Chapter 22

Dryland Systems

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Main Messages

Drylands cover about 41% of Earth's land surface and are inhabited by more than 2 billion people (about one third of world population). Drylands are limited by soil moisture, the result of low rainfall and high evaporation, and show a gradient of increasing primary productivity, ranging from hyper-arid, arid, and semiarid to dry subhumid areas. Deserts, grasslands, and woodlands are the natural expression of this gradient.

Dryland populations on average lag far behind the rest of the world on human well-being and development indicators (*high certainty*). The current socioeconomic condition of dryland peoples, about 90% of whom are in developing countries, lags significantly behind that of people in other areas.

Existing water shortages in drylands are projected to increase over time due to population increase, land cover change, and global climate change. From 1960 to 2000, global use of fresh water (drylands included) expanded at a mean rate of 25% per decade. The availability in drylands is projected to decline further from the current average of 1,300 cubic meters per person per year (in 2000), which is already below the threshold of 2,000 cubic meters required for minimum human well-being and sustainable development. This increased water stress will lead to reduced productivity of croplands and availability of fresh water, resulting in further adverse impacts on human well-being in drylands. There is a high degree of certainty that global climate change, land use developments, and land cover changes will lead to an accelerated decline in water availability and biological production in drylands.

Transformation of rangelands and other silvipastoral systems to cultivated croplands is leading to significant, persistent decrease in overall dryland plant productivity. Extreme reduction of rangeland vegetation cover through grazing of forage and collection of fuelwood exposes the soil to erosion. Transformation of rangelands to cultivated systems (approximately 15% of dryland grasslands, the most valuable dryland range, were converted between 1950 and 2000), in combination with inappropriate dryland irrigation and cultivation practices has led to soil salinization and erosion. These processes reduce the provision of water-related services, which affects the provision of many other significant dryland services and goods, culminating in persistent reduction of primary production.

Among dryland subtypes, ecosystems and populations of semiarid areas are the most vulnerable to loss of ecosystem services (*medium certainty*). Population density within drylands decreases with increasing aridity from 10 persons per square kilometer in the hyper-arid drylands to 71 persons in dry subhumid drylands. Conversely, the sensitivity of dryland ecosystems to human impacts that contribute to land degradation increases with increasing aridity. Therefore, the risk of land degradation is greatest in the median section of the aridity gradient (mostly the semiarid drylands), where both sensitivity to degradation and population pressure (expressed by population density) are of intermediate values.

It is thought that some 10–20% of the world's drylands suffer from one or more forms of land degradation (*medium certainty*). Despite the global concern aroused by desertification, the available data on the extent of land degradation in drylands (also called desertification) are extremely limited. In the early 1990s, the Global Assessment of Soil Degradation, based on expert opinion, estimated that 20% of drylands (excluding hyper-arid areas) was affected by soil degradation. A recent MA commissioned desk study (Lepers 2003) based on regional data sets (including hyper-arid drylands) derived from literature reviews, erosion models, field assessments and remote sensing found much lower levels of land degradation in drylands. Coverage was not complete, but the main areas of degradation were estimated to cover 10% of global drylands. Most likely the true level of degradation lies somewhere between the 10% and 20% figures. To identify precisely where the problems occur and the true extent of degradation will require a more in-depth follow-up to these exploratory studies.

Desertification, which by definition occurs only in drylands, causes adverse impacts on non-dryland ecosystems (*high certainty*). Desertification has both direct and indirect impacts on non-dryland ecosystems and peoples. For example, dust storms resulting from wind soil erosion, driven by degradation of the dryland vegetation cover, may affect people and ecosystems elsewhere. Similarly, transport of sediments, pesticides, and nutrients from dryland agricultural activities affects coastal ecosystems. Droughts and loss of land productivity are considered predominant factors in the migration of people from drylands to other areas (*medium certainty*).

Traditional and other current management practices contribute to the sustainable use of ecosystem services. Many existing practices help prevent desertification. These include enhanced and traditional water harvesting techniques, water storage and conservation measures, reuse of safe and treated wastewater for irrigation, afforestation for arresting soil erosion and improving ground water recharge, conservation of agrobiodiversity through diversification of crop patterns, and intensification of agriculture using technologies that do not increase pressure on dryland services. Policies that involve local participation and community institutions, improve access to transport and market infrastructures, and enable land users to innovate are essential to the success of these practices.

