Chapter 20

Natural and Human Dimensions of Land Degradation in Drylands: Causes and Consequences

James F. Reynolds · Fernando T. Maestre · Paul R. Kemp · D. Mark Stafford-Smith · Eric Lambin

20.1 Introduction

Land degradation in drylands, which is referred to as desertification, is viewed by many as one of the most critically important issues facing many countries (e.g., Darkoh 1998; Dregne 1996; Kassas 1995). The United Nations portrays it as one of the "most important global change issues facing mankind" (UNCCD 1994). Land degradation is a vital societal concern because of its impacts on human populations (food security, economics, sustainability, etc.) and environment quality (dust storms, trace gas emissions to the atmosphere, soil erosion, etc.) (Vitousek et al. 1997). Like global climate change and biodiversity, desertification is the subject of an international framework convention, the Convention to Combat Desertification (CCD), the aim of which is to "target poverty, drought and food insecurity in dryland countries experiencing desertification, particularly those in Africa" (United Nations 1994). The CCD was established by the United Nations in order to facilitate the role of national governments in enacting policies to combat land degradation. The Convention provides for a large infrastructure (e.g., a Secretariat and the Global Mechanism), which is designed to mobilize and channel financial resources, including the transfer of technology to developing countries (details in Chasek and Corell 2002).

However, in spite of its high profile and acknowledged importance, desertification has remained stubbornly intractable. Part of the problem is that desertification tends to stir up more disagreement and controversy than consensus (e.g., Leach and Mearns 1996; Reynolds and Stafford Smith 2002a; Thomas and Middleton 1994). While the reasons underlying the uncertainty and confusion associated with this topic are numerous (see reviews by Grainger et al. 2000; Reynolds 2001; Reynolds and Stafford Smith 2002a), the bottom line is that desertification has proven to be a complex problem that is not amenable to simple solutions. A second aspect of the problem appears to reside with the CCD itself. The CCD model has been roundly criticized for its deficiency of directed research efforts, for lacking connections to "real-world" problems, and for serving solely as a mechanism for some countries to elicit funds from donor nations (Toulmin 2001). In spite of these criticisms, the CCD is the primary vehicle for addressing desertification and has inspired some successful spin-off activities that engage scientists and various stake-holders (see Corell 1999).

In this chapter we provide a brief overview of the most significant issues of land degradation in global drylands, with an emphasis on the interaction between human and natural dimensions of the problem. Despite considerable work on case studies of land degradation in individual regions of the globe, there is little integration between social and biophysical sciences, and there are great opportunities for comparative studies across the many different social and biophysical systems. We discuss some of the underlying causes of land degradation and their consequences. Further, we discuss a joint initiative on desertification of the Global Change and Terrestrial Ecosystems (GCTE) and Land-Use and Land-Cover Change (LUCC) programs, which provided a framework to facilitate directed research effort and progress on this important global environmental issue. Land degradation is an excellent topic for such an initiative given that LUCC is geared to improve the understanding of land-use and land-cover change dynamics, GCTE was focused on synthesis activities on critical topics in the terrestrial biosphere, and both programs are keen to engage both the physical and social science communities for the development of science relevant to global change.

20.2 Drylands, Desertification, Drivers, and Scales

20.2.1 Distribution of People and Land-Cover Types

In general, drylands are characterized by low and variable rainfall, extreme air temperatures, and seasonally high potential evaporation. Technically, drylands are defined as regions that have an index of aridity (ratio of mean annual precipitation to mean annual potential evapotranspiration) of 0.05 to 0.65 (see Middleton and Thomas 1997). Drylands can be further subdivided as arid (0.05–0.20 index of aridity; ca. 30% of drylands), semiarid (0.20–0.50 index of aridity, ca. 45% of drylands), and sub-humid (0.50–0.65 index of aridity, ca. 25% of drylands) and together cover approximately 5.2 billion hectares or about 40% of the land surface of the globe (Table 20.1a). Drylands have two primary types of human uses: the overwhelming majority serve as rangelands (>75% of drylands), while nearly 20% are rainfed or irrigated cropland. In terms of a land-cover classification, shrubland is the dominant cover type (24% of drylands), followed by cropland (20%), savanna (15%), grassland (13%), forest (8%) and urban (3%) (Table 20.1b).

Drylands are home to over two billion people: 42% of the Asian population, 41% of Africans, and 25 to 30% of the rest of the world (Table 20.1c). Combined, Asia and Africa contain 84% of all global drylands, dwarfing the amount of dryland area on other continents. In terms of importance, however, these numbers can be somewhat misleading. While Europe contains only ca. 6% of the world's drylands, this represents about 32% of its land mass and is home to 25% of its population. Similarly, Australia contains about 13% of the world's drylands but they cover over 75% of the continent and are home to 25% of its population. Hence in both Europe and Australia, drylands are crucial determinants of the economy, culture and climate. Some of the highest densities of human populations are in the dry sub-humid and semiarid areas of cropland, e.g., those in India, eastern China, and Europe, and in the savannas of Africa (White et al. 2003).

20.2.2 Defining Land Degradation and Desertification

Land degradation and desertification are composite phenomena that have no single, readily identifiable attribute. Perhaps this is why there are so many conflicting and confusing definitions (see reviews by Reynolds 2001;

