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The Interactive Role of Human and Environmental Dimensions in the Desertification Debate

Mark Stafford Smith[1] and James F. Reynolds[2]

1 *Desert Knowledge Cooperative Research Centre, PO Box 2111, Alice Springs, NT 0871 Australia*

2 *Department of Biology & Division of Environmental Science and Policy, Nicholas School of the Environment and Earth Sciences, Duke University, Durham, NC 27708 USA*

Abstract: We summarize a new synthetic framework for understanding and responding to desertification that emerged from the 88th Dahlem workshop on "An Integrated Assessment of the Ecological, Meteorological and Human Dimensions of Global Desertification". We refer to this framework as the Dahlem Desertification Paradigm. This paper then examines one thread through this framework – the chain of logic that runs from the assertion that simultaneous consideration of both the human and environmental aspects of desertification if critical for any advances on dealing with desertification and degradation at all scales; that the coupled human and environmental parts of the system change over time, in ways that may be more or less dysfunctional; to emphasize the critical importance of assisting the rate of development of appropriate local environmental knowledge (LEK) in minimizing dysfunction. Given the increasing rates of change being imposed on our worlds, and the particular difficulties in developing experiential knowledge quickly in variable arid environments, we conclude that support for better integration of LEK with the scientific method is one critical pillar in creating a learning society in drylands.

Key words: Dahlem Desertification Paradigm, thresholds, land degradation, local environmental knowledge, learning, resilience, sustainability.

The Convention to Combat Desertification (CCD) (http://www. unccd. int/main.php, United Nations 1994) defines land degradation in terms of a number of ecological factors, e.g., productivity and erosion. The problem is that humans are often concerned only with that subset of this broad definition that affects some human activity (whether at the local land use level or through feedbacks at a wider scale). Consequently, there is disagreement concerning the causes and processes of land degradation and its importance. Issues include the extent to which land changes are natural (climate-driven) vs. anthropogenic, the role of 'grass-roots' abatement efforts vs. scientific and technological ones, how to determine the amount of land affected or at risk, and whether or not desertification is reversible (Darkoh, 1998; Reynolds, 2001). A new synthetic framework that encompasses all these issues is required to resolve the tangle of issues, disagreements, and misinterpretations surrounding desertification. In the absence of such a framework, the answer to most questions is: "it depends!" This leads to endless and relatively unproductive debates, which have been one of the legacies of desertification research, and which have resulted in negligible impacts on effective policy and on the programs intended to help people living in these lands.

In an effort to address this challenge, we convened a Dahlem Conference (http://www.fu-berlin.de/dahlem/) in 2001, which was entitled "The Meteorological, Ecological, and Human Dimensions of Global Desertification." The key product of the meeting was the development of a new synthetic framework for global desertification, which we call the Dahlem Desertification Paradigm (DDP). As is the case for many paradigms, the constituent ideas themselves are generally not new, but bringing them together reveals a fresh view of an 'old' problem, providing a new depth of insight. The DDP focuses on the interrelationships within coupled human-environment systems that cause desertification. It draws heavily from the chapters of the resulting Dahlem book, *Global Desertification. Do Humans Cause Deserts?* (Reynolds and Stafford Smith 2002), and considers a wide variety of issues, including non-linear processes, resilience, vulnerability, traditional range ecology, human perceptions, panarchy theory, social structures, and economic factors.

The general model emerging from the Dahlem workshop is outlined in Stafford Smith and Reynolds (2002), and we briefly recapitulate the highlights here. The original statement (and certainly the recapitulation here!) was so abbreviated that it is useful to take some elements of the DDP and explore them in more detail. Although we believe that the DDP, as a collective statement from 40 experts attending the Dahlem workshop, is a valuable step forward, it is clearly a work-in-progress. The subsequent sections of this paper aim to add further to that progress, and we welcome critical feedback. In fact, our long term goal is for the international desertification community to critically debate the veracity of the DDP (Reynolds *et al.*, 2003). For example, Lynam and Stafford Smith (2003) have explored the implications of the model specifically for issues to do with monitoring. In this paper we focus on one of the key assertions: that it is pointless to look at only the biophysical or only the socio-economic aspects of the problem, and expand some of the implications of this statement.

The Dahlem Desertification Paradigm in Brief

The Dahlem Desertification Paradigm (DDP) is composed of 9 assertions (Table 1). The first three relate to the working framework while the others focus on implementation, limitations, and potentials of the paradigm. Details are given in Stafford Smith and Reynolds (2002), of which the following is a brief summary, with some greater detail about the assertions which we return to in the later sections.

Assertion 1. Desertification always involves human and environmental drivers

At the core of the DDP is the unequivocal affirmation that desertification is a phenomenon that encompasses both biophysical and socio-economic dimensions (Reynolds, 2001) - neither dimension can be universally regarded as the sole predisposing factor (Fig. 1). Any effort to detect a 'decline' in the condition of

Table 1. The nine assertions of the Dahlem Desertification Paradigm, and some of their implications (after Stafford Smith and Reynolds (2002), but focused on the human/environment interactions). These assertions are not all-encompassing but provide the framework for a new paradigm