Alternative livelihoods have a lower impact on dryland ecosystem services. These livelihoods still depend on the condition of drylands services but rely less on vulnerable services and make use of the competitive advantages drylands can offer over other systems. They can include dryland aquaculture for production of high-value food and industrial compounds, controlled-environment agriculture (such as greenhouses) that requires relatively little land, and tourism-related activities.

Depending on the level of aridity, dryland biodiversity is relatively rich, still relatively secure, and is critical for the provision of dryland services. Of 25 global "biodiversity hotspots" identified by Conservation International, 8 are in drylands. The proportion of drylands designated as protected areas is close to the global average, but the proportion of dryland threatened species is lower than average. At least 30% of the world's cultivated plants originated in drylands and have progenitors and relatives in these areas. A high species diversity of large mammals in semiarid drylands supports cultural services (mainly tourism); a high functional diversity of invertebrate decomposers in arid drylands supports nutrient cycling by processing most arid primary production; a high structural diversity of plant cover (including microphyte diversity of soil crusts in arid and semiarid areas) contributes to rainfall water regulation and soil conservation, hence to primary production and its generated diversity of the dryland wild and cultivated plants.

22.1 Introduction

This chapter describes the current condition of dryland systems with respect to the services they provide and the drivers that determine trends in their provision. Within the context of the mounting global concern caused by land degradation in drylands (defined as desertification in the text of the United Nations Convention to Combat Desertification), the chapter assesses desertification as a persistent reduction in the services provided by dryland ecosystems, leading to unsustainable use of the drylands and their impaired development. The chapter also explores options for the sustainable use of drylands and points to human and societal responses that have succeeded or failed.

"Desertification" means land degradation in arid, semiarid, and dry subhumid areas resulting from various factors, including climatic variations and human activities. Land degradation means reduction of or loss in the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, range, pasture, forest, or woodlands resulting from land uses or from processes arising from human activities and habitation patterns (UNCCD 1992). Though this definition excludes the hyper-arid drylands, this chapter explores land degradation in all global drylands, including the hyper-arid areas.

22.1.1 Definition and Subtypes of Dryland Systems

Drylands are characterized by scarcity of water, which constrains their two major interlinked services—primary production and nutrient cycling. Over the long term, natural moisture inputs (that is, precipitation) are counterbalanced by moisture losses through evaporation from surfaces and transpiration by plants (evapotranspiration). This potential water deficit affects both natural and managed ecosystems, which constrains the production of crops, forage, and other plants and has great impacts on livestock and humans.

Drylands are not uniform, however. They differ in the degree of water limitation they experience. Following the UNEP terminology, four dryland subtypes are recognized in this assessment—dry subhumid, semiarid, arid, and hyper-arid—based on an increasing level of aridity or moisture deficit. The level of aridity typical for each of these subtypes is given by the ratio of its mean annual precipitation to its mean annual evaporative demand, expressed as potential evapotranspiration. The long-term mean of this ratio is termed the aridity index.

This chapter follows the *World Atlas of Desertification* (Middleton and Thomas 1997) and defines drylands as areas with an aridity index value of less than 0.65. The UNCCD, although excluding the hyper-arid dryland from its consideration, adopted the classification presented in the *World Atlas,* which is based on a global coverage of mean annual precipitation and temperature data collected between 1951 and 1980. The temperature data, together with the average number of daylight hours by month, were used to obtain a global coverage of corrected Thornthwaite's potential evapotranspiration values (Middleton and Thomas 1997). Aridity index values lower than 1 indicate an annual moisture deficit, and the *World Atlas* drylands are defined as areas with $AI \leq 0.65$—that is, areas in which annual mean potential evapotranspiration is at least ~1.5 greater than annual mean precipitation.

Using index values, the four dryland subtypes can be positioned along a gradient of moisture deficit. Together, these cover more than 6 billion hectares, or 41.3% of Earth's land surface. (See Table 22.1.) Though the classification of an area as a dryland subtype is determined by its aridity index, which relates to the mean values of precipitation, it is important to remember that these areas do experience large between-year variability in precipitation.

Dryland subtypes can also be described in terms of their land uses: rangelands, croplands, and urban areas. (See Table 22.2.) Rangelands and croplands jointly account for 90% of dryland areas and are often interwoven, supporting an integrated agropastoral livelihood.