Table 20.1. Distribution of global drylands, their major land cover types, and human populations

a Distribution of drylands (million ha)[a]	Arid	Semiarid	Dry sub-humid	% of global drylands	% of continental land area
Asia	625.7	693.4	352.7	32.3	39.3
Africa	503.5	513.8	268.7	24.9	43.4
Europe	11.0	105.2	183.5	5.8	31.5
South America	44.5	264.5	207.0	10.0	29.2
North America	81.5	419.4	231.5	14.2	33.4
Oceania	303.0	309.0	51.3	12.8	75.2
World totals	1 569 (30%)	2 305 (45%)	1 295 (25%)	100.0	39.7% of globe
b Distribution of land cover types (million ha)[b]	**Arid**	**Semiarid**	**Dry sub-humid**	**Total**	**% of continental land area**
Shrubland	683	534	50	1 268	24
Cropland	47	530	475	1 052	20
Savanna	83	402	303	788	15
Grassland	181	473	65	719	13
Forest	11	140	284	436	8
Urban/developed	26	82	66	173	3
Other[c]	559	213	149	922	17
World totals	1 591	2 374	1 391	5 356	100
c Distribution of human population (%)[b]	**Arid**	**Semiarid**	**Dry sub-humid**	**Percent of population living in drylands**	
Asia (Incl. Russia)	5	18	19	42	
Africa	6	18	17	41	
Europe	0	5	20	25	
South America	2	16	12	30	
North America	2	16	5	23	
Central America and Caribbean	6	11	8	25	
Oceania	1	5	19	25	
World totals	4	4	17	37	

[a] See Reynolds (2001) for citations.
[b] Based on GLCCD 1998; ESRI 1993; UNEP/GRID 1991; see White and Nackoney (2003) for citations.
[c] Includes barren or sparsely vegetated land; open water; permanent wetlands; snow and ice; and islands.

Thomas 1997). For example, a common misunderstanding among land managers and stakeholders is to equate land degradation solely with soil degradation. The definition of Stocking and Murnaghan (2001) emphasizes changes in biophysical variables and implies an impact on human populations: land degradation is how one or more land resources (soils, vegetation, water, landforms, etc.) has changed "for the worse," signifying a temporary or permanent decline in the productive capacity of the land. While heuristic, we favor the definitions used by the CCD (UN 1994), which go a step further by making it clear that while biophysical components of ecosystems and their properties are involved, the interpretation of change as 'loss' is dependent upon the integration of these components within the context of the *socio-economic* activities of human beings. The CCD's definition states that land degradation is the reduction or loss of the biological and economic productivity and complexity of terrestrial ecosystems, including soils, vegetation, other biota, and the ecological, biogeochemical, and hydrological processes that operate therein. In drylands, this involves soil erosion and sedimentation, shifts in natural fire cycles, the disruption of biogeochemical cycling, and a reduction of native perennial plants and associated microbial and animal populations. The CCD's definition of desertification explicitly focuses on the linkages between humans and their environments that affect human welfare in arid and semi-arid regions.

20.2.3 What Drives Land Degradation and Desertification?

Desertification is caused by a relatively large number of factors that vary from region to region, and that often act in concert with one another in varying degrees. Geist and Lambin (2004) carried out a worldwide review of the causes of desertification, and from 132 case studies identified four major categories of proximal causal agents: (1) increased aridity; (2) agricultural impacts, including livestock production and crop production; (3) wood extraction, and other economic plant removal; and (4) infrastructure extension, which could be separated into irrigation, roads, settlements, and extractive industry (e.g., mining, oil, gas). They concluded that only about 10% of the case studies were driven by a single cause (with about 5% due to increased aridity and 5% to agricultural impacts). About 30% of the case studies were attributable to a combination of two causes (primarily increased aridity and agricultural impacts), while the remaining cases were combinations of three or all four proximal causal factors.

A primary objective of Geist and Lambin's (2004) review was to identify general global patterns in causation of desertification. As such, the study identified specific agents as more or less important in particular regions, and indicated that these agents derive from underlying forces associated with particular combinations of socio-economic (including technology) and biophysical factors characteristic of particular regions. For example, two underlying forces, climate and technological factors (either new technologies or deficiencies in technology) were the key drivers of desertification in the majority (54%) of the case studies in southern Europe. In Africa, climate, alone or acting in concert with population demography, was a key driver in the 38% of the case studies. In the United States, 50% of the case studies were attributable to a combination of climate and technology drivers or these two factors interacting with economic forces. Desertification processes in Asia, Latin America, and Australia could only be attributed to more complex interactions among four or more underlying forces.

20.2.4 Estimating the Extent of Desertification

Not surprisingly, obtaining accurate estimates of the amount of drylands affected by desertification is a difficult task, fraught with numerous obstacles and complications. Nevertheless, the extent of global desertification is routinely reported as high as 70% of all drylands (UNCCD 2000)! Thomas and Middleton (1994) and others view such estimates as suspect because they are largely derived from the subjective judgments of scientists and laypersons, surveys completed by local governments, qualitative assessments, and data of varying authenticity and consistency. Unfortunately, the CCD definition of desertification (Sect. 20.2.2), which we consider most authoritative at present, is not amenable to easy quantification, especially as a single number or synthetic index.

A variety of problems confound estimates of the extent of desertification. For instance, observations made on short-term ecosystem dynamics are often cited as evidence of desertification ignoring the fact that drylands are highly variable over time (both intra- and inter-annually) and that a temporary loss of vegetation cover due to a short-term drought or to local land use (e.g., grazing) is distinct from – and not necessarily related to – a permanent loss of vegetation associated with desertification (Reynolds 2001). Inaccurate estimations are also fueled by technological barriers that preclude the monitoring of relevant variables, such as the cover of dry vegetation, that cannot be easily estimated using traditional approaches (Asner et al. 2003). Another crucial, but often overlooked, concern is that desertification is usually promoted by two or more causal agents (see Sect. 20.2.3). In spite of the CCD definition, most estimates of desertification are derived solely from either biophysical factors (e.g., soil erosion, loss of plant cover, change in albedo) or socio-economic factors (decreased production, economic loss, population movements, etc.), but rarely both types simultaneously (Stafford Smith and Reynolds 2002). When assessments are made without good knowledge of the underlying causes, it brings into question the validity of the variables or sets of variables being used in the assessment.