Assertion	Implications
1. Desertification always involves human and environmental drivers	Always expect to include both socio-economic and biophysical variables in any monitoring or intervention scheme
2. 'Slow' variables are critical determinants of system dynamics	Identify and manage for the small set of 'slow' variables that drive the 'fast' ecological goods and services that matter at any given scale
3. Thresholds are crucial, and may change over time	Identify thresholds in both biophysical and socio-economic change variables at which there are significant increases in the costs of recovery, and quantify these costs, seeking ways to manage the thresholds to increase resilience
4. The cost of intervention rises non-linearly with increasing degradation	Intervene early where possible, and invest to reduce the transaction costs of increasing scales of intervention
5. Desertification is a regionally emergent property of local degradation	Take care to define precisely the spatial and temporal extent of and processes resulting in any given measure of local degradation. But don't try to probe desertification beyond a measure of generalized impact at higher scales
6. Coupled human-environment systems change over time	Recognize the 'co-evolution' of the human and environmental sub-systems, and understand and manage the circumstances in which their evolutionary paths become 'de-coupled'
7. The development of appropriate local environmental knowledge (LEK) must be accelerated	Create better partnerships between LEK development and conventional scientific research, employing good experimental design, effective adaptive feedback and monitoring
8. Systems are hierarchically nested	Recognize and manage the fact that changes at one level affect others; create flexible but linked institutions across the hierarchical levels, and ensure biophysical and socio-economic processes are managed with scale-matched institutions
9. A limited suite of processes and variables at any scale makes the problem tractable	Analyze the types of syndromes at different scales, and seek the investment levers which will best control their effects - awareness and regulation where the drivers are natural, changed policy and institutions where the drivers are social

some parcel of land by measuring soil fertility and grain production, with the intent of assigning 'risk' or designing an 'intervention' strategy, is meaningless unless one is also monitoring appropriate socio-economic factors such as household debt ratio, local land use goals, and labor issues.

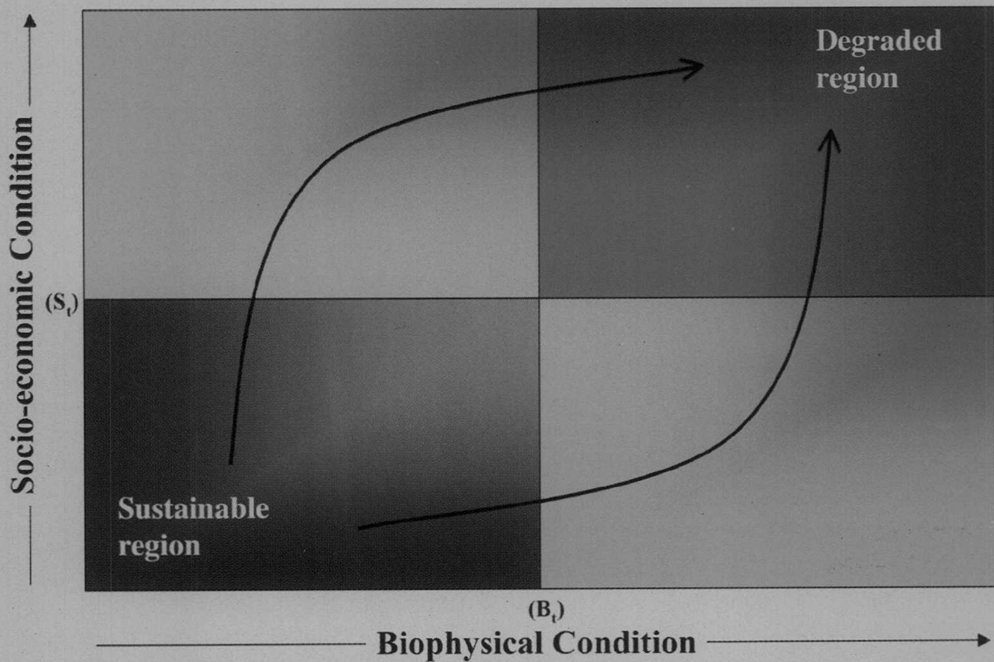

Fig. 1. Conceptual representation of degradation framework. Desertification must simultaneously include both biophysical and socio-economic dimensions (x and y-axes respectively here). The various states of a system are shown as sustainable (green, with boundaries at Bt and St), unsustainable (yellow), and permanently-degraded (red); these boundaries are often fuzzier than shown here. Although a 2-dimensional representation is an oversimplification, there are a limited number of ways in which local factors interact to create a 'syndrome of desertification' (Assertion 9). Modified from Fernández et al. (2002).

Assertion 2. 'Slow' variables are critical determinants of system dynamics

There is a growing acceptance that a small number of 'slow' variables act as the critical determinants in human-environment systems (Holling *et al*., 2002). Hence, the axes in Fig. 1 should display 'slow' variables, in contrast to 'fast' ones that are very sensitive to short-term events and are thus of little value in characterizing the state of human-environment systems, particularly in systems subject to high temporal variability. Of course, the terms 'slow' and 'fast' are relative and depend upon the scale at which a system is being studied.

Assertion 3. Thresholds are crucial, and may change over time

Thresholds (Fig. 1) represent critical points in the slow variables (whether biophysical or socio-economic), beyond which the system moves into a new state or condition. These thresholds, which are not fixed, are a function of the system's internal dynamics. For example, from a biophysical point of view, thresholds of grain production may be the result of long cycles of above- and below-average rainfall; from a socio-economical perspective, they may result from changes in the social capital of a community or its taxation environment. Some thresholds are amenable to intervention so that they can be deliberately expanded or contracted. It is important that we focus on efforts to expand the range of conditions in which people can operate before a threshold is reached; in other words, we should seek to build and maintain the adaptive capacity of the human-environment system as a whole (Assertion 7).