Drylands occur on all continents (between 63° N and 55° S; see Figure 22.1) and collectively comprise nearly half of the global landmass. The rest of the land area is primarily taken up by polar and by forest and woodland systems (the latter overlapping with the dryland system; see Box 22.1).

Drylands are not spread equally between poor and rich countries: 72% of the global dryland area occurs within developing countries and only 28% within industrial ones. Furthermore, the proportion of drylands occupied by developing countries increases with aridity, reaching almost 100% for the hyper-arid areas. (See Figure 22.2.) Consequently, the majority of dryland peoples live in developing countries (that is, from 87% to 93%, depending on how the former Soviet Union countries are categorized), and only 7–15% reside in industrial countries. (See Figure 22.3.)

22.1.2 Ecosystems in Drylands

Although there are only four dryland subtypes, there are a greater number of dryland ecosystems within the subtypes. These are aggregated into large, higher-order units known as biomes, which are characterized by distinctive life forms and principal plant species (such as tundra, rainforest, grassland, or desert biomes). Whereas the MA dryland subtype boundaries are determined by two climatic factors (precipitation and evaporation), many environmental factors are used to delineate the boundaries of the different biomes. Many different systems of biome classification are presently used. Five well-recognized classification systems of terrestrial biomes identify 12–17 biomes within drylands, depending on the scheme adopted. (See Chapter 4.)

This chapter uses the classification of the World Wide Fund for Nature that designates terrestrial biomes as "terrestrial ecoregions." Each ecoregion delineates large land units containing a distinct assemblage of ecosystems, with boundaries approximating the extent of natural ecosystems prior to major land use change (Olson et al. 2001). These are further aggregated into four "broad" dryland biomes—desert, grassland, Mediterranean (mainly scrubland), and forest (mainly woodland)—that successively replace each other along the aridity gradient (see Figure 22.4), with decreased aridity leading to an increase in plant cover, stature, and architectural complexity. However, there is no exact match between the four dryland subtypes and the four broad dryland biomes, such that forest and grassland, for example, may occur at different areas of the same dryland subtype. The number of broad biomes that may occur within a dryland subtype increases with reduced aridity, and the diversity of biomes peaks in the semiarid subtype, which also covers the largest area of the various subtypes.

The presence of different biomes within each dryland subtype demonstrates that biological species respond not only to overall moisture deficit but also to other environmental variables, such as soils and geomorphological and landscape features. Furthermore, a greater degree of species richness and diversity of ecosystem services is observed as aridity declines. Although dryland services are provided by the biomes' ecosystems, the MA opted to report on ecosystems, or simply "systems," unified primarily by their range of aridity. This approach is justified for two reasons. First, it bypasses the many inherent differences in biome classification systems. Second, it better reflects current trends, as many dryland ecosystems have been and continue to be transformed into more simplified, cultivated ecosystems whose functioning is overwhelmingly dominated by the moisture deficit.

22.2 Ecosystem Services

The MA categorized ecosystem services into supporting, provisioning, regulating, and cultural services. (See Chapter 1.) The

Table 22.1. Statistical Profile of the Dryland System (Area from Deichmann and Eklundh 1991; global area based on Digital Chart of the World data (147,573,196.6 sq. km; year 2000 population from CIESIN 2004)

Subtypes	Aridity Index	Current Area		Dominant Broad Biome	Current Population	
		Size	Share of Global		Total	Share of Global
		(mill. sq. km.)	*(percent)*		*(thousand)*	*(percent)*
Hyper-arid	<0.05	9.8	6.6	desert	101,336	1.7
Arid	0.05–0.20	15.7	10.6	desert	242,780	4.1
Semiarid	0.20–0.50	22.6	15.2	grassland	855.333	14.4
Dry subhumid	0.50–0.65	12.8	8.7	forest	909,972	15.3
Total		**60.9**	**41.3**		**2,109,421**	**35.5**

Table 22.2. Land Uses in Drylands (MA core data)