Over the years, in different arid and semiarid regions of the world, there has been a concerted effort to categorize and map various forms of land degradation at various scales, but these efforts have failed to include a careful, systematic identification of the critical variables that cause the observed dynamics (Stafford Smith and Reynolds 2002). This problem lies at the base of the confusion about how much 'desertification' there really is (see Batterbury et al. 2002). Stafford Smith and Reynolds (2002) argued that much of this confusion could be eliminated by focusing on a small number of critical variables that contribute to an understanding of the cause, rather than effect, of desertification. Of course, this is all the more problematic when we try to account for the causal factors driving desertification in different regions of the world and at different times: approaches developed to estimate desertification in one region may not be effective in others. The failure to recognize these issues has led to the disparities of estimates of desertification in the literature and is responsible for many of the disagreements alluded to above (Stafford Smith and Pickup 1993; Stafford Smith and Reynolds 2002).

20.2.5 Consequences of Desertification

There are few disagreements that desertification has a large number of biophysical and socio-economic consequences, which range across a wide spectrum of spatial and temporal scales. An in-depth treatment of the different consequences is beyond the scope of this chapter, but some relevant ones are presented in Table 20.2 (and see group reports in Reynolds and Stafford Smith 2002b). From the socio-economic point of view, most consequences (especially in pastoral systems) are a direct consequence of the decline in 'productivity' or the capacity of the land to support plant growth and animal production. During early stages of desertification such losses are compensated by the social resilience of the local human populations, especially in developing countries, or by economic inputs from government (Vogel and Smith 2002). However, when certain thresholds are crossed, social resilience or government subsidies may not be enough to compensate for the loss of productivity, and this fuels a battery of socio-economic changes that range from modifications in trade promoted by lower agricultural production to large population migrations (Fernández et al. 2002).

Virtually all of the biophysical consequences start with the loss of vegetation and soil (Table 20.2). These losses have a 'cascading' effect on other components and processes, leading to a progressive deterioration of the ecological structure and functioning of the system (Fernández et al.

Table 20.2. Some biophysical and socio-economic consequences of desertification in drylands and approximate spatial scales at which they are most relevant. The list is not exhaustive. See Sect. 20.2.5

Dimension	Consequence	Scale[a]	Examples
Socio-economic	Reduction in crop yield	F, C, D	Zaman (1997)
	Reduction in animal production	F, C, D	Fredrickson et al. (1998)
	Loss of economical important species	C, N	Latchininsky and Gapparov (1996)
	Migratory movements	C, D, N	Pamo (1998)
	Loss of local environmental knowledge	C, D, N	Bollig and Schulte (1999)
	Loss of traditional agricultural structures	D	Gallart et al. (1994)
	Changes in land use patterns	C, D, N	Zhao et al. (2005)
Biophysical	Loss of soil and nutrients	P, L	Schlesinger et al. (1999)
	Decreased infiltration	P	Sharma (1998)
	Modification of geomorphology	P, R	Lavee et al. (1998)
	Addition of sediments to water bodies	P, L, R	Kelley and Nater (2000)
	Reduction of plant cover	P, L, R	Asner et al. (2003)
	Shifts in species composition and richness	P, L, R	Gonzalez (2001)
	Changes in primary net productivity	P, L, R	Huenneke et al. (2002)
	Changes in the spatial pattern of resources	P, L, R	Schlesinger et al. (1990)
	Loss of biodiversity	R, G	Whitford (1993)
	Loss of biological soil crusts	P, L	Belnap and Eldridge (2001)
	Depletion of soil carbon stocks	P, L, R, G	Jackson et al. (2002)
	Depletion of soil nitrogen stocks	P, R	Asner et al. (2003)
	Reduction in ecosystem resilience	P, L, R	Von Handenberger et al. (2001)
	Modification of climate	R, G	Rosenfeld et al. (2001)

[a] Socio-economic: *F:* farm/household, *C:* community, *D:* district/provincial, *N:* national/international; biophysical: *P:* patch, *L:* landscape, *R:* regional, *G:* global.

2002). The specific biophysical consequences of desertification differ substantially between geographical areas of the globe as a function of the intensity and number of driving forces at work, the extent of the impacted area, the duration of the deterioration, and the resilience of the system components (especially vegetation). Even within a particular area we may find that there are different consequences depending upon the unique characteristics of the system. For instance, while Krogh et al. (2002) found that some keystone species associated with grasslands are negatively affected by shrub encroachment into former grasslands (a form of desertification, Schlesinger et al. 1990), recent studies in the southwestern United States have shown that shrub encroachment is associated with an increase in the species richness of birds (Pidgeon et al. 2001), mammals (Whitford 1997) and ants (Bestelmeyer 2005). Thus, some generalizations regarding biophysical consequences of desertification may be misleading or incorrect when applied to specific situations.

20.2.6 Scale and Hierarchy

The importance of scale is manifest in a number of ways when evaluating the extent and effects of desertification (Sect. 20.2.4). Obviously, humans are most concerned with the local subset of degradation that impacts them personally. Reynolds and Stafford Smith (2002a) use a hypothetical case-study of gully formation (overgrazing by cattle leads to loss of vegetative cover and, ultimately, soil erosion) to illustrate how different segments of society (the stake-holders) see such problems with differing degrees of concern. Whereas an ecologist might view erosion gullies as a breakdown in ecosystem function, this will resonate with a farmer only if the gullies have a demonstrable impact on his values, i.e., meat production by his cattle. If not, the farmer will not consider this as 'degradation'. Alternatively, other stake-holders, such as urban dwellers in a nearby town, may consider this localized soil erosion and gully formation a more serious problem because of the potential for silt runoff into the town's reservoir and its adverse effects on water quality.