Assertion 4. The cost of intervention rises non-linearly with increasing degradation

As the state of the linked human-environment system described by the slow variables 'declines,' the cost of intervention to 'recover' the system increases (e.g., Milton *et al.*, 1994). This increase generally creates another type of threshold, related to the cost of recovery, because of a fundamental biophysical (e.g., switch from overland water flow to gully erosion) or socio-economic non-linearity in the system. For example, the latter commonly result from the necessity to call on resources from higher (e.g., provincial, state or international) or broader (e.g., other households or communities) scales in order to reverse the change (see examples in Fernández *et al.*, 2002; Robbins *et al.*, 2002).

Assertion 5. Desertification is a regionally emergent property of local degradation

The CCD definition of desertification should be applied at a broad, but not local scale (Chasek and Corell, 2002; Prince, 2002). By comparison, 'degradation' must be assessed at the household to community social scales and comparably modest spatial scales. This is because degradation (of some specified aspect of biological productivity under current human use) is the local expression of regional desertification, but there is no general concept of land degradation that is uniformly applicable to all situations. It will always be necessary to define what factor is degraded, thereby providing guidance as to what to measure, and how to direct management and remediation efforts.

Assertion 6. Coupled human-environment systems change over time

At any particular point in time, a dryland system is the product of a set of complex interactions between biophysical factors (biogeochemical cycles, population dynamics, climate variability, etc.), social factors (conflict resolution, role of culture in shaping attitudes, etc.), and economic factors (supply-demand, economic stratification, work force, etc.). Hence, these systems are not static, but are constantly changing in response to dynamic drivers, both external (e.g., climate) and internal (e.g., soil nutrient-plant growth feedbacks, or farmer responses to declining soil nutrients). The implications of this dynamism are significant. In the past, there has been a tendency for some external observers to conclude that what 'used to work' in drylands is necessarily correct and must therefore be returned to, regardless of evidence to the contrary (Ellis *et al.*, 2002); the debate about pastoral mobility is tinged by this view (Batterbury *et al.*, 2002). On the other hand, overly-optimistic free-marketers tend to overlook the presence of natural, internal constraints that limit the ability of dryland systems to change in certain directions: for example, while a donor-supported program to supply a new drought-resistant strain of millet to farmers is well-intended, it may be folly in the face of constraints like low soil fertility and the lack of an adequate labor base.

Assertion 7. The development of appropriate local environmental knowledge (LEK) must be accelerated

The application of knowledge to better manage arid and semi-arid systems must ultimately occur by practitioners, whether these are individual farmers, or policy-makers (in the broadest sense) who create the context within which the individual managers operate. No amount of scientific knowledge or external hectoring can be effective unless it is put to use by these practitioners. However, these practitioners operate on the basis of their own mental models (Robbins *et al.*, 2002), which are modified from a community-level set of norms generally termed "local environmental knowledge" (LEK). Traditional ecological knowledge, defined as knowledge that has evolved over long periods of time, served long-persisting nomadic pastoral groups or aboriginal people (e.g., in Australia or North America) well in the past (Mauro and Hardison, 2000). The ability to develop LEK depends on feedback from outcomes of actions coupled with an appropriate attribution of impacts, and is developed over generations through trial and error, at a cost of great individual human suffering. Usually most LEK is acquired experientially, which is a double-edged sword: on the one hand it is the source of the intimate knowledge that individual farmers have about their own land, but on the other hand it is often un-replicated and localized (making its value for generic use questionable). Some researchers too readily dismiss its credibility, whilst others overstate its value. In reality, the key to successful change in human-environment systems is an appropriately-validated body of LEK, where the human community has some degree of common vision about how to best interact with its environment given the constraints of the social circumstances (Turner *et al.*, 2000).

Assertion 8. Systems are hierarchically nested

There are numerous linkages or connections between the different levels in the hierarchy (*cf.* Allen and Starr, 1982) of human-environment systems (the strength of which may change with time), there are feedbacks or constraints imposed by one level on another, and multiple interactions are constantly occurring within and between levels. As a result, we will always have an imperfect and uneven understanding across the hierarchy. Differing objectives, perspectives, and attitudes of various stake-holders inevitably cause them to focus on different measures; hence, a useful framework must encompass all these and enable people to see why their perception might be at odds with that of a player acting at a different scale of concern.

Assertion 9. A limited suite of processes and variables at any scale makes the problem tractable

The foregoing assertions could sound terrifyingly complex! Is it possible to elucidate explanations that are useful, but also pragmatic, general and simple? Holling *et al.* (2002) argue that to understand the interactions of ecological, economic, and social systems we must be able to distinguish what is understandable or predictable (even if uncertain) from that which is inherently unpredictable. In truth, there are a limited number of ways in which all of these factors interact; these characteristic syndromes are discussed further in the Dahlem volume (Lambin *et al.*, 2002).

Focusing on the Human/ Environment System Linkages

Given the brief summary of the previous section, we now wish to concentrate on the assertions which relate most closely to the importance of considering both human and environment systems in dealing with desertification. In doing so, we will draw on examples, issues and thinking from other chapters in the Dahlem volume, as well as developments since that time. Figure 2 is an example of a relatively rare type of systems diagram. While most disciplinary diagrams show the environment as a minor input to or outcome of a social or economic model, or show all the action in the environmental side with scant reference to the effects of the social side (except perhaps as a minor element of external context), Fig. 2 emphasises the equal significance of both subsystems, and highlights the major linkages between the systems in both directions, rather than the internal functioning of either subsystem.

Does Desertification Always Involve Both Systems?

