response to year-to-year variations in rainfall.
3. Aside from their yearly oscillations, *the average position of the thresholds can be shifted through changes in the system and through external factors.* Climate change, for example, could have this type of effect, either in a positive or a negative way. Other examples using Figure 17.4 would be *Bt* moving to the left as perennial grass species diversity declines or if soil erosion occurs, and *St* moving downwards as alternative income sources (or available credit) decline. If this happens, then the resilience of the system declines and the "sustainable" states of the system are reduced to those in the area of the box demarcated in Figure 17.4 by Bt_1 and St_1. Resilience has been lost.

More than thirty years ago Eugene Odum (1969) showed that increased agricultural production is often achieved by moving ecosystems to early successional stages, i.e., at the expense of reduced resilience. By analogy, if all the grass species in a rangeland were replaced by the species with the highest growth rate, production would be higher and more efficient in normal years, but the system would be less able to withstand droughts, fire, pest outbreaks, etc.; thus, the diversity of responses would have been lost. Having said that, technology has allowed for the increase of production in many systems and this may or may not have affected resilience. With careful analysis, then, it may be possible to use technology to increase both the resilience and productivity of ecological systems.

Clearly, the message from the framework for policy and management is to focus on how to keep *Bt* and *St* as broad as possible, which amounts to building and maintaining the adaptive capacity of the system. The challenge is to understand the socio-ecological system and determine ways in which the resilience zone can be expanded, understanding that thresholds should not be considered immutable. This broadening of the resilience zone (as defined by point *1* in this section) is preferable, and very likely is more economically sensible, than starting with areas already in the upper-right quadrant (red zone) and trying to bring them back again. But resilience has to be worked on both its axes: a system that is resilient in terms of biophysical variables will be always at risk of becoming deteriorated if the safe zone is not wide enough along the socioeconomic dimension (as in trajectory *b*, Figure 17.4). The wider the green zone, the more buffered the system is against market, policy, and weather vagaries.

Our model explains why farmers who decide to take measures to improve their land are often for some time at higher risk than less innovative ones. This is so because, by allocating financial resources to improvement of the system, these progressive farmers may temporarily worsen their situation along the socioeconomic axis (as shown in Figure 17.4, trajectory *c*). While doing so, they are exposed to the risk of "being caught" outside the safe zone of the systems' space by any factor that lowers the SE threshold. As some of these factors (e.g., federal taxation policy) are at a higher hierarchical level, and therefore outside control of the HH/F, caution is not only understandable but may also be wise.

CASE STUDIES: APPLYING THE DESERTIFICATION FRAMEWORK

Grazing in the Savannas of Northern Australia

Background

Grazing by beef cattle is the major land use in the savannas of northern Australia. The majority of this grazing land is open eucalyptus woodland with an understory dominated by native perennial grasses. Pastoral properties are large, ranging in size from a few thousand to over a million hectares. Most are extensively managed with Brahman cattle, rely on few inputs, and have only modest outputs per unit of land. A highly variable climate means that forage supply varies greatly from year to year and this, together with relatively infertile soils, creates an environment that is susceptible to overgrazing and degradation (Ash et al. 1997).

The two key long-term variables appropriate to exemplify the adaptive-capacity framework are perennial grass percentage (biophysical) and equity in the grazing enterprise (socioeconomic). Under conservative grazing management, perennial grasses remain dominant and the soil remains in good condition. However, when overgrazing occurs perennial grasses are lost from the system. For northeastern Australia the threshold utilization level that triggers loss of perennial grasses is of about 60%. The loss is not linear, i.e., there is some initial resistance and then a rapid decline in cover.

Recovery is usually slower than loss; that is, there is a hysteresis effect. As perennial grasses are lost, soil cover and litter generally decline, macropore structure is lost, there are fewer interruptions to surface water flow and, together, these changes result in reduced infiltration. When the perennial grass percentage decline below the threshold, the biophysical system is degraded and it will take considerable intervention or an unusual sequence of favorable seasons to return it to a productive state. This is so because the soil deterioration that accompanies loss of perennial grasses results in an environment that makes it difficult for perennial grass plants to germinate and establish. Economic analyses in the region indicate that when equity ratios drop below about 80%, debts become extremely difficult to service. This, of course, is not an absolute limit to the sustainable state. There is a fuzzy region of risk. Still, as the household approaches such region, there is greater risk of moving towards a degraded situation.

Figure 17.5 illustrates three conceivable management scenarios:

1. A conservative manager would attempt to remain in the lower left portion of the sustainable quadrant to avoid the risk of crossing any threshold. A series of drought years will push the system towards its biophysical threshold but it generally will not be

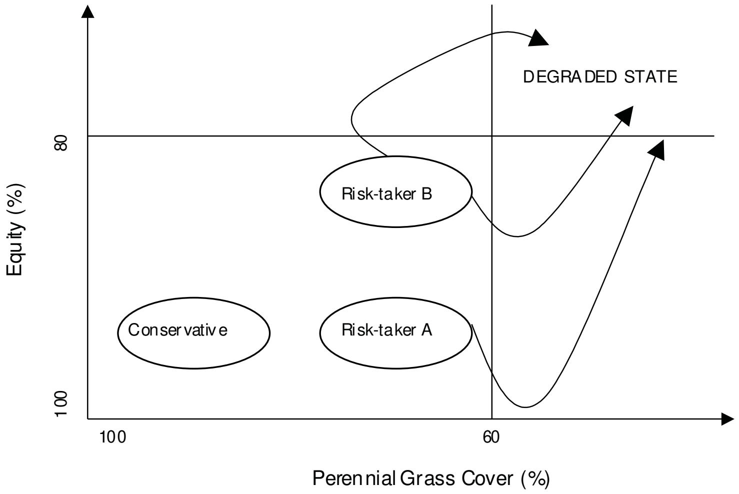


Figure 17.5 Two-dimensional representation of the possible approaches for management of a northern Australia cattle-grazing system. Trajectories explained in the text.

crossed. For most farmers in this situation there is generally high equity. It is difficult to pursue this conservative management strategy where equity levels are lower because there is not enough income to service the debt.

2. Risk Taker A — this is a farmer with initially low debt but who because of a will to increase income or some short-term economic pressures starts "mining" the rangeland and thus deteriorating the biophysical system. Unfavorable seasonal conditions can result in the biophysical threshold being crossed. In response to lower cattle production and lower income associated with this degraded state, the farmer borrows money for supplementary feed which takes him into debt, and eventually towards the degraded state (upper-right corner of Figure 17.5).
3. Risk Taker B — this is a farmer with significant debt who to service this debt has to push the system to its natural limits. To remain close to both the socioeconomic and biophysical threshold and not cross it requires considerable management acumen, which anyway is likely to be ineffectual under a sequence of adverse seasons.