Because local activities often have regional consequences (e.g., localized erosion gullies impacting regional water quality) and regional issues can, in turn, have local impacts, it behooves us to assume a multifactor, multiscale, hierarchical view of desertification. In Table 20.3, we illustrate representative scales of interest in desertification viewed from both socio-economic and biophysical perspectives. Coupled socio-economic and biophysical systems must be hierarchically nested in order to avoid errors that will undoubtedly occur if we attempt to extrapolate understanding over a range of scales that is too great, e.g., trying to predict what will happen at the

Table 20.3. Examples of various socio-economic and biophysical scales of concern in desertification and associated key variables. The socio-economic scales are from Stafford Smith and Reynolds (2002) and the biophysical scales approximate those used by Prince (2002). The list of key variables associated to each scale is not exhaustive and some are relevant at more than one scale

Socio-economic		Biophysical	
Scale	**Some key variables**	**Scale**	**Some key variables**
Farm/household	Household size Labor attributes Characteristics of food supply (e.g. security, flexibility, etc.) Technological development Land management patterns	Patch	Plant cover Soil nutrients Soil infiltration and water holding capacity Abiotic attributes (e.g., slope, aspect)
Community or village	Land tenure and ownership Local government attributes Population size Flexibility of job market	Landscape	Sediment transport Species composition and richness Net primary productivity
District/provincial	District land planning Decentralization of planning for communal land Land reform Conflicts between groups (ethnic, social and economical) Financial constraints (subsidies) Economic opportunities 'Natural' disasters (e.g., floods, drought, fire, pests, diseases)	Regional	Geomorphology Soil nutrient stocks (e.g. carbon and nitrogen) Ecosystem resilience
National/international	Human population growth Macro-economic indicators National policies (e.g., resettlement programs, economic incentives) National and international conflicts (e.g., war)	Global	Climate (e.g., rainfall, radiation, albedo) Biodiversity Cover of vegetation types

household level based on observations made at the national scale. Sørbø (2003) describes examples from east Africa to show the importance of scale in pastoral herding communities. These pastoral communities are networked into various localized units, which function in a complex interplay of local and regional social, economic, and political factors, all of which have evolved over many years against a backdrop of severe environmental instability and unpredictable contingencies. It is not surprising that 'top-down' attempts to 'manage' these systems fall short of expectations. This is consistent with Batterbury et al.'s (2002) observations that, in arid and semiarid lands, the highest levels of the 'management hierarchy' are invariably quite remote from marginal lands and, consequently, have weak political and economic feedbacks. An important objective of institutions such as the CCD should be to provide a context within which levels in the hierarchy become more integrated and aware of the issues (Batterbury et al. 2002; Lambin et al. 2002).

20.3 Joint GCTE-LUCC Desertification Initiative

The simultaneous assessment of biophysical and socio-economic drivers (and consequences) of desertification has been recognized as one of the most challenging – but potentially rewarding – topics for further research (see review by Reynolds 2001). In an attempt to address this challenge, the GCTE and LUCC programs of the International Geosphere-Biosphere Programme joined forces to establish an initiative on desertification. The intent of this initiative was to bring together researchers from the various global change programs, representing both natural and human-influenced systems, with the objective of stimulating, developing, and refining a new paradigm to bear on this important global change concern.

One of the key, initial products of this GCTE-LUCC initiative was a book on global desertification (*Global Desertification. Do Humans Cause Deserts?*), which explicitly addresses many of the significant interactions and feedbacks between natural and human-influenced dryland systems. Focusing on the multitude of interrelationships within coupled human-environment systems that cause desertification, and drawing heavily from the chapters of this book, Stafford Smith and Reynolds (2002) proposed the *Dahlem Desertification Paradigm* (DDP). The DDP is a new synthetic framework that is unique in two ways:

- First, the DDP attempts to capture the multitude of interrelationships within human-environment systems that cause desertification, within a *single*, synthetic framework; and
- Second, the DDP is testable, which ensures that it can be revised and improved upon as a *dynamic* framework.

In this section we briefly present an outline of the key elements or assertions of the DDP and describe one method we are using for testing it. As is the case for many paradigms, the constituent ideas contained within the DDP themselves are generally not new, but rather, they bring together much of the previous work on this difficult topic in a way that reveals new insights.

20.3.1 Dahlem Desertification Paradigm

The DDP consists of nine assertions (Table 20.4), which embrace a hierarchical view of land degradation and highlight key linkages between socio-economic and biophysical systems at different scales. The first three assertions relate to the working framework of the DDP while the remaining ones focus on its implementation, limitations, and potentials. The main points of the DDP are:

1. that an integrated approach, which simultaneously considers both biophysical and socio-economic attributes in these systems, is absolutely essential to understand land degradation (assertions #1, #7);
2. that the biophysical and socio-economic attributes that govern or cause land degradation in any particular region are invariably 'slow' (e.g., soil nutrients) relative to those that are of immediate concern to human welfare – the 'fast' variables (e.g., crop yields). It is necessary to distinguish these in order to identify the causes of land degradation from its effects (assertion #2);
3. that socio-ecological systems in drylands of the world are not static (assertions #3, #6);
4. that while change is inevitable, there does exist a constrained set of ways in which these socio-ecological systems function, thereby allowing us to understand and manage them (assertion #9);
5. that restoring degraded socio-ecological systems to more productive, sustainable states requires outside intervention (assertion #4)
6. that socio-ecological systems in drylands of the world are hierarchical (assertion #8). Hence, scale-related concerns abound and desertification itself is a regionally-emergent property of localized degradation (assertion #5)

The strength of the Dahlem Desertification Paradigm is in its cross-scale conceptual holism. While the term desertification is only useful at the higher levels of aggregation, and degradation (appropriately refined) at the lower levels, the DDP framework embraces all these levels of concern. For example, at the international level, implementation of the CCD must be framed in terms of changes in coupled human-environment systems that matter to humans, which dramatically changes the meaning of the "extent of desertification" (Sect. 20.2.4) and both the timing and distribution of funding for inter-

Table 20.4. The nine assertions of the Dahlem Desertification Paradigm, and some of their implications. From Stafford Smith and Reynolds (2002)

	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 the 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 costs 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	Understand and manage the circumstances in which the human and environmental sub-systems 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 (manage the hierarchy!)	Recognize and manage the fact that changes at one level affect others; create flexible but linked institutions across the hierarchical levels, and ensure processes are managed through 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

vention. Similarly, at the household or community level, where concern is on the specific type of land degradation that is occurring and its local socio-economic consequences, the DDP channels resources towards identifying those essential biophysical and socio-economic slow variables that really matter in terms of quantifying current and future risk.