	Rangelands[a]		Cultivated		Urban		Others[b]	
	Area	Share of Dryland Subtype	Area	Share of Dryland Subtype	Area	Share of Dryland Subtype	Area	Share of Dryland Subtype
	(sq. km)	*(percent)*	*(sq. km)*	*(percent)*	*(sq. km)*	*(percent)*	*(sq. km)*	*(percent)*
Dry subhumid	4,344,897	34	6,096,558	47	457,851	4	1,971,907	16
Semiarid	12,170,274	54	7,992,020	35	556,515	2	1,871,146	8
Arid	13,629,625	87	1,059,648	7	152,447	1	822,075	5
Hyper-arid	9,497,407	97	55,592	0.6	74,050	1	149,026	2
Total	**39,642,202**	**65**	**15,203,818**	**25**	**1,240,863**	**2**	**4,814,155**	**8**

[a] Rangeland figures are based on available data on rangelands in drylands of developing countries (Reid et al. 2004; Thornton et al. 2002) and estimates for rangeland areas in the remaining drylands based on the assumption of uniformity in the rangeland's share of each dryland subtype.

[b] Inland water systems in drylands (3%) and other areas unaccounted for by the assessed land uses (5%).

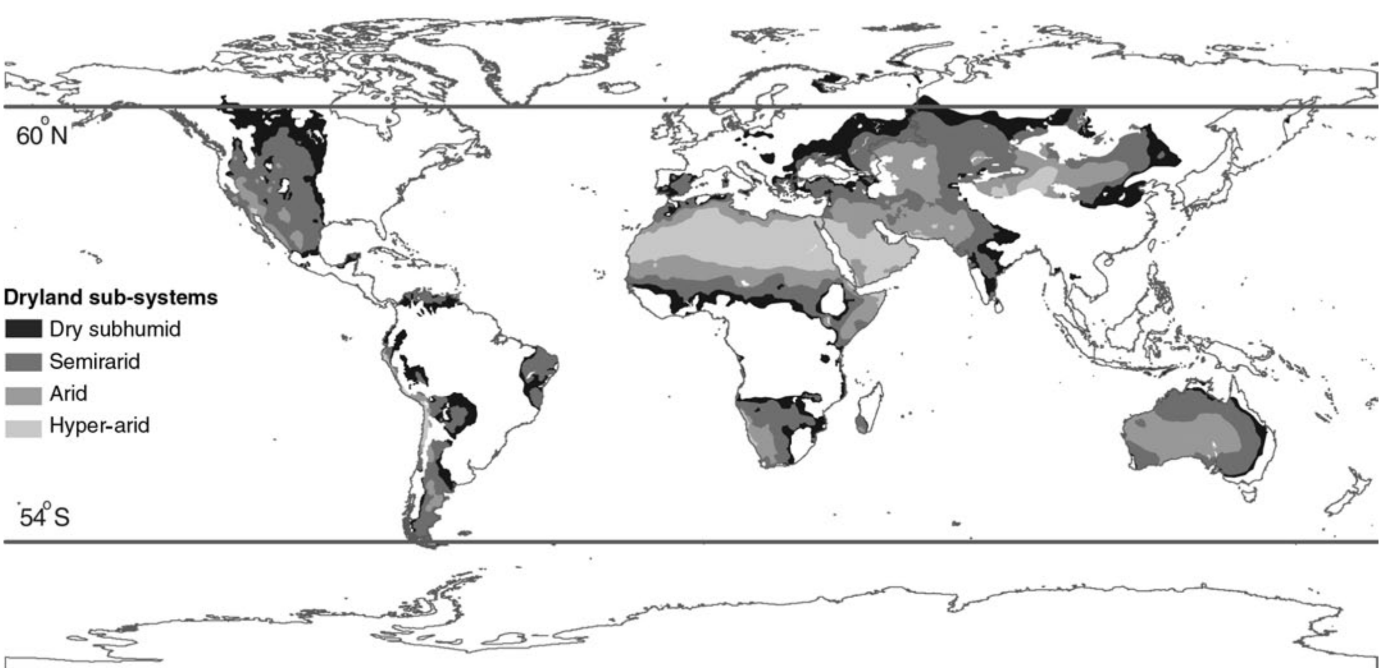
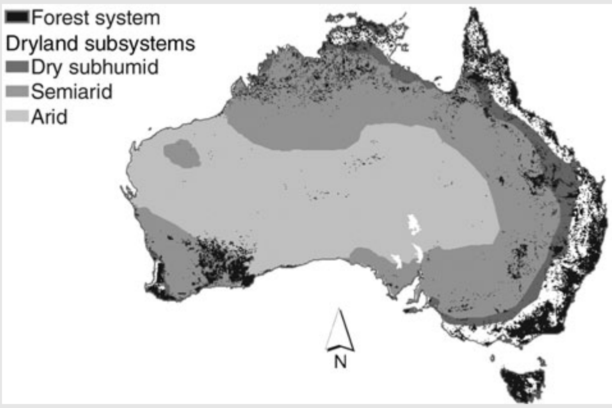