Building and Losing Adaptive Capacity

We here provide two examples of how adaptive capacity can be improved: seasonal weather forecasts and improved grazing management strategies. Mid-term forecasts, where available, allow a farmer to adjust stock numbers to take advantage of good seasons through increasing stock numbers and to reduce the risk of overstocking and degrading the land by reducing stock numbers prior to poor seasons. In the longer term, increased average incomes from using forecasts would allow the farmer to service a higher debt level i.e., the economic threshold increases. They also provide an opportunity to keep closer to the bottom left corner of the "green" zone, which provides more buffering. Grazing systems that are more flexible potentially allow the enterprise in the longer term to operate further from the biophysical threshold. Alternatively, the forecasts could allow the farmer to operate closer to the biophysical threshold with more confidence. However, where these systems involve a lot of infrastructure and capital they can require an initial pushing of the system to the limits and there is in fact an increased risk of crossing into a degraded state (as discussed toward the end of the section on DEGRADATION IN LINKED SOCIO-ECOLOGICAL SYSTEMS).

There are also common situations leading to the loss of adaptive capacity. For example, increasing interest rates make it more difficult for farmers to service their debts. The equity required to cope with debt therefore shifting the economic threshold downwards. In the biophysical sub-system, adaptive capacity can be lost through invasion or deliberate introduction of exotic species that in the short-term may provide the same forage supply to herbivores but in the longer term can make the system more susceptible to degradation because of possible loss of species diversity (see Determinants of Resilience in DEGRADATION IN LINKED SOCIO-ECOLOGICAL SYSTEMS).

Cross-scale Interactions

Historically, drought subsidies in Australia at the national level took the form of fodder and supplementary feeds. Subsidies of this type tended to further deteriorate the biophysical environment which made it more difficult for farmers to return to a sustainable state; i.e., it reduced their adaptive capacity and increased their reliance on support mechanisms. More recently, drought assistance has taken the form of low interest loans and transport subsidies to remove stock from the land. These incentives provide financial support in a way that encourages a shift back towards a sustainable biophysical state by lowering the stocking pressure on the land.

From a more global perspective the latest climate projections for the region suggest little change in rainfall and a warming of 2–6° C by 2070, with atmospheric CO_2 levels in the order of 550–650 ppm. Increased evaporation associated with warming will decrease available water but the increased CO_2 concentrations may allow plants to increase their water use efficiency (e.g., Polley et al. 1994). The balance of these two likely trends suggests an overall improvement in water use efficiency that would be beneficial, particularly in dry years; i.e., the biophysical threshold could increase. Much of this depends on how community composition is affected, particularly the woody-grass balance. Most woody species are of C3 physiology, and it is usually considered that in a high-CO_2 world C3 plants will have a competitive advantage over C4 plants (Navas 1998). However, for Australia the increased-temperature effects could be more important and C4 species (most of which are grasses) may outcompete C3 species (Henderson et al. 1994). The outcome of these processes will strongly influence the determinants and position of the biophysical thresholds.

Producing Karakul Pelts in Namibia

In this example, we examine sheep farming on the Gamis ranch, which is 250 km southwest of Windhoek, Namibia. Mean rainfall is 180 mm/yr which, besides having a large interannual variation, is also very patchy. The ranch covers 30,000 ha and is devoted to Karakul fur production (for details see Stephan et al. 1998). A sophisticated grazing management has protected the land from degradation, hence guaranteeing the farmer's economic survival. The main indicator of the long-term biophysical condition of the system is as in the previous example perennial vegetation basal cover, a slow-changing variable directly related to the capacity of the rangeland to respond to favorable weather conditions (i.e., production of green biomass: the "fast" variable). The main indicator of the socioeconomic state of the system is the quality of the fur produced, which is mainly dependent on the genetic makeup of the herd. Both recovery of vegetation basal cover and animal genetic improvement are relatively slow processes.

Grazing management involves three herds with a rotational scheme that takes advantage of the spatial heterogeneity of the rangeland, and also the rainfall amount that each particular paddock has received during the season. If rainfall is adequate, the paddock is subjected to short-term, high-intensity grazing (ca. 2 wk), and then rested for at least 2–3 months. In addition, each paddock is rested once every three years for the entire growing season. With increasingly poorer rainfall, the following successive strategies are used: (1) flexible resting according to vegetation state, (2) reduced number of lambs and moving stock to rented land, (3) reduced size of herd, no resting, (4) rent additional pasture/rangeland, and finally (5) use other source(s) of income (e.g., tourism).

Stephan et al. (1998) simulated the development of the vegetation and the Karakul herds according to long-term observations by the farmer. The aim of the model was to understand the basis of this strategy's success. For example, the authors compared the long-term outcome of three possible stocking strategies that modify the rule involving resting every three year: Strategy A: No season-long resting; Strategy B: the "Gamis strategy" with season-long resting in years with sufficient rain; and Strategy C: Season-long resting also in years with insufficient rain. Economic success of a strategy was measured by the number of sheep that can be kept on the farm when the stocking rate is adapted to the carrying capacity (i.e., measured via the production of green biomass). Repetitions of stochastic simulations with different rainfall sequences show that the overstocking Strategy A is more successful on the short term, but that a series of dry years may rapidly reduce the perennial vegetation basal cover (the slow variable indicating the long-term biophysical condition of the system), thus leading to biophysical degradation. It appeared that the Gamis strategy (i.e., B), although not economically superior on average, builds in just enough adaptive capacity to buffer the large stochastic environmental fluctuations, reducing the risk of land degradation and thus of complete economic failure.

In Figure 17.6 we represent these various management strategies in the phase-plane of slow biophysical and economic variables (as per Figure 17.4). Strategy A is profitable as long as rainfall conditions remain favourable, but a series of dry years may cause a transition to the degraded state with low production of green biomass which drives the ranch into economic failure. Strategy *C* maintains a conservatively low number of animals and succeeds in keeping sufficient plant cover, but a drop of the fur prize at the market may cause a transition into economic debts and force the farmer to overstock and finally to pass as well the cause the transition to the degraded vegetation state. Finally, Strategy *B*, the one actually followed by the farm, is apparently the only one that maintains the system within the sustainable region.