DDP Assertion 1 baldly asserts that one should always consider both biophysical and social aspects of the system in dealing with desertification. At one level this is a truism emerging from the definition of desertification. It is in fact impossible to say what degree of local biophysical change matters (i.e., becomes 'degradation' as opposed to 'change') unless one is clear about to whom it matters, and why. This immediately leads to the need to understand the values of the social system, although this is certainly not always done. Equally, the Convention to Combat Desertification (UN, 1994) is explicitly about biophysical change, so one cannot usefully assert that there is desertification in terms of the social system alone. Thus we have no hesitation in affirming the basic truth of the Assertion!

However, other parts of the DDP imply a far stronger application of this Assertion. Building on the developing field of Resilience Theory (Gunderson and Holling, 2001), Fernández *et al.* (2002) proposed the primacy of the model illustrated in Fig. 1. They argue that the most powerful cases of interaction occur where crossing a threshold on either one axis will eventually result in the threshold on the other axis being crossed and the system moving into the red 'degraded' region. A classic example provided in the original description has debt (or, more precisely, an equity ratio) on the social axis and longterm grass productivity on the biophysical axis (Fig. 3). If a pastoralist raises stock numbers to the point where the perennial grass cover starts to decline drastically on the biophysical axis, the declining productivity places an economic burden on the enterprise such that debt levels rise. Equally, if the pastoralist over-invests in stock or land and increases debt too far, he may then overgraze

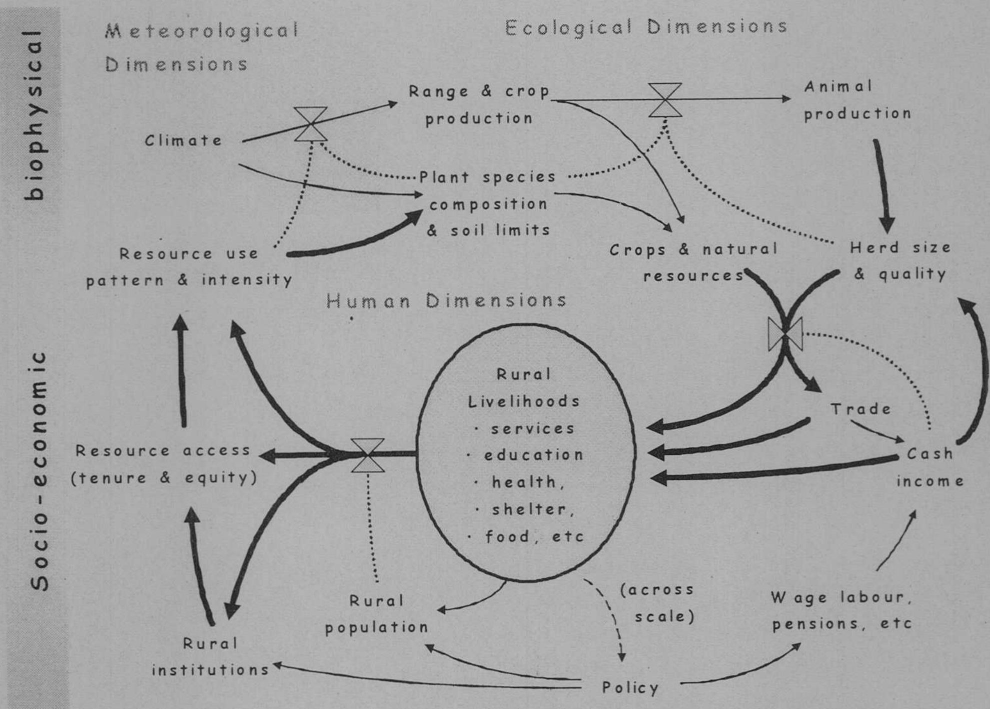

Fig. 2. Example of a preliminary mechanistic model which emphasizes the links between, rather than the internal function of the human and environment sub-systems, for rangelands/human interactions in subsistence pastoral systems of Africa. Note that this model can be applied at various scales. Solid lines indicate driving processes, dashed lines controlling feedbacks, and the heavier arrows (and their feedbacks) indicate where there is a close integration of social and biophysical factors. [Modified from Odada et al. (1996), Reynolds and Stafford Smith (2002)].

the pasture to attempt to obtain short-term economic gains to recover the debt. Each axis thus interacts such that exceeding a certain point on either can cause a threshold of economic viability or sustainable production to be exceeded on the other.

The model depicted in Figs. 1 and 3 simplifies reality into a single social axis and a single biophysical axis. In fact these two axes are representative of an *n-x-m* dimensional space with *n* social axes and *m* biophysical ones, these axes being circumscribed (Assertion 2) to the key slow variables. Even though this restricts the number of axes to a modest number, it would be unlikely that behaviour on every axis would meet the strict criterion that, if a threshold is crossed on that axis, equivalent thresholds will eventually be crossed on all *n+m* axes. It remains generally true that to determine what level of change