Figure 22.1. Dryland Systems and Subtypes

BOX 22.1

Forests in Drylands

This is not an oxymoron—forests do occur in drylands. Eighteen percent of the area of the dryland system is occupied by the forest and woodland system, though the probability of encountering forests in drylands decreases with their aridity. Australia is a good example, as seen in the Figure (which is a magnification of a section of Figure 20.1).



In general, aridity increases inland, and the forest and woodland system prevails along the coasts. The dry subhumid dryland subtype that is adjacent to the forest and woodland system has the greatest amount of overlap between the two systems, as compared with other drylands subtypes. But the distribution of forest in dry subhumid areas is patchier than it is within the forest and woodland system outside the drylands. Forests also occur in the much wider semiarid zone of Australia but are there mostly confined to the less dry seaward direction.

Forests occur in the dry subhumid subtype in Africa but are very scattered and rare in the semiarid zone. In China and India, with dry subhumid areas wider than in Australia, forests penetrate deep into dry subhumid areas. In Europe, where many dry subhumid areas are surrounded by non-drylands, forests are scattered all over the dryland areas. In the Americas, forests are patchily distributed in dry subhumid and semiarid regions. If forests do occur in the relatively humid range of the drylands and seem well adapted to these dryland conditions, why is their distribution patchy and not contiguous? Do the dryland forest patches occur in patches of locally less arid conditions, or is the patchiness a result of human exploitation? Answers to these questions may be critical for evaluating the use of the carbon sequestration service of these two dryland subtypes, which constitute nearly a quarter of Earth's surface area.

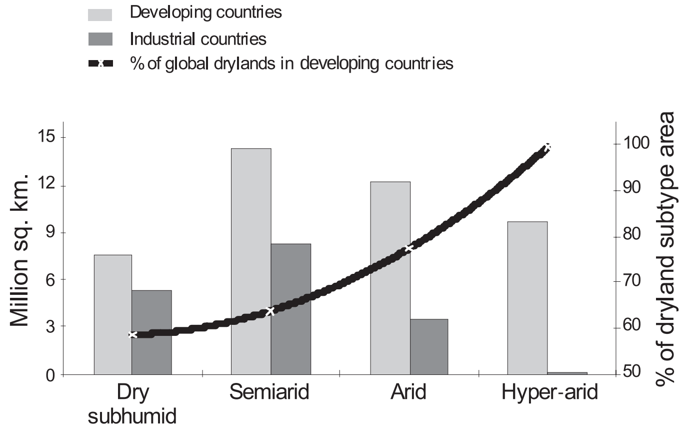


Figure 22.2. Dryland Subtypes and Socioeconomic–Political Status. The relative share of developing and industrial countries in the global drylands, by area and percentage taken up by developing countries. (MA core data)

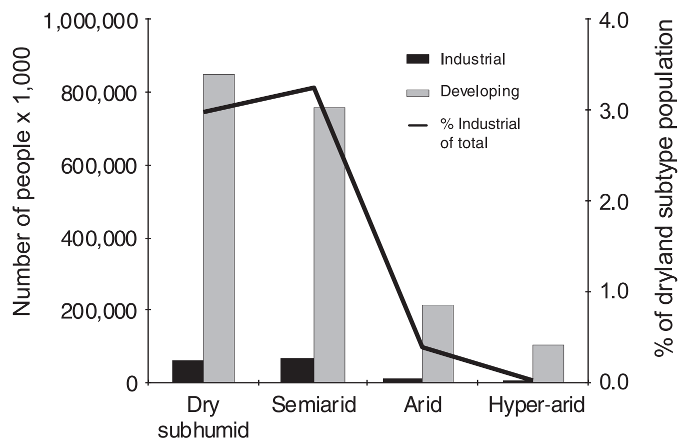


Figure 22.3. Population of Developing and Industrial Countries in Different Dryland Subtypes and Population of Industrial Countries in each Dryland Subtype as Percentage of Total Global Dryland Population (CIESIN 2004)

condition of dryland-significant services in each of these groups and the trends in their provision to dryland peoples are assessed in this section. For many services, however, data about global condition and trends are not readily available, and only generic information about processes governing the condition of these services is provided.