Small-scale Farmers in Semi-arid Areas of South Africa

This example is intended to illustrate how the framework can be applied to farmers operating in a system that has undergone substantial policy change. In this instance, the framework

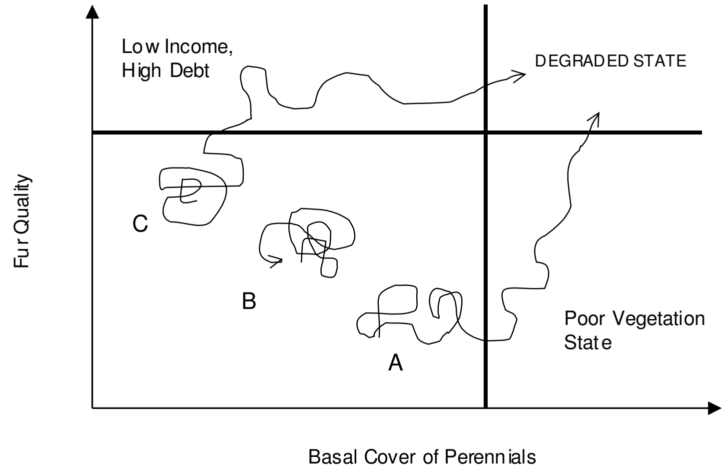


Figure 17.6 Three potential management strategies (*A*, *B*, and *C*) for the Gamis Karakul farm in Namibia. See text for details.

represents simplified case studies of small-scale, black farmers and larger-scale, commercial, white farmers in South Africa. Rainfall is usually less than 500 mm per annum, and the areas represented here are punctuated by regular dry periods. In many areas variability of rainfall is high. The lack of high-potential agricultural land and various other factors also mean that farmers usually farm on marginal lands, often in areas with poor soil quality and limited supplies of water (May et al. 2000). In contrast to the previous examples, in which the focus was more on the choices faced by the individual farmer, we attempt to capture in this example the experiences of farming households operating within varying institutional constraints. This case also illustrates cross-scale issues, i.e., how interventions at higher levels can influence the state of HH/F systems, and how land-management practices and various state policies can either reduce or enhance sustainability.

Let us first consider the case of small-scale agriculture. Black, communal, and small-scale farmers discussed here were previously part of designated "homeland areas." These farmers were and are nonetheless a heterogeneous group and may occupy various positions in the biophysical/socioeconomic space (Figure 17.7). Some of them (group 1) are seen as well within the sustainable ("green") region of the diagram, while others are more towards the unsustainable ("yellow," groups 2–3) or permanently-degraded phase ("red," group 4).

During the apartheid era, several of these farmers and their households were operating, however, in "'socially-marginal" or "at risk" situations (Figure 17.7, group 2). This was because they were often denied access to farm inputs, infrastructure, markets, and services usually made available to commercial farmers. Starting in 1994, appropriate state intervention, including land reform and other changes in agricultural policy, such as broadening the access to resources (e.g., Van Zyl et al. 1996), set the stage to potentially improve the farming environment for small holders. We interpret these changes as providing an opportunity for a potentially favourable shift in the socioeconomic threshold, thus expanding the sustainable, green region, and reducing the number of at-risk farmers (St_0 moving to St_1 in Figure 17.7). These changes have the potential to enable some farmers, that may have been operating under

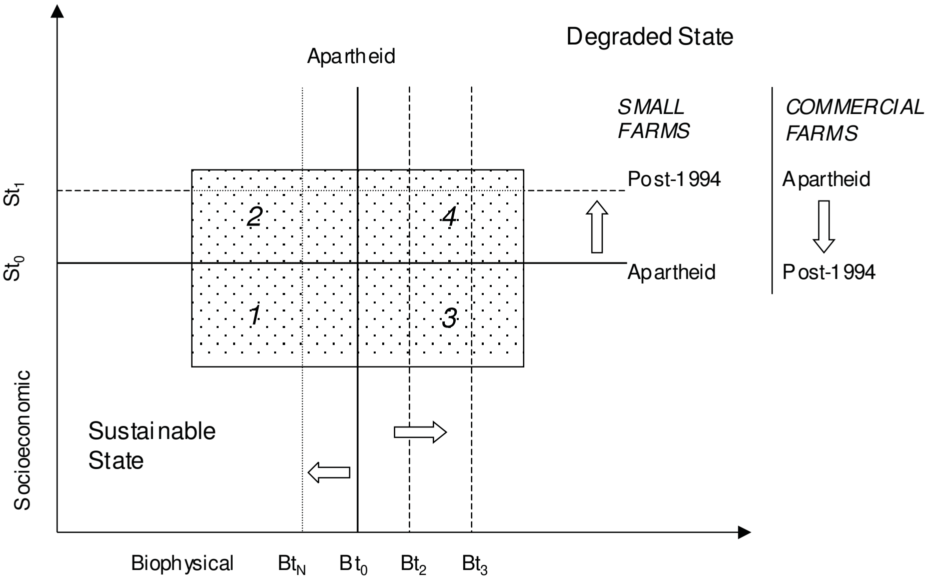


Figure 17.7 Situation of small-scale farmers in South Africa through time and under several hypothetical climate and policy changes. The right-hand side legend refers to other type of farmers (see text).

biophysically-marginal conditions (group 3), to farm in a more sustainable way. Ultimately, the "green" region of the diagram along the horizontal axis (Bt_2, Bt_3 in Figure 17.7) could expand. The expectation is that, over time, the success of these policy changes should enable farmers to better manage their risks, farm in a more sustainable manner, and avoid sliding into the most degraded states.

Using the same framework, one can also visualize what may happen if such policies are not well implemented and if a severe biophysical shock or change were to occur. In this case, for example, during an extreme drought (e.g., associated with an El Niño Southern Oscillation [ENSO] event) the shape and size of the sustainable space could change. In the absence of a good drought mitigation policy, the biophysical threshold could shift to the left, thereby reducing or "shrinking" the resilience space (Bt_N, Figure 17.7). A well-directed drought policy, however, should seek to enable most farmers to remain in the sustainable space despite the biophysical stresses on the system. However, if there is no integrated drought management policy, the critical social threshold may also shift downwards. In this situation, farmers' livelihood resources erode and their situation becomes increasingly "squeezed" (Vogel 1995, 1997, 1998).