20.3.2 Initiatives to Test the Dahlem Desertification Paradigm

The joint GCTE-LUCC initiative on desertification is embodied within the ARID*net*[1] research network (Reynolds et al. 2003). The general objectives of this network are to foster international cooperation, discussion, and exchange of ideas about global desertification (as summarized in the DDP), to conduct case studies, representing a range of biophysical/socio-economic land degradation types around the world, and to facilitate communication between researchers to foster more practical, field-level interactions with stakeholders in sustainable land management.

To accomplish these objectives, ARID*net* is organized into three nodes (North/South America; Asia/Australia; Europe/Africa) and is pursuing four specific tasks (Fig. 20.1):

[1] Assessment, Research, and Integration of Desertification.

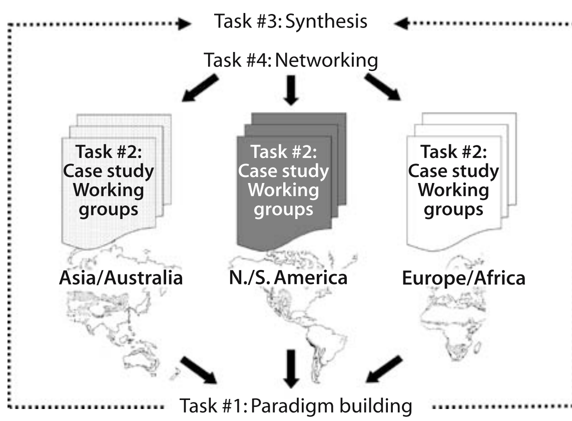

Fig. 20.1. ARID*net* is an international research network organized into three nodes (North/South America; Asia/Australia; Europe/Africa) and is pursuing four tasks (see text): paradigm-building, conducting case studies, developing a synthesis, and to facilitate participation via network-building

- *Paradigm-building*. Using workshops and symposia conducted in different parts of the world, ARID*net* will develop and refine the contents of the DDP through the joint participation of the international community of desertification researchers, stakeholders, and policy-makers;
- *Case studies*. Working Groups are specifically formed to develop case studies throughout the world in order to test the DDP in a well-stratified, comparative manner. These case studies are based on existing data and specific stakeholders, and represent a wide range of

the biophysical and socio-economic conditions existing in drylands;
- *Synthesis*. The numerous case studies will feed into a quantitative assessment of what really matters in desertification. This synthesis will especially focus on those interactions between key biophysical and socio-economic variables; and
- *Network-building*. ARID*net* strives to recruit and foster the participation of a diversity of researchers from different fields and countries in the activities of the network.

20.4 Management of Desertified Drylands

In preceding sections we provided examples of the magnitude and importance of desertification as a major local and global environmental problem. In order to prevent further degradation and to restore degraded lands, a number of countries have enacted environmental policies to establish management actions to combat desertification. These actions are diverse but can be grouped under three headings: avoidance, monitoring, and restoration.

20.4.1 Avoidance

Management actions to avoid desertification are rarely proactive. If they exist, they normally are focused on the human drivers of desertification. Such actions vary widely according to the socio-economic conditions of a particular country, but often include the use of economic subsidies to promote changes in land use or crops (Harou 2002), the diversification of human activities in the areas affected (Pamo 1998), and the establishment of educational programs to improve education and social welfare (Vogel and Smith 2002). The latter activity is of crucial importance since one of the core causes of desertification in developing nations is the extreme pressure on the land resulting from high population growth (Geist and Lambin 2004; Le Houérou 1996). However, there are examples of success in reducing demographic growth and in implementing sustainable production systems in desertified areas worldwide (Arkutu 1995; Vogel and Smith 2002), indicating that with appropriate resources and political willingness, some of the most important desertification drivers can be controlled.

20.4.2 Monitoring

The monitoring of desertification is an increasingly important development in the management of dryland areas. The establishment of long-term and rigorous monitoring programs is an effective way to assess the status of natural resources and the evolution of desertification processes. Such programs could provide an "early warning" of pending concerns, e.g., the detection of changes in ecosystem attributes and processes at stages where management actions would be most cost-effective (see Fernández et al. 2002).

It is encouraging to see increased research dedicated to the development of easily accessible monitoring methods based on simple soil and vegetation indicators (e.g., Pyke et al. 2002; Tongway and Hindley 1995). These methods are based on the collection of basic information of those vegetation attributes and soil properties (e.g., cover, spatial pattern, resistance to penetration and texture) that largely determine the ecosystem's resilience to erosive forces and its ability to use water and nutrients. An important goal of these methods is to minimize the training and equipment required so as to increase their availability to nations with low economic resources. These ground-based methods are complemented with the use of remote sensing data, which have been successfully employed to monitor desertification processes in the U.S. (Asner and Heidebrecht 2005), South America (Asner and Heidebrecht 2003), Africa (Prince et al. 1998), Australia (Bastin et al. 2002) and Europe (Imeson and Prinsen 2004). Remote-sensing approaches are often based on measuring the same vegetation and soil attributes as ground-based methods, but they allow the establishment of monitoring programs at larger spatial scales. However, they often require the use of expensive equipment and appropriate training, two factors not available in many countries. Furthermore, recent studies suggest that traditional remote sensing measurements (e.g., NDVI measured during the growing season) do not provide an adequate indication of biophysical degradation (Asner et al. 2003). Further advancement in desertification monitoring depends upon a coordination between ground- and remote sensing-based research and the establishment of sound and cost-effective methodologies appropriate for particular regions.