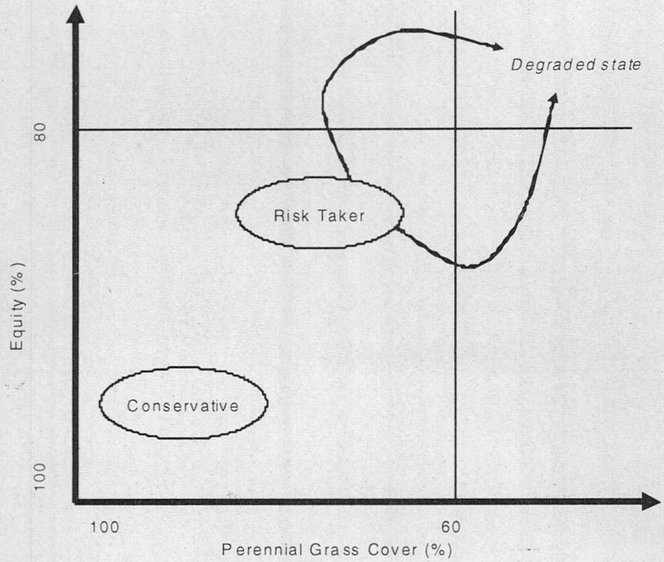

Fig. 3. Case study example from management of a northern Australian cattle-grazing system of the processes represented in Figure 1. The "Conservative" manager with high equity stocks lightly and is resilient to shifts in either threshold caused by drought years on the biophysical axis and rising interest rates on the socio-economic axis. The "Risk Taker' has poorer pasture condition and greater debt (lower equity). Increasing stock numbers may give temporary debt relief but causes degradation (crossing a critical threshold in the diagram as shown) which subsequently decreases profits and increases debt again; attempting to improve pasture condition with fewer stock may also decrease profits to the point where the debt cannot serviced. Either pathway has a high risk of leading into the degraded state, and the risk is exacerbated by poor rainfall or rising interest rates (ie, the thresholds move closer to the origin). Simplified from Figure 17.5 in Fernández et al. (2002).

matters on the biophysical axes, one must define them in terms of social goals; and the point at which change on the social axis matters is determined by the response pattern on the biophysical axes. However the links are not necessarily subject to full feedback loops. It is possible to think of many examples of one-way links where the social elements determine the significance of a biophysical change, or cause it; and where biophysical change causes a social change. For instance, social policy instruments (such as tax) can cause changes in management which lead to degradation (but there is negligible feedback to policy makers) (Fig. 4c), or social factors such as the cost of getting children through school can trigger short term overstocking

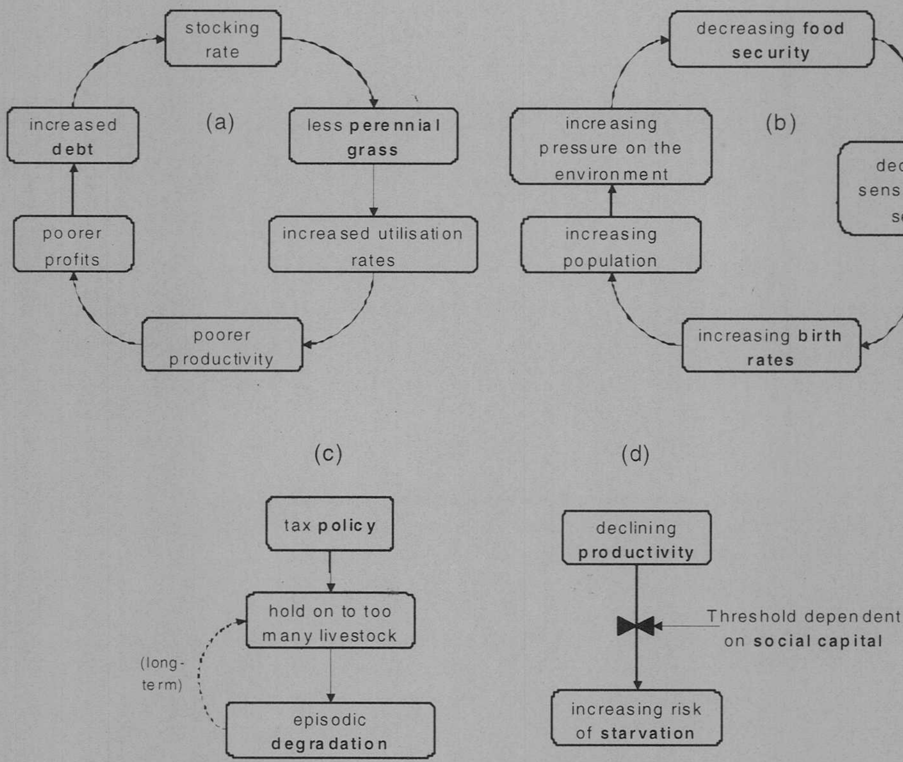

Fig. 4. A variety of types of systems linkages among social and biophysical axes. (a, b) show two potential feedback loops, where (a) is a reasonably well-documented example at the ranch scale, and (b) is a more hypothetical case at a regional scale, where there are many other likely interacting factors making it hard to be sure of causation. (c) and (d) show other types of linkages between social and biophysical axes: (c) illustrates a one way link with poor or no feedback (eventually degradation may cause managers to stop overgrazing, but there is often little feedback up to the policy level which is promoting the degrading management behaviour), while (d) shows a case where the interaction mainly relates to affecting the threshold at which the state of one axis (productivity) becomes critical with respect to the other (starvation). In all cases the potential slow variables on the axes are shown in bold.

leading to longer term environmental damage beyond the age of schooling. Equally lost primary production may send a farmer out of business, but if he sells up there may be no feedback to the management of the new owners coming in with different expectation. A variety of other examples may be found in Reynolds and Stafford Smith (2002), particularly in Fernández *et al.* (2002).