The experience of commercial livestock farmers operating under similar biophysical conditions has been, and continues to be different. During the apartheid era, an extensive subsidy and aid infrastructure enabled many of these farmers to operate at artificially high levels of production (usually buffered against climate and market controls). In the context of our framework, this means that the apartheid policies outlined above set the *SE* threshold at a higher, more favorable, level for these commercial farmers than for black smaller scale farmers (Figure 17.7, right-hand caption). Recent changes in agricultural policy, however, now seek to widen support to include small-holders, with revisions in commercial agricultural support. Credit subsidization and availability has, for example, been reduced. Deregulation of the agricultural commodity marketing infrastructure has also removed many of the supports for marketing strategies on which commercial farmers depended prior to the early 1990s (e.g., Van Zyl et al. 1996; Vink and Kirsten 2000).

Using the framework here (Figure 17.7), during an extreme shock event, e.g., ENSO, commercial farmers may find the adaptive space reduced in both its biophysical and social dimensions. The onus is therefore increasingly on the South African commercial farmer to either find HH/F level effective strategies to remain within adaptive space — similar to the experience of the Australian cattle farmers described above — or to simply discontinue commercial farming (which for this group, unlike for the small-scale farmer, may constitute a viable option). In the current political scenario, cross-scale interventions and subsidies that applied in past droughts, are, however, no longer assured.

For both groups, factors that reduce adaptive capacity, may be exacerbated by poorly implemented policy, e.g., land reform, agricultural policy, and effective drought mitigation policy. Repeated and possibly more frequent droughts (as suggested by the latest IPCC reports) could mean that these areas become more degraded over time. If, however, various effective cross-scale policies are put into effect, supported by suitable structures for implementation (e.g., long-term seasonal forecasts of an ENSO are accessible and reach farmers; affordable and sustainable water-management and farming strategies are in place and maintained), farmers should be able to “ride out the stresses” and sustainably farm in the area. While it is acknowledged that this simple example leaves out much of the complex social dynamics that continue to beset agriculture in South Africa, it nonetheless provides a rudimentary framework that can be used and adapted to carry home the message that degradation is the interaction between past and present social and physical dynamics that cascade and operate across various time and spatial scales.

Crop-livestock System of Production in Southern Sahel, Western Niger

Background

This case is our most elaborate one, and we use it to illustrate how the framework can be tailored to deal with more than two variables. It concerns a crop-livestock production system under 300–500 mm rainfall per year, in Western Niger. The production system is dual, that is, each farm is involved in two agriculture activities: cropping and livestock husbandry (see Hiernaux and Turner, this volume, for details). Cropping commodities are dominated by staple cereal (mainly millet and some sorghum) aimed at subsistence, associated with a range of secondary crops, either dual purpose legumes (cowpea, bambara nut, ground nut) or cash crops (sesame, sorrel). Livestock husbandry involves cattle, sheep, and goats together with donkeys and a few camels and horses as draught animals[1].

Households in the community studied by Hiernaux and Turner can be subdivided into two groups as a function of their type of dwelling: (1) concentrated village households (mostly

---

[1] Draught animals are used throughout the world for many diverse tasks, including ploughing, planting and weeding, transporting water and fuel, and for logging and land excavation.

Jerma people), and (2) dispersed camp households (mostly Fulani people). Both groups are sedentary. Village households (VHs) comprise about 70% of the total community households, camp households (CHs) about 30%. Only the VHs have primary rights to the land for cropping and thus the CHs must contract their usage from the VHs. Given their pastoral culture, the CHs have greater husbandry skills — especially regarding long distance seasonal transhumance or herding — and, in general, this results in better performance of livestock, less reliance on local forage resources, the ability to maintain more livestock than VHs (5 to 20 tropical livestock units [TLU, 250 kg live weight equivalent] per household), and a greater source of manure for use on the crop fields. In contrast, the VH raise livestock in more limited numbers, the majority (60%) managing 10–25 ha with less than 2 TLU (below ,we identify a small group of wealthier village farmers [ca. 10% of households] who manage 20–30 ha and have 10–15 TLU).

With exception of the rangelands (the nonarable component of the landscape, which is about 15 % on average) — the soils in this region of Western Niger are very sandy, have low organic matter, and are deficient in phosphorus and nitrogen. Average yield of millet crop is close to 300 kg/ha on unmanured fields providing they are fallowed (“rested”) frequently enough (see below). Millet grain yield reaches 600 kg/ha in average on fields that are manured at the rate of 6t/ha every three years. Yields of unmanured and unfallowed fields decline rapidly to 100 kg/ha or less. The bottleneck of the millet cropping system is the labor required for weeding: 0.15 ha per adult equivalent per day (furthermore, weeding must be done within 2–3 weeks).

Grazing resources are managed communally. The livestock is divided into “resident” and “migrant” herds. The migrant herd is sent in seasonal transhumance outside the community lands, especially during the wet season (towards northern sahelian pastures), which requires skilled labor. While this improves the livestock performance it reduces the manure harvest. The resident livestock are not permitted to graze in cropped fields during the growing season (3–4 months) but are free to graze rangelands and all fallowed fields year around, as well as all cropped fields after crop harvest. Thus, the number of livestock that can be bred is limited by the amount and quality of fodder resources as determined at the community, not farm, scale. As the density of the resident herd increases, they exert increasingly high pressure on the fallow fields and rangelands, particularly as the proportion of cropped area increases. On most of the rangelands (i.e., on the shallow soils of the plateau and the loamy-sandy soils of the upslope) heavy grazing pressure during the wet season results in soil compaction, accompanied by a severe reduction in herbaceous cover. The herbaceous layer becomes increasingly dominated by short-cycle species that tolerate frequent defoliation (e.g., the legume, *Zornia glochidiata*, and the grasses, *Microchloa indica* and *Sporobolus microprotus*.

Applying the Framework

For both crop and animal products — and in all farm types — productivity is limited by soil fertility, which can be considered the main service provided by the ecosystem. Because of the dual commodities and their interactions and trade-offs, soil fertility cannot be related to a single driving variable but to a combination of two land-use variables — fallowing and herbage intake by livestock (Turner 1995). These are closely tied to an economic variable that determine household (HH) sustainability. We consider each of these in order.