20.4.3 Restoration

While we might hope that future actions of land owners, communities, regions, and nations will begin to adopt management practices and policies that minimize or avoid desertification, the sad fact is that vast areas of drylands are already in a wretched state, with varying degrees of reduced plant cover, impoverished species diversity, and depleted or eroded soils (Whisenant 1999). Restoration actions in these lands have traditionally focused on the biophysical variables, especially those aimed at increasing plant cover and halting soil erosion. Often, and irrespective of the underlying drivers of desertification, restoration efforts involve the establishment of woody plants (Whisenant 1999), which is deemed crucial to stop further degradation, and to foster recovery of ecosystem structure, composition, and functioning (Reynolds 2001). Such afforestation programs, which have been carried out since the 1800s, have resulted in millions of hectares of conifer trees (mainly) planted in drylands of Spain, Turkey, Morrocco, Algeria, Argentina, China, and many other countries (Richardson 1998; Pausas et al. 2004; Sánchez Martínez and Gallego Simón 1993; Gao et al. 2001). While some of these efforts have been effective in controlling desertification, many have failed (Odera 1996), and in some cases have exacerbated the degradation process (see review by Maestre and Cortina 2004).

In other instances, restoring desertified lands has involved instituting changes in land management practices (e.g., Pyke et al. 2002; Sørbø, 2003). Again, these may be undertaken without full understanding of the causal mechanisms involved, or without an appreciation of the socio-economic conditions (Sørbø, 2003), and again are prone to failure. This history of lack of success suggests a clear need to address fundamentals. First, as we have emphasized throughout this chapter, it is important to have a sound understanding of both the biophysical and human dimensions of causality. Second, we must incorporate as much of our knowledge of dryland structure and functioning as possible into our management actions. In this respect, important advances have been made in the application of conceptual and practical ecosystem models. Third, we must carefully evaluate and incorporate existing socio-economic attributes. Fourth, we must assess the potential for successful rehabilitation. Lastly, we must strive for improved restoration methodologies, including the use of new understanding of key ecosystem processes, e.g., plant-plant interactions (Maestre et al. 2001) and the role of soil heterogeneity in plant establishment (Maestre et al. 2003).

20.5 Summary and Conclusions

While conceptual, methodological and technological advances have been made during the past several decades to help land managers establish appropriate strategies for combating desertification, there have been relatively few successes in desertification abatement (Le Houérou 1996). As discussed in this chapter, desertification may have numerous underlying causes, which involve a complex interplay among biophysical and human dimensions. We propose that a key aspect of the prevention and remediation of desertification is the development of a integrative, theoretical framework in which biophysical and socioeconomic components are treated as coupled processes fostering desertification.

We further suggest that the Dahlem Desertification Paradigm provides the necessary theoretical framework for bringing researchers and policy-makers together for the purpose of developing testable hypotheses and methodologies regarding the monitoring, prevention and remediation of desertification. The DDP emphasizes the need to address all socio-economic levels (local, regional, national, international) in the development of effective desertification policy decisions. The DDP emphasizes moving beyond isolated studies of various parts of the desertification problem and toward establishing an integrated program of causal links of dryland degradation, from climate dynamics to ecological impacts to policy response strategies, which can be applied to a wide range of temporal and spatial scales. The challenges of building the necessary political and scientific bridges are enormous, but so is the need for urgent action to understand and manage desertified drylands worldwide.

Acknowledgments

The authors acknowledge the helpful comments and critiques provided by Greg Asner and an anonymous reviewer. This research was supported by the National Science Foundation (grant NSF-DEB-02–34186 to ARID*net)* and the Center for Integrated Study of the Human Dimensions of Global Change, through a cooperative agreement between the NSF (SBR-9521914) and Carnegie Mellon University. FTM acknowledges support via a Fulbright fellowship from the Spanish Ministry of Education and Science, funded by Secretaría de Estado de Universidades and Fondo Social Europeo. JFR acknowledges partial support by the Alexander von Humboldt-Stiftung during the preparation of this manuscript and the excellent hospitality of the Lehrstuhl für Pflanzenökologie at the University of Bayreuth.

References

Arkutu A (1995) Family planning in Sub-Saharan Africa: Present status and future strategies. Int J Gyn Obst 50: S27–S34

Asner GP, Heidebrecht KB (2003) Imaging spectroscopy for desertification studies: Comparing AVIRIS and EO-1 Hyperion in Argentina drylands. IEEE Trans Geosci Rem Sens 41:1283–1296

Asner GP, Heidebrecht KB (2005) Desertification alters regional ecosystem-climate interactions. Global Change Biol 11:182–194

Asner GP, Borghi CE, Ojeda RA (2003) Desertification in central Argentina: Changes in ecosystem carbon and nitrogen from imaging spectroscopy. Ecol Appl 13:629–648

Asner GP, Elmore AJ, Olander LP, Martin RE, Harrias T (2004) Grazing systems, ecosystem responses, and global change. Annu Rev Environ Resour 29:261–299

Bastin G, Ludwig JA, Eager RW, Chewings VH, Liedloff AC (2002) Indicators of landscape function: comparing patchiness metrics using remotely-sensed data from rangelands. Ecol Indic 1:243

Batterbury SPJ, Behnke RH, Döll PM, Ellis JE, Harou PA, Lynam TJP, Mtimet A, Nicholson SE, Obando JA, Thornes JB (2002) Responding to desertification at the national scale: detection, explanation, and responses. In: Reynolds JF, Stafford Smith M (eds) Global Desertification: Do Humans Cause Deserts? Dahlem University Press, Berlin, pp 357–386

Belnap J, Eldridge DJ (2001) Disturbance and recovery of biological soil crusts. In: Belnap J, Lange OL (eds) Biological Soil Crusts: Structure, Function, and Management Springer-Verlag, Berlin, pp 363–384