A comparison of the above examples is illuminating. The strong definition of interaction illustrated in Fig. 3 requires that there must be a feedback loop between the two axes (Fig. 4a, b). This feedback in practice must be quite strong to be observable and rather simple to be attributable (*cf.* the much more attenuated linkages shown in Fig. 2; also compare Fig. 4a and b). When observed, however, it provides a very direct link with system resilience (Fig. 4a essentially represents the feedback loop for Fig. 3). The weaker type of interaction is widespread and only implies a one-way causal link (which may itself be hard enough to determine) (Fig. 4c). Indeed the linkage may not affect the state of the system directly, but just alter the threshold at which the state matters (Fig. 4d). There are other syndromes with equally important lessons – for example in Fig. 4c there may be feedback to local management but not across scale from the biophysical outcomes and policy-making. There is a valuable task to be undertaken in collating a wide range of interactions that specifically relate to systems linkages between the human and environment subsystems, and seeking a categorization of types of linkages that might provide some predictive power. At a theoretical level, one could take the basic phase model and explore the different ways one can actually move around the diagram and see if each has characteristic failings to look for. This is beyond the scope of this paper and we leave it to a reader to pursue, as we turn to consider why the understanding of these linkages is so important.

Why Does Understanding the Linkages Matter?

The discussion of the interactions between social and biophysical factors so far has implicitly focused on factors within a generally defined system. However, Assertion 6 observes that the whole system may evolve over time; this is essentially a specific example of the implication of Assertion 8, in that the first set of changes are embedded with broader hierarchical levels, and these too may change. While panarchy theory (Gunderson and Holling, 2001) tends to address these changes in relatively catastrophic modes, they can also be evolutionary.

An excellent example of a coupled and changing human-environment system is provided by Jiang (2002). In 40 years, the population of the Uxin banner in Inner Mongolia has tripled, the cash income per capita has risen 50-fold, pasture land has been privatized to the household, and irreversible changes in household consumption and market-oriented aspirations have occurred in the population. During that period, one policy aimed to make the existing livestock production hazard-resistant through forage shrub plantations and irrigated cropping, succeeding to the extent that the region is now self-sufficient in winter forage and stock mortalities have dropped from 8-17% to 1.5%. The irrigated cropping now mostly produces cash crops, but remains often in close proximity to plantations that help to protect against sand movements. These practices originated with immigrating Chinese Han people, but are spreading to the indigenous Mongolians also. During the same period, a second policy aimed at stabilizing sand dunes, the mobilization of which was the main indicator of desertification in the region. The North China Revegetation Program sought to plant trees, shrubs and grasses on the dunes, with periodic injections of effort from the central government in Beijing, which is affected by sandstorms from the region. However, an unanticipated outcome is that the irrigation is drawing down the shallow watertable in the region. The landscape is increasingly polarised and consolidated into irrigated areas with high cover and production, and sandy areas with a declining watertable and worsening sand movement. Intermediate grasslands are declining in productivity and extent. There is no question of the region's human aspirations retreating. The issue is now whether the local understanding of the watertable-mediated connection between higher overall production and increasing area of mobile sands will develop to the point where action on the trade-off in values can be taken. Whatever the social and environmental drivers at the household level, there are now emergent regional impacts that require addressing.

This case study illustrates several points. First, changing land practices apparently to the better in one area is causing desertification elsewhere (within the one heterogeneous land use matrix). Second, the introduction of agricultural knowledge with immigrating Han people has caused the expectations of the human system (including those of the original Mongolian inhabitants) to evolve; the simplistic assessment of moving sand as desertification is no longer easily related to the regional aspirations – even if this degradation was fixed up, the Mongolians do not want to go back to grazing the sandy areas. In summary, not only is one person's improvement often another's problem (highlighting the need to consider social values in evaluating biophysical change); but also the human-environment system evolves interactively. Indeed, it is no longer possible to feed the growing regional population through nomadic herding alone anyway. In response to this, it is necessary to look at different slow variables, such as water table levels instead of grass and tree cover.

In this example, social forces including the immigration of Han people brought new practices into the region. These affected the environmental system, changing the patterns of land use and affecting the productivity of traditional grazing lands. These changes led to further changes in the expectations of the original inhabitants, such that their land use is now changing too. This 'co-evolutionary' change of human and environment sub-systems is immensely important. Formally, dryland systems are prototypical examples of complex adaptive systems, in which properties such as plant cover and capital wealth emerge from the interactions among the various components of the entire system and which themselves feed back to influence the subsequent development of those interactions, including thresholds (Levin, 1998). Consequently, the behavior of coupled human-environment systems (i) is emergent rather than predetermined, (ii) can rarely if ever be reversed to some exact prior state, and (iii) has a changing path that is often unpredictable. Both research strategies and policy decisions in desertification must take this into account as a fundamental property of coupled human-environment systems. It is particularly important in drylands because it can be particularly hard to identify cause and effect in these variable environments.

Furthermore, the human-environment system may change in a positive 'co-evolutionary' way, or it may change in a dysfunctional way such that the human and environmental sub-systems become 'decoupled' (Robbins *et al.*, 2002) or out of balance. We need to understand more clearly when this decoupling is likely to occur, and what mechanisms may minimize the risk of this. One clear approach to this is the subject of Assertion 7 (local environmental knowledge), but there are undoubtedly others.