Fallowing is an important management tool to maintain the soil fertility of nonmanured croplands. Of course, if a farmer has enough livestock to manure all his arable land (A), fallowing is unnecessary. A household with no or insufficient access to manure can maintain soil fertility (and hence acceptable yields) if it fallows (A_{fallow}) at least 3/8 of the arable lands it manages that does not benefit from manure; this "3/8" value represents a threshold. The proportion of arable land on a farm that is manured (A_{manure}) will vary depending on the number of resident livestock managed by each farmer within the community lands. Hence, an index of sustainability with regard to soil fertility, as affected by fallowing ($IS_{fallowing}$[2]) , is calculated as:

$$\mathrm{IS}_{fallowing} = 100 * (\mathrm{A}+\mathrm{A}_{\mathrm{manure}}) / (\mathrm{A}+\mathrm{A}_{\mathrm{fallow}}) / (3/8) \tag{17.1}$$

The size of the breeding resident livestock herds depends on the total forage available , which in turn is affected by the wet season stocking rate on the rangelands. That is, in the wet season livestock has only access to fallow and rangelands grazing resources, and herd size depends on the extent of the grazing pressure exerted by all the herds in the community on these limited resources. Therefore, soil fertility is also affected by the ratio of total herbage intake (H_{intake}) by resident livestock to total palatable herbage available on rangelands and fallows during the wet season. The threshold for sustainability is set at one third of the mass of palatable herbage at the end of the growing season (H_{end}), to account for the progressive growth of annual plants during the wet season and also to account for the limits of grazing efficiency (Breman and de Ridder 1991). Hence, an index of sustainability with regard to the rangeland and fallow grazing resources, as affected by herbage intake (IS_{intake}) is calculated as:

$$\mathrm{IS}_{\mathrm{intake}} = 100 * 3 * \mathrm{H}_{\mathrm{intake}} / \mathrm{H}_{\mathrm{end}}. \tag{17.2}$$

Next, we address economic sustainability at the HH level. This can be expressed by the ability of the farm to cover the basic needs of its HH members, which will vary from year to year depending upon the agricultural production level and the number of HH members. Aggregated agricultural production (P_{agg}) consists of crop yields, dairy products, and livestock sold (all of which may be expressed in units of kg of millet grain equivalents based on their monetary value at the farm gate). It follows that P_{agg} may be compared to a minimum threshold for the basic needs of the household members (Nb) and, following Equations 17.1 and 17.2, an index of economic sustainability (IS_{econ}) at the HH level is calculated as:

$$\mathrm{IS}_{\mathrm{econ}} = 100 * \left(\mathrm{Nb}/\mathrm{P}_{\mathrm{agg}}\right). \tag{17.3}$$

The application of this crop-livestock production system within our conceptual framework is presented in Figure 17.8, where we examine more than 500 farms from three communities in western Niger within the IS_{econ} and $IS_{fallowing}$ axes. In Figure 17.8 the farms are grouped into 5 types based on the location of the dwelling and endowments in land and livestock (see Hiernaux and Turner, this volume): village farmers that are highly (*Vh*) or poorly (*Vp*) endowed in terms of land; village mixed farmers[3] (*Vmix*); camp agro-pastoralists that are highly

---

[2] Note that this index, as well as subsequent ones, are set to yield 100 at the threshold.

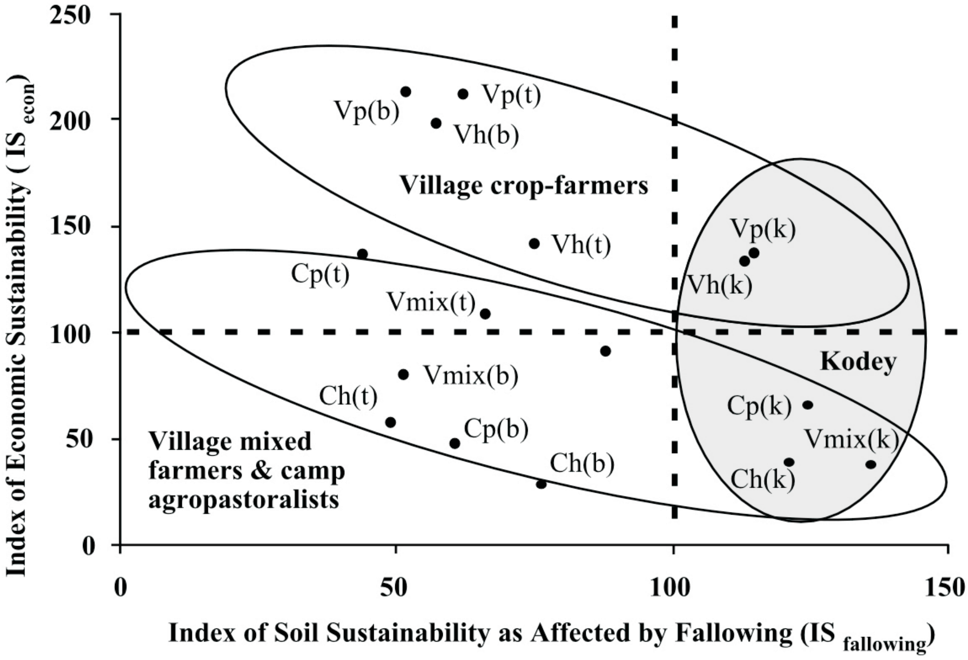


Figure 17.8 Plot of five farm types in western Niger based on two indices of sustainability — soil fertility ($IS_{fallowing}$, Equation 17.1) and economic (IS_{econ}, Equation 17.3). The farm types are: *village* farmers that are highly (*Vh*) or poorly (*Vp*) endowed in terms of land; *village* mixed farmers (see footnote 3 in text) (*Vmix*); *camp* agro-pastoralists that are highly (*Ch*) or poorly (*Cp*) endowed in terms of livestock. Data from three communities are shown: Banizoumbou (*b*), Tigo Tegui (*t*), and Kodey (*k*). This framework captures the juxtaposition of two competing forces in this crop-livestock production: human population increases versus livestock capital increases. See text for details.

(*Ch*) or poorly (*Cp*) endowed in terms of livestock. Data from three communities are shown: Banizoumbou (*b*), Tigo Tegui (*t*), and Kodey (*k*). Note that the “green” area is defined by the intersection of the $IS_{fallowing}$ and IS_{econ} thresholds; in the case of $IS_{fallowing}$, this represents fallowing 3/8 of the arable land whereas for IS_{econ} this is the ratio of Nb/P_{agg} (both scaled to 100). Plots within the IS_{econ} and $IS_{fallowing}$ plane suggests a rearrangement of the farms in 3 general types: (1) village farmers in economic deficit, (2) village mixed farmers and camp agro-pastoralists that are well-endowed and economically sustainable, and (3) all farm types in the village of Kodey, which have unsustainable soil fertility management of their nonmanured land.

---

[3] This refers to the fact that the minority of village farmer not only have easy access to land for cropping (as all other village farmers) but also own a large number of animals as the camp farmers.