Bestelmeyer BT (2005) Does desertification diminish biodiversity? Enhancement of ant diversity by shrub invasion in south-western USA. Divers Distrib 11:45–55
Bollig M, Schulte A (1999) Environmental change and pastoral perceptions: Degradation and indigenous knowledge in two African pastoral communities. Human Ecol 27:493–514
Chasek P, Corell E (2002) Addressing desertification at the international level: the institutional system. In: Reynolds JF, Stafford Smith M (eds) Do Humans Create Deserts? The Ecological, Meteorological, and Human Dimensions of Global Desertification. Dahlem University Press, Berlin, pp 275–296
Corell E (1999) The Negotiable Desert: Expert Knowledge in the Negotiations of the Convention to Combat Desertification. Linköping Studies in Arts and Science No. 191. Linköping University, Linköping, Sweden
Darkoh MBK (1998) The nature, causes and consequences of desertification in the drylands of Africa. Land Degrad Develop 9:1–20
Dregne HE (1996) Desertification: challenges ahead. Ann Arid Zone 35:305–311
Fernández RJ, Archer ERM, Ash AJ, Dowlatabadi H, Hiernaux PHY, Reynolds JF, Vogel CH, Walker BH, Wiegand T (2002) Degradation and recovery in socio-ecological systems: a view from the household/farm level. In: Reynolds JF, Stafford Smith M (eds) Do Humans Create Deserts? The Ecological, Meteorological, and Human Dimensions of Global Desertification. Dahlem University Press, Berlin, pp 297–324
Fredrickson E, Havstad KM, Estell R, Hyder P (1998) Perspectives on desertification: South-western United States. J Arid Environ 39:191–207
Gallart F, Llorens P, Latron J (1994) Studying the role of old agricultural terraces on runoff generation in a small Mediterranean mountainous basin. J Hydrol 159:291–303
Gao J, Zha Y, Ni S (2001) Assessment of the effectiveness of desertification rehabilitation measures in Yulin, north-western China using remote sensing. Int J Rem Sens 22:3783–3795
Geist HJ, Lambin EF (2004) Dynamic causal patterns of desertification. Bioscience 54:817–829
Gonzalez P (2001) Desertification and a shift of forest species in the West African Sahel. Clim Res 17:217–228
Grainger A, Stafford Smith M, Squires V, Glenn E (2000) Desertification and climate change: the case for greater convergence. Mitig Adapt Strat Global Change 5:361–377
Harou PA (2002) What is the role of markets in altering the sensitivity of arid land systems to perturbation? In: Reynolds JF, Stafford Smith DM (eds) Global Desertification: Do Humans Cause Deserts? Dahlem University Press, Berlin, pp 253–274
Huenneke LF, Anderson JP, Remmenga M, Schlesinger WH (2002) Desertification alters patterns of aboveground net primary production in Chihuahuan ecosystems. Global Change Biol 8:247–264
Imeson AC, Prinsen HAM (2004) Vegetation patterns as biological indicators for identifying runoff and sediment source and sink areas for semi-arid landscapes in Spain. Agric Ecosyst Environ 104:333–342
Jackson RB, Banner JL, Jobbagy EG, Pockman WT, Wall DH (2002) Ecosystem carbon loss with woody plant invasion of grasslands. Nature 418:623–626
Kassas M (1995) Desertification: a general review. J Arid Environ 30:115–128
Kelley DW, Nater EA (2000) Historical sediment flux from three watersheds into Lake Pepin, Minnesota, USA. J Environ Qual 29:561–568
Krogh SN, Zeisset MS, Jackson E, Whitford WG (2002) Presence/absence of a keystone species as an indicator of rangeland health. J Arid Environ 50:513–519
Lambin EF, Chasek PS, Dowing TE, Kerven C, Kleidon A, Leemans R, Lüdeke M, Prince SD, Xue Y (2002) The interplay between international and local processes affecting desertification. In: Reynolds JF, Stafford Smith M (eds) Do Humans Create Deserts? The Ecological, Meteorological, and Human Dimensions of Global Desertification. Dahlem University Press, Berlin, pp 387–402
Latchininsky A, Gapparov FA (1996) Consequences of the Aral sea's drying up on the regional locust situation. Secheresse 7:109–113
Lavee H, Imeson AC, Sarah P (1998) The impact of climate change on geomorphology and desertification along a mediterranean-arid transect. Land Degrad Develop 9:407–422
Le Houérou HN (1996) Climate change, drought and desertification. J Arid Environ 34:133–185
Leach M, Mearns R (eds) (1996) The Lie of the Land: Challenging Received Wisdom on the African Environment. Heinemann Press, Portsmouth, N.H
Maestre FT, Cortina J (2004) Are *Pinus halepensis* plantations useful as a restoration tool in semiarid Mediterranean areas? For Ecol Manage 198:303–317
Maestre FT, Bautista S, Cortina J, Bellot J (2001) Potential for using facilitation by grasses to establish shrubs on a semiarid degraded steppe. Ecol Appl 11:1641–1655
Maestre FT, Cortina J, Bautista S, Bellot J, Vallejo R (2003) Small-scale environmental heterogeneity and spatiotemporal dynamics of seedling establishment in a semiarid degraded ecosystem. Ecosystems 6:630–643
Middleton NJ, Thomas DSG (eds) (1997) World Atlas of Desertification. U.N. Environment Programmem, Edward Arnold, New York
Odera J (1996) L'état de dégradation actuel des écosystèmes fragiles dans les zones sèches et le rôle de la foresterie dans la restauration, Note de secrétariat nº 1. Réunion Internationale d'experts sur la restauration des ecosystèmes forestiers dégradés. Portuguese Ministry of Agriculture, UNP/UNSO, IPF, CCD & RIOD, Lisbon
Pamo ET (1998) Herders and wildgame behaviour as a strategy against desertification in northern Cameroon. J Arid Environ 39:179–190
Pausas JG, Bladé C, Valdecantos A, Seva J, Fuentes D, Alloza J, Vilagrosa A, Bautista S, Cortina J, Vallejo R (2004) Pines and oaks in the restoration of Mediterranean landscapes of Spain: New perspectives for an old practice. Plant Ecol 171:209–220
Pidgeon AM, Mathews NE, Benoit R, Nordheim EV (2001) Response of avian communities to historic habitat change in the northern Chihuahuan Desert. Cons Biol 15:1772–1788
Prince SD (2002) Spatial and temporal scales for detection of desertification. In: Reynolds JF, Stafford Smith M (eds) Global Desertification: Do Humans Cause Deserts? Dahlem University Press, Berlin, pp 23–40
Prince SD, de Colstoun EB, Kravitz LL (1998) Evidence from rain-use efficiencies does not indicate extensive Sahelian desertification. Global Change Biol 4:359–374
Pyke DA, Herrick JE, Shaver PL, Pellant M (2002) Rangeland health attributes and indicators for qualitative assessment. J Range Manage 55:584–597
Reynolds JF (2001) Desertification. In: Levin S (ed) Encyclopedia of Biodiversity, Volume 2. Academic Press, San Diego, CA, pp 61–78
Reynolds JF, Stafford Smith M (2002a) Do humans cause deserts? In: Reynolds JF, Stafford Smith M (eds) Global Desertification: Do Humans Cause Deserts? Dahlem University Press, Berlin, pp 1–22
Reynolds JF, Stafford Smith M (eds) (2002b) Global Desertification: Do Humans Cause Deserts? Dahlem University Press, Berlin
Reynolds JF, Stafford Smith DM, Lambin EF (2003) ARIDnet: Seeking novel approaches to desertification and land degradation. IGBP Global Change Newsletter 54, 5–9 (PDF available at: http://www.igbp.kva.se)
Richardson DM (1998) Ecology and biogeography of *Pinus*. Cambridge University Press, Cambridge
Rosenfeld D, Rudich Y, Lahav R (2001) Desert dust suppressing precipitation: A possible desertification feedback loop. Proc Natl Acad Sci USA 98:5975–5980
Sánchez Martínez JD, Gallego Simón VJ (1993) La Política de repoblación forestal en España, siglos XIX y XX: Planteamientos, Actuaciones y resultados, estado de la cuestión y recopilación bibliográfica. MAPA. Secretaria General Técnica. Serie Recopilaciones Bibliográficas nº 10, Madrid
Schlesinger WH, Reynolds JF, Cunningham GL, Huenneke LF, Jarrell WM, Virginia R, Whitford WG (1990) Biological feedbacks in global desertification. Science 247:1043–1048
Schlesinger WH, Abrahams AD, Parsons AJ, Wainwright J (1999) Nutrient losses in runoff from grassland and shrubland habitats in Southern New Mexico: I. rainfall simulation experiments. Biogeochemistry 45:21–34