Creating a Learning Society in Arid Regions

The third point that we wish to expand upon in this paper is the issue of what mediates coordinated change in human and environment sub-systems, which may therefore help to guard against catastrophic feedback loops of the type described in Fig. 4a,b. In the Inner Mongolian case described above, the people of the region used to require knowledge about how to graze the environment sustainably; when 'sandification' began due to overgrazing and a possible shift in climate, they had to develop new local knowledge about how to plant and stabilize the sand dunes. All of this hinged on an understanding of local effects: grazing destabilized a particular dune; planting there (and perhaps across the immediately surrounding area) potentially stabilized it again. With the development of irrigation, however, there was suddenly a 'teleconnection' across the landscape mediated by changes in the watertable, such that water use in one area could cause tree deaths on dunes at some distance. It is not clear from the study to what extent local people have so far absorbed this change and worked out systems for engaging with irrigators about their impacts at a distance, but this is clearly the type of new local environmental knowledge (LEK) that is required. In short, LEK is the key lubricant to make the squeaky wheels of co-evolution turn rapidly and in a coordinated way. The faster local people can work out how to manage their environment as it changes, the less likely it is that they will cause permanent damage to the environment or themselves in the meantime.

That much is true in any environment. The poignant problem in variable dryland environments arises from the traditional, experiential means of obtaining local knowledge. LEK continually becomes outdated over time, as the systems in which it was learned are themselves undergoing constant change, whether as a result of environmental drivers such as exotic species introductions, shifts in climate and changing farming technologies, or social drivers such as population growth, loss of mobility, and border controls. Worse, today the process of developing the knowledge is itself failing as change comes upon many systems far faster than the experiences can accumulate. Whilst this is a problem for agro-ecological systems worldwide, it is particularly acute in arid and semi-arid systems where management impacts take time to have detectable effects over climate-driven noise, across vast areas, and often with low population densities. Where population densities are low, there are also issues related to efficient ways of diffusing a common-held view of LEK among the population to the point where important components of knowledge become widely-held paradigms. Clearly identifying the most critical slow variables, their critical thresholds and the reasons why they are important is vital, as is developing an understanding of the appropriate social processes in different circumstances.

Given these problems, the need to be able to develop appropriate new LEK faster (and preferably with less social disruption) becomes more acute (Haney and Power, 1996; Janssen *et al.*, 2000; Tiwari *et al.*, 1996). It is likely that new and mutually respectful partnerships between local knowledge systems and western scientific methods would provide significant opportunities for speeding up the development of LEK, and creating effective, "learning societies" in drylands. This highlights the importance of intelligent monitoring systems which provide feedback as fast as possible within an experimental or adaptive management framework (Lynam and Stafford Smith, 2003). An effective monitoring system is an essential component of speeding up the generation of appropriate and timely LEK, whether this is at the scale of individual land managers, or the analogous processes that occur at a policy level, where policy managers also have to develop the mental models of how to obtain the best policy interventions. The latter is likely to include aspects such as significant local participation, but will also depend on feedback from appropriate monitoring of the outcomes of policy-induced actions locally. This is particularly important in rangelands since policy makers are usually remote from the regions and have a poor understanding of what is occurring there.

This all places a strong onus on building the capacity of our hinterlands and recognizing when lessons from more highly settled regions are irrelevant. Viewed in the context of the adaptive capacity of humans for change, Berkes and Jolly (2001) note that coping mechanisms, which change rapidly, are more likely to emerge at the individual and household levels (and at smaller spatial scales), whereas adaptive strategies, which are related to variables such as cultural values that change more slowly, are more likely to emerge at larger spatial scales. In short, intervention and management of particular processes needs to take place at the appropriate scale for those processes – setting detailed stocking rate directives at a national scale usually fails, for example. In general, national activities should set the context and leave the details of management to a local scale.

Implications and Conclusions

The cross-scale conceptual holism of the Dahlem Desertification Paradigm (DDP) raises many implications, including:

1. The DDP framework focuses the attention of those concerned with the implementation of the Convention to Combat Desertification on recognizing that the problem cannot be framed in terms of biophysical nor socio-economic measures alone, let alone any single measure. Significant research and synthesis is needed to formalize the ideal

measures. However, this should not paralyze progress, since the relevant measures, together with their implications for action, are determinable, and many are already apparent.

2. The DDP framework provides guidance for implementation agencies and for non-government organizations (NGOs). Whilst integrating biophysical and socio-economic activities, they should intervene to increase resilience with respect to the slow variables of concern, and should take care with the cross-scale implications of any interventions.

3. The DDP framework highlights the need to focus on mechanisms for speeding up the development of local environmental knowledge to cope with increasing rates of change in the world today, which are particularly problematic in dryland regions subject to variable drivers. Any desire to create a learning society in drylands demands that we must continue to move beyond the application in isolation of either traditional experiential modes of learning or the western scientific method, to creating new partnerships between these knowledge systems. The DDP framework provides a basis for understanding what extrinsic and intrinsic characteristics of any given system are driving change and therefore need focus in this effort to speed up institutional learning.

A major goal for the future must be for the international desertification community to critically debate and extend the veracity of the Dahlem Desertification Paradigm (Reynolds *et al.*, 2003), through a coordinated approach to integrated research studies and syntheses. As indicated in the focus of this paper, a major priority of the required integration is to bring together the human and environmental aspects of the problem.

References

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

Batterbury, S., Behnke, R., Döll, P., Ellis, J., Harou, P., Lynam, T., Mtimet, A., Nicholson, S., Obando, J. and Thornes, J. 2002. Responding to desertification at the national scale: Detection, explanation, and responses. In *Global Desertification: Do Humans Cause Deserts*? (Eds. J.F. Reynolds and M. Stafford Smith), pp. 357-385. Dahlem University Press, Berlin.

Berkes, F. and Jolly, D. 2001. Adapting to climate change: Social-ecological resilience in a Canadian western Arctic community. *Conservation Ecology* 5: 18 [online] URL: http://www.consecol.org/vol15/iss12/art18.