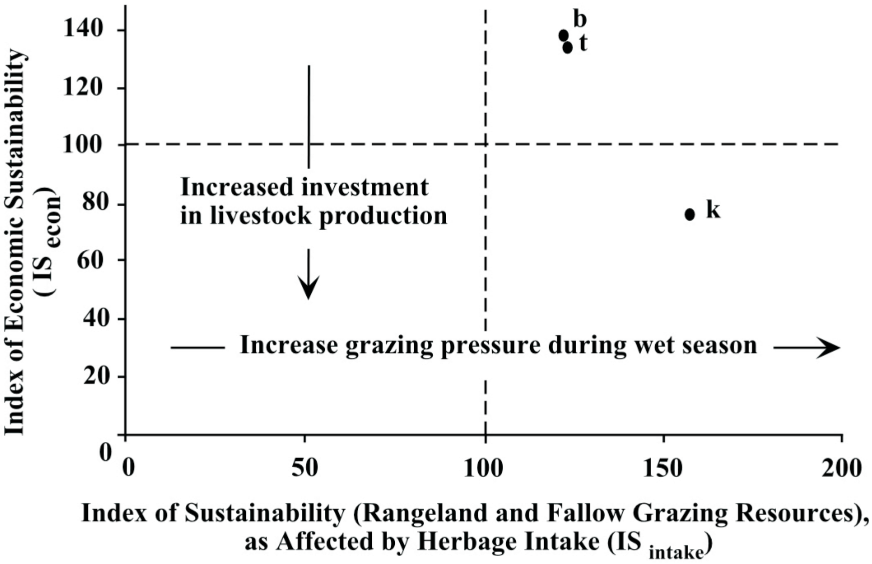


Figure 17.9 Plot of three farm communities in western Niger based on an index of sustainability with regard to the rangeland and fallow grazing resources (as affected by *herbage intake*, IS_{intake}, Equation 17. 2) and an economic index of sustainability (IS_{econ}, Equation 17.3). Values are computed as community averages. Communities are Banizoumbou (*b*), Tigo Tegui (*t*), and Kodey (*k*). Increased investment in livestock production tends to satisfy economic needs; however, increased grazing pressure tends to have a negative impact on soil fertility. See text for details.

In the villages of Banizoumbou and Tigo Tegui, the average agricultural production of the crop-farmers is not sufficient to cover basic needs at the HH level (see *Vh(b)*, *Vp(b)*, *Vh(t)*, *Vp(t)* in Figure 17.8). This is true in spite of their practice of short-fallowing nonmanured cropland. Crop-farmers in Kodey (see *Vh(k)*, *Vp(k)*, Figure 17.8) not only suffer from the economic fallout of production deficits but also from decreases in soil fertility of their un-manured croplands.

Note that it is possible to calculate indices of sustainability for individual farms, or compute averages for farms, farm types or communities. In the case of the soil fertility index of sustainability as affected by herbage intake (i.e., IS_{intake}) it can only be calculated at community scale. In Figure 17.9 IS_{econ} and IS_{intake}, both computed as community aggregate *s*, are shown for Banizoumbou, Tigo Tegui, and Kodey. All three sites surpassed the intake threshold (i.e., one third of the mass of palatable herbage at the end of the growing season). However, soil degradation was more severe in Kodey since rangelands and fallow only cover 25 % of the region (i.e., 75% of the land is cropped and thus not accessible to livestock during the wet season). The average farm in Banizoumbou and Tigo Tegui is suffers from production deficits. However, Figure 17.8 shows that farm types within each of these villages were affected differently: crop-farmers, the majority, were suffering from deficit while, in general, mixed farmers and agro-pastoralist were at least covering their basic needs. Note that the average depends on the status of each farm type, and also of the number of farms per type, which differs from site to site. This explains why average farms in Banizoumbou and Tigo Tegui suffer from production deficits: they are largely dominated by village farmers that are in deficit, while camp farmers are proportionally in higher numbers in Kodey. The reason why the average Kodey farm is better off — in spite of the severity of soil and grazing resources degradation — is, in part, due to the fact that a larger fraction of the farms are camp farms that rely on forage resources outside the community land to feed their livestock; also, perhaps, there is a more severe depletion of soil resources, which in the long term could lead to a decrease of crop production.

Of course, other drivers influence the thresholds shown in Figures 17.8 and 17.9. For example, woody plant density may affect survival of resident livestock during a drought; the proportion of crop land devoted to dual purpose legume or cash crop may be as important as livestock in sustaining household economies; adoption of draught animals could alleviate labor constraints for weeding millet fields; and changes in skilled labor can influence transhumance.

Building Adaptive Capacity

Building capacity in this system will vary according to scale. However, some general directions can be highlighted that will tend to widen the "green" box (Figure 17.4) beyond the thresholds associated with IS_{econ}, $IS_{fallowing}$, and $IS_{intake.}$.

- Ease of access to inorganic fertilizer (investments made by a farmer, provisions by farmer associations to buy fertilizer, national and international trade or tax policies, etc.)
- Crop diversification (especially if toward dual purpose legumes and other cash crops that improve access to inorganic fertilizers)
- Adapting agroforestry activities (plant diverse field hedges with multipurpose trees and shrubs can help diversify farm products as well as provide other valuable services, such as shading, nutrient recycling, etc.)
- Enhancing crop-livestock integration (an increase in livestock population on a farm will improve sources of manure, increase diversification of products and assets, but also has increased labor cost and impacts on land)
- Enhanced farmers' husbandry skills (this is key in reducing the reliance of livestock nutrition on sole local grazing resources). The organization of seasonal transhumance out of the village lands provides herds access to feed resources from outside the village lands. This increases the "green box" for grazing resources available at farm scale. However, the pressure of these migrant animals on grazing resources may have reverse effect at the scale of the region, which includes the rangelands grazed by the transhumant herds.

Cross-scale LInkages

The linkages between HHs and the community are stronger for this case than for the others described previously (CASE STUDIES: SAVANNAS OF NORTHERN AUSTRALIA, KARAKUL PELTS IN NAMIBIA, SMALL-SCALE FARMERS IN SOUTH AFRICA). For example, the existence of communal rangeland determines that available forage for livestock in each household is directly dependent on community livestock density (note that the type of forage available also depends on the communal fraction of small ruminants in livestock). On the social-capital side, access to wet-season forage is strongly influenced by the proportion of land that neighbors leave fallowed and how many milk cows they keep. Apart from the effects of markets — which is shared by the other examples — the crop-livestock system of production in southern Sahel includes international linkages because of seasonal transhumance (a mobile, pastoral economy). The access to cross-border rangelands clearly has an impact on the household production system and well-being of the local peoples.

DISCUSSION

What Is Conceptually New?