Sharma KD (1998) The hydrological indicators of desertification. J Arid Environ 39:121–132
Sørbø GM (2003) Pastoral ecosystems and the issue of scale. Ambio 32:113–117
Stafford Smith DM, Pickup G (1993) Out of Africa, looking in: understanding vegetation change. In: Behnke RH Jr., Scoones I, Kerven C (eds) Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannas. Overseas Development Institute and International Institute for Environment and Development, London, pp 196–244
Stafford Smith DM, Reynolds JF (2002) The Dahlem Desertification Paradigm: A new approach to an old problem. In: Reynolds JF, Stafford Smith M (eds) Global Desertification: Do Humans Cause Deserts? Dahlem University Press, Berlin, pp 403–424
Stocking M, Murnaghan N (2001) Handbook for the Field Assessment of Land Degradation. Earthscan, London; Sterling, VA
Thomas DSG (1997) Science and the desertification debate. J Arid Environ 37:599–608
Thomas DSG, Middleton N (1994) Desertification: Exploding the Myth. John Wiley & Sons, Chichester
Tongway DJ, Hindley N (1995) Assessment of soil condition of tropical grasslands. CSIRO Ecology and Wildlife, Canberra
Tongway DJ, Ludwig JA (1996) Rehabilitation of semiarid landscapes in Australia. I. Restoring productive soil patches. Restor Ecol 4:388–397
Toulmin C (2001) Lessons from the theatre: Should this be the final curtain call for the Convention to Combat Desertification? WSSD Opinion Series. International Institute for Environment and Development. Available from: www.iied.org
UNCCD (1994) United Nations Convention to Combat Desertification, Intergovernmental Negotiating Committee For a Convention to Combat Desertification, Elaboration of an International Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa. U.N. Doc. A/AC.241/27, 33 I.L.M. 1328. United Nations, New York
UNCCD (2000) Fact Sheet 2: The Causes of Desertification. United Nations Secretariat of the Convention to Combat Desertification. Available from: http://www.unccd.int/publicinfo/factsheets/showFS. php?number=2 [Geo-2–171]
United Nations (1994) Earth Summit. Convention on Desertification. United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 3–14 June 1992. In. United Nations, New York, p 44
Vitousek PM, Mooney HA, Lubchenco J, Melillo JM (1997) Human domination of Earth's ecosystems. Science 277:494–499
Vogel CH, Smith J (2002) Building social resilience in arid ecosystems. In: Reynolds JF, Stafford Smith DM (eds) Global Desertification: Do Humans Cause Deserts? Dahlem University Press, Berlin, pp 149–166
von Hardenberg J, Meron E, Shachak M, Zarmi Y (2001) Diversity of vegetation patterns and desertification. Phys Rev Let 87: 198101–1–198101–4
Whisenant SG (1999) Repairing Damaged Wildlands. Cambridge University Press, Cambridge
White RP, Nackoney J (2003) Drylands, people, and ecosystem goods and services: A web-based geospatial analysis. World Resources Institute, Washington, DC
White R, Tunstall D, Henninger N (2003) An Ecosystem Approach to Drylands: Building Support for New Development Policies. World Resources Institute, EarthTrends Publication Series. Available online: http://earthtrends.wri.org/features/view_feature.cfm?fid=37&theme=39
Whitford WG (1993) Animal feedbacks in desertification: An overview. Rev Chil Hist Nat 66:243–251
Whitford WG (1997) Desertification and animal biodiversity in the desert grasslands of north America. J Arid Environ 37:709–720
Zaman S (1997) Effects of rainfall and grazing on vegetation yield and cover of two arid rangelands in Kuwait. Environ Cons 24: 344–350
Zhao WZ, Xiao HL, Liu ZM, Li J (2005) Soil degradation and restoration as affected by land use change in the semiarid Bashang area, northern China. Catena 59:173–186