Chasek, P. and Corell, E. 2002. Addressing desertification at the international level: The institutional system. In *Global Desertification: Do Humans Cause Deserts*? (Eds. J.F. Reynolds and M. Stafford Smith), pp.275-294. Dahlem University Press, Berlin.

Darkoh, M.B.K. 1998. The nature, causes and consequences of desertification in the drylands of Africa. *Land Degradation and Development* 9: 1-20.

Ellis, J., Prince, K., Yu, F., Christensen, L. and Yu, M. 2002. Dimensions of desertification in the drylands of northern China. In *Global Desertification: Do Humans Cause Deserts*? (Eds. J.F. Reynolds and M. Stafford Smith), pp.167-180. Dahlem University Press, Berlin.

Fernández, R., Archer, E.R.M., Ash, A.J., Dowlatabadi, H., Hiernaux, P.H.Y., Reynolds, J.F., Vogel, C.H., Walker, B.H. and Wiegand, T. 2002. Degradation and recovery in socio-ecological systems: A view from the household/farm level. In *Global Desertification: Do Humans Cause Deserts*? (Eds. J.F. Reynolds and M. Stafford Smith), pp. 297-323. Dahlem University Press, Berlin.

Gunderson, L.H. and Holling, C.S. (Eds.) 2001. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, DC: Island Press. 450 p.

Haney, A. and Power, R.L. 1996. Adaptive management for sound ecosystem management. *Environmental Management* 20: 879-886.

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

Janssen, M.A., Walker, B.H., Langridge, J. and Abel, N. 2000. An adaptive agent model for analysing co-evolution of management and policies in a complex rangeland system. *Ecological Modelling* 131: 249-268.

Jiang, H. 2002. Culture, ecology, and nature's changing balance: Sandification on Mu Us Sand Land, Inner Mongolia, China. In *Global Desertification: Do Humans Cause Deserts*? (Eds. J.F. Reynolds and M. Stafford Smith), pp. 181-196. Dahlem University Press, Berlin.

Lambin, E.F., Chasek, P., Downing, T., Kerven, E.C., Kleidon, A., Leemans, R., Lüdeke, M., Prince, S.D. and Xue, Y. 2002. The interplay between international and local processes affecting desertification. In *Global Desertification: Do Humans Cause Deserts*? (Eds. J.F. Reynolds and M. Stafford Smith), pp. 387-401. Dahlem University Press, Berlin.

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

Lynam, T. and Stafford Smith, M. 2003. Monitoring in a complex world - seeking slow variables, a scaled focus, and speedier learning. *Proceedings of the VII International Rangelands Congress*, Durban Jul 2003: CD-ROM, 14 p.

Mauro, F. and Hardison, P.D. 2000. Traditional knowledge of indigenous and local communities: International debate and policy initiatives. *Ecological Applications* 10: 1263-1269.

Milton, S.J., Dean, W.R.J., Duplessis, M.A. and Siegfried, W.R. 1994. A conceptual model of arid rangeland degradation: The escalating cost of declining productivity. *Bioscience* 44: 70-76.

Odada, E., Totolo, O., Stafford Smith, D.M. and Ingram, J. (Eds.) 1996. *Global Change and Subsistence Rangelands in Southern Africa: The Impacts of Climatic Variability and Resource Access on Rural Livelihoods.* GCTE Working Document 20. GCTE Core Project Office, Canberra, Australia.

Prince, S.D. 2002. Spatial and temporal scales for detection of desertification. In *Global Desertification: Do Humans Cause Deserts?* (Eds. J.F. Reynolds and M. Stafford Smith), pp. 23-40. Dahlem University Press, Berlin.

Reynolds, J.F. 2001. Desertification. In: *Encyclopedia of Biodiversity* (Ed. S. Levin), Volume 2, pp. 61-78. CA: Academic Press, San Diego.

Reynolds, J.F. and Stafford Smith, M. (Eds.) 2002. *Global Desertification: Do Humans Cause Deserts?* Dahlem University Press, Berlin.

Reynolds, J.F., Stafford Smith, D.M. and Lambin, E.F. 2003 ARID*net:* Seeking novel approaches to desertification and land degradation. *IGBP Global Change Newsletter* 54: 5-9 (PDF available at: http://www.igbp.kva.se).

Robbins, P.F., Abel, N., Jiang, H., Mortimore, M., Mulligan, M., Okin, G.S., Stafford Smith, D.M. and Turner, II B.L. 2002. Desertification at the community scale: Sustaining dynamic human-environment systems. In *Global Desertification: Do Humans Cause Deserts?* (Eds. J.F. Reynolds and M. Stafford Smith), pp. 325-355. Dahlem University Press, Berlin.

Stafford Smith, D.M. and Reynolds, J.F. 2002. Desertification: A new paradigm for an old problem. In *Global Desertification: Do Humans Cause Deserts?* (Eds. J.F. Reynolds and M. Stafford Smith), pp. 403-424. Dahlem University Press, Berlin.

Tiwari, S., Ramaswamy, R. and Rao, J.S. 1996. Adaptive control in a resource management model. *Ecological Modelling* 84: 53-62.

Turner, N.J., Ignace, M.B. and Ignace, R. 2000. Traditional Ecological Knowledge and Wisdom of aboriginal peoples in British Columbia. *Ecological Applications* 10: 1275-1287.

United Nations 1994. *Earth Summit. Convention on Desertification.* United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 3-14 June 1992. DPI/SD/1576, United Nations, New York.