> The real voyage of discovery " … is not in seeking new landscapes, but in having new eyes."
> — Marcel Proust

In sum, we are suggesting not that desertification is a qualitative state, but rather that there is a *continuum* of degradation in which thresholds are crossed. These thresholds represent situations beyond which the system cannot restore or return itself — via internal mechanisms — to previous, less-deteriorated states. Such restoration is only possible with an external supply of resources (i.e., energy "subsidies"). Thus, the process is continuous and nonlinear. It is also scale-dependent in the sense that the amounts of external resources required for restoration increase as one moves to higher hierarchical levels.

Land degradation is a problem that encompasses both biophysical and socioeconomic dimensions and cannot be adequately comprehended focusing on just one of them. Our central proposition is that, whatever the trigger, desertified lands are always the combined result of biophysical and socioeconomic deterioration (see "triggering" versus "propagating" factors in Okin, this volume). Of course, from region to region and farm to farm the specifics will vary and the path to degradation can start within either "yellow" zone (cf. Figure 17.4). That is, either the socioeconomically or the biophysically-degraded one. The end result will, however, always represent deterioration in both dimensions ("red" in Figure 17.4).

We argue that current approaches to tackle the problems of land degradation are not comprehensive enough to provide an adequate framing of the relevant questions. A narrower focus incurs a serious risk of ignoring early warning signals that can be used to prevent further deterioration. In terms of seeking new insights into an old problem, we embrace Marcel Proust's remark about the importance of "having new eyes" in the voyage of discovery. We suggest that our framework allows us to re-state old questions with a fresh format.

The only thing we can be certain of is that the world is changing. This framework for desertification highlights the importance of being ready to face these inevitable changes and surprises by building resilience. The challenge lies in translating these ideas into operational terms. In the context of land degradation in aridlands, we see the ultimate goal as:

- being able to detect more indicators of danger, earlier;
- being able to attribute these changes to their proper causes with greater confidence;
- being able to characterize the system well enough to make educated projections; and

- being able to generate a rich array of alternatives and actions to build resilience, taking into account that what is considered desirable today may not be so appreciated in the future (more on this below).

Research Implications

A research agenda devised to maintain and improve the resilience of aridlands should consider, at minimum, the following:

- *The set of crucial variables that collectively govern the trajectories of the desired ecosystem services*. We have shown that these variables are few and exhibit relatively slow dynamics compared to those directly representing ecosystem good and services. Managers tend to notice, monitor and attempt to manage the fast variables from which they derive utility, yet it is the slower, controlling variables that determine the resilience of the production system.
- *The parameters that determine the dynamics of this set of slow variables*. For example, in many rangelands and pastoral systems these parameters are likely to include grazing pressure (livestock numbers) and fire frequency, which often determine the actual dynamics of slower-moving, controlling ones (such as woody vegetation biomass).
- *The factors defining the position and nature of the boundaries of the ecosystem's sustainable state*. Some of these factors cannot be influenced locally (such as long term climate change), but others can. These last ones represent potential points of intervention for preventing or reversing degradation. Lack of knowledge of these factors will lead us to miss windows of opportunity for pushing boundaries of sustainability outward and increasing system resilience (e.g., Holmgren and Scheffer 2001).
- *The cross-scale linkages between the farm level and levels above it*. One key research task might consider whether socioeconomic thresholds are more often determined by cross-scale factors than are biophysical thresholds.

The insights and simplification required to gather all this information are usually only available once a system is well known. There seem to be no shortcuts, barring those facilitated by researchers' ingenuity, experience, and ability to ask new, yet tractable questions. Still, the comparison of similar ecosystems in the light of our framework could somewhat accelerate the process.

Policy Implications

The new conceptual model for desertification has significant implications for policy and management:

There is a "new orthodoxy." Strategies to address land degradation should aim to increase system resilience and improve adaptive capacity. That is, with reference to our conceptual model, interventions should seek to increase the thresholds along the biophysical and socioeconomic axes and thus to increase the system's region of sustainable activity. Further intervention efforts should focus on maintaining the adaptive capacity of the system (i.e., in maintaining the thresholds at their higher levels).

Act proactively. Restoration efforts and interventions should occur before resource managers have moved, or find themselves across either threshold and, thus, in need of restoration efforts requiring progressively higher scales of resource mobilization. In this way, policy measures that build adaptive capacity and increase system resilience are far more cost-effective and efficient than short-term "after-the-fact" crisis responses. As shown, the wider the system's region of sustainability, the more buffered it is to the vagaries of external stressors, such as market and climate. Several examples of such interventions were presented in case studies, including "well-directed" drought mitigation policies, effective application of seasonal weather forecasts, introduction of improved farming techniques (such as water-wise irrigation systems). and the encouragement of more nonagricultural income earning opportunities for land tenants. Valuable work on such measures has been done, more is in progress, but much more is still needed to deal with the many problems faced by decision makers at all levels.

Focus your efforts. Related to the previous point, it seems wise to focus resources on times and areas that need them. This may seem obvious, but its logical consequence is *not* so obvious: do not spread efforts evenly among areas, regions, or activities. By not giving every year to everyone, resources are saved for a more weighty help when and where its really needed. (The points above indicate when this is: whenever it will impact the most in terms of long-term, sustained production.) Critical points of intervention should be identified and flagged for action, and the framework could be invaluable in this regard.

Improve communication channels. We advocate a wider use of "adaptive management" and participatory approaches in dealing with attribution issues. We urge scientists and policy makers to become involved in a learning process in which science is not the only source of knowledge. In an iterative process, feedback from policy application should serve to strengthen everybody's understanding of the issues at hand and to enable tools, interventions, and solutions to be refined and better directed.

Enhance institutional capacity. Institutional inertia can be a boon when we need to avoid hasty action, as well as a bane when the underlying conditions have changed to a degree that past implementation methods need to be thoroughly rethought. Conditions conducive to institutional learning and capacity-building should be identified and facilitated — work on this subject has recently come to the fore in considering environmental problems. Improved communication provides merely one such opportunity and there are many others, some general and some case-specific. In some instances (cf. Robbins et al. , this volume), the perspective shift encouraged in this chapter is likely to have little impact in policy-making communities unless fundamental institutional changes take place.

POSTSCRIPT

One implicit assumption pervading much of the above is that the existing "system" continues to be the desired one, which is not necessarily so. Much of our first rangeland examples is based on the southern Australian sheep-rangelands system for wool production, in which grass production is the important ecosystem service. In the mid 1990s a combination of declining wool prices and increasing goat meat prices changed this situation, and in a number of areas the desired system changed to goat-rangelands. The corresponding important ecosystem service became grass and shrub production and the "degraded" rangelands (from a wool perspective) were desired, sustainable states. All socio-ecological systems behave like "complex adaptive systems" (Levin 1998), and their future trajectories will depend upon a combination of human desires and ecological possibilities, both of which are influenced by developing technologies and changing human values. Some trajectoriesas in "classical" desertification, or formerly-lush Easter Island are undesirable under any conceivable scenarios of future changes in values, climate, and technology, and the first objective is to learn enough about the system to prevent it from following such trajectories. This raises the issue of event-driven changes and the adaptive cycle (Carpenter et al. 2001; Gunderson and Holling 2002), which is beyond the purview of this chapter.

ACKNOWLEDGMENTS

Workshop participants, mainly P. Doell, T. Downing, S. Nicholson, and S. Prince, kindly provided us with useful feedback.

REFERENCES

Allen, T.F.H., and T.B. Starr. 1982. Hierarchy: Perspectives for Ecological Complexity. Chicago: Univ. of Chicago Press.

Ash, A.J., J.G. McIvor, J.J. Mott, and M.H. Andrew. 1997. Building grass castles: Integrating ecology and management of Australia's tropical tallgrass rangelands. *Rangeland J.* **19**:123–144.

Breman H., and N. de Ridder, eds. 1991. Manuel sur les pâturages des pays sahéliens. Paris: Editions Karthala.

Carpenter, S.R., and M.G. Turner. 2001. Hares and tortoises: Interactions of fast and slow variables in ecosystems. *Conserv. Ecol.* **3**:495–497.

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

Costanza, R., R. Darge, R. Degroot et al. 1997. The value of the world's ecosystem services and natural capital. *Nature* **387**:253–260.

Gunderson, L.H., and C.S. Holling, eds. 2002. Panarchy: Understanding Transformations in Human and Natural Systems. Washington, D.C.: Island Press.

Henderson, S., P. Hattersley, S. von Caemmerer, and C.B. Osmond. 1994. Are C4 pathway plants threatened by global climatic change? In: Ecophysiology of Photosynthesis, ed. E.-D. Schulze and M.M. Caldwell, vol. 100, pp. 529–549. Berlin: Springer.

Holling, C.S., L.H. Gunderson, and D. Ludwig. 2002. In quest of a theory of adaptive change. In: Panarchy: Understanding Transformations in Human and Natural Systems, ed. L.H. Gunderson and C.S. Holling, pp. 3–22. Washington, D.C.: Island Press.

Holmgren, M., and M. Scheffer. 2001. El Niño as a window of opportunity for the restoration of degraded arid ecosystems. *Ecosystems* **4**:151–159.

Levin, S.A. 1998. Ecosystems and the biosphere as complex adaptive systems. *Ecosystems* **1**:431–436.

May, J., C. Rogerson, and A. Vaughan. 2000. Livelihoods and assets. In: Poverty and Inequality in South Africa: Meeting the Challenge, ed. J. May, pp. 230–256. Cape Town: David Philip and London: Zed Books.

Navas, M.L. 1998. Individual species performance and response of multispecific communities to elevated CO_2: A review. *Funct. Ecol.* **12**:721–727.

Odum, E.P. 1969. The strategy of ecosystem development: An understanding of ecological succession provides a basis for resolving man's conflict with nature. *Science* **164**:262–270.

Polley, H.W., H.B. Johnson, and H.S. Mayeux. 1994. Increasing CO_2: Comparative responses of the C-4 grass *Schizachyrium* and grassland invader *Prosopis. Ecology* **75**:976–988.

Reynolds, J.F. 2001. Desertification. In: Encyclopedia of Biodiversity, vol. 2, ed. S. Levin, pp. 61–78. San Diego: Academic.

Schiller, A., C.T. Hunsaker, M.A. Kane et al. 2001. Communicating ecological indicators to decision makers and the public. *Conserv. Ecol.* **5(1)**:19.

Stephan, T., F. Jeltsch, T. Wiegand et al. 1998. Sustainable farming at the edge of the Namib: Analysis of land use strategies by a computer simulation model. In: Ecosystems and Sustainable Development, ed. J.L. Usó, C.A. Brebbia, and H. Hower, pp. 41–50. Southampton: Computational Mechanics Publ.

Sterman, J.D. 1987a. Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. *Manag. Sci.* **35(3)**:321–339.

Sterman, J.D. 1987b. Testing behavioral simulation models by direct experiment. *Manag. Sci.* **33(12)**:1572–1592.

Sterman, J.D. 1989a. Misperceptions of feedback in a dynamic decision making. *Org. Behav. Hum. Dec. Proc.* **43(3)**:301–335.

Sterman, J.D. 1989b. Systems simulation: Expectation formation in behavioral simulation models. *Behav. Sci.* **32**:190–211.

Turner, M.D. 1995. The sustainability of rangeland to cropland nutrient transfer in semi-arid West Africa: Ecological and solial dimensions neglected in the debate. In: Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa, ed. J.M. Powell, S. Fernandez-Rivera, T.O. Williams, and C. Renard, pp. 435–452. Proc. of an Intl. Conf. on Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa. Addis Ababa, Ethiopia: ILCA (Intl. Livestock Centre for Africa).

Van Zyl, J., H.P. Biswanger, and J.F. Kirsten, eds. 1996. Agricultural Land Reform in South Africa: Policies, Markets and Mechanisms. Oxford: Oxford Univ. Press.

Vink, N., and J. Kirsten. 2000. Deregulation of Agricultural Marketing in South Africa: Lessons Learned. Free Market Foundation Monograph 25. Sandton: Free Market Foundation of Southern Africa.

Vogel, C. 1995. People and drought in South Africa: Reaction and mitigation. In: People and Environment in Africa, ed. T. Binns, pp. 249–256. Chichester: Wiley.

Vogel, C. 1997. Drought Management Best Practice: Lessons for Namibia. Namibia Drought Policy and Strategy Dossier, Document VII. Windhoek: National Drought Task Force. (see also contributions to the White Paper on Disaster Management, South Africa).

Vogel, C. 1998. Vulnerability and global environmental change. *LUCC Newsl.* **3**:15–19.

Walker, B.H., S.R. Carpenter, N.A. Abel et al. 2002. Analyzing resilience in a social-ecological system: An evolving framework for workshops of the Resilience Alliance. (In Preparation)

Walker, B.H., D. Ludwig, C.S. Holling, and R.M. Peterman. 1981. Stability of semi-arid savanna grazing systems. *J. Ecol.* **69**:473–498.

Please update, if possible.