22.2.1 Supporting Services

22.2.1.1 Soil Development: Formation and Conservation

Though primary production in drylands is constrained by water, it is soil properties that determine how much of the rainfall will be stored and subsequently become available during dry periods. The availability of moisture in soil is also an important factor in nutrient cycling, a requisite for primary production. Therefore, soil formation and soil conservation are key supporting services of dryland ecosystems, the failure of which is one of the major drivers of desertification.

The slow process of soil formation, in which plants and microorganisms are intimately involved, is frequently countered by faster soil degradation expressed through erosion or salinization. Hence the services of soil formation and conservation jointly determine the rate of soil development and its quality. The rate of soil formation (hundreds to thousands of years) (Rust 1983) and its degree of development (depth of soil, infiltration depth, and organic content) decline with aridity (Nettleton and Peterson 1983; Sombroek 1990).

In hyper-arid areas, surfaces are often capped with mineral crusts that reduce infiltration and help generate soil-eroding flashfloods. In many arid drylands, dispersed plant clumps are often embedded in a matrix of apparently bare soil covered by a thin crust of photosynthetic cyanobacteria, with mosses and lichens added in semiarid drylands (Büdel 2001). The crusts reduce water penetration and thus channel runoff, sediments, nutrients, and seeds to the plant clumps, which then become active sites of

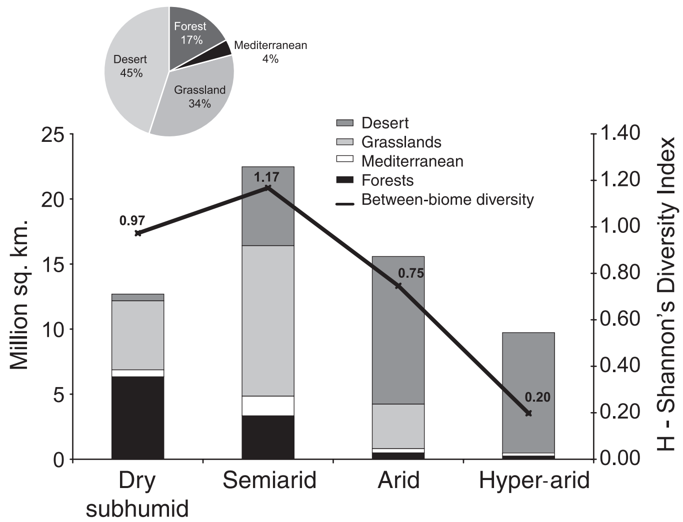


Figure 22.4. Global Area Covered by Dryland Subtypes and Their Broad Biomes. The line, points, and figures stand for the broad biome diversity index (Shannon's H); the pie chart shows the aggregated percentages for broad biomes by dryland subtypes.

soil formation and organic matter decomposition (Puigdefabregas et al. 1999). These crusts are therefore instrumental in soil development in and around the clumps and in soil conservation in the surrounding matrix (Aguiar and Sala 1999). However, they develop slowly and are sensitive to trampling or air pollution. Dry subhumid soils, on the other hand, are protected from erosion by multilayered, structurally complex vegetation (Poesen et al. 2003) that permits high water infiltration and storage, as well as water extraction by the same vegetation (Puigdefabregas and Mendizabal 1998).

22.2.1.2 Nutrient Cycling

This service supports the services of soil development and primary production through the breakdown of dead plant parts (thus enriching the soil with organic matter) and the regeneration of mineral plant nutrients. Unlike non-drylands, where soil microorganisms are major players in nutrient cycling, invertebrate macro-decomposers are the most important in drylands, and their significance increases with aridity. The significance of microorganisms, such as microbes and fungi, declines with aridity due to their strict moisture dependence. In addition, the role of large herbivores in nutrient cycling in arid and hyper-arid areas is limited due to lack of drinking water sources. Therefore macro-decomposers such as termites, darkling beetles (*Tenebrionidae*), and other invertebrates (many of which are soil dwellers) that are less water-sensitive become important for nutrient cycling in drylands. These organisms ''prepare'' the litter for microbial activity and increase the soil infiltration capacity.

When arid drylands are used as rangelands, however, most of the primary production takes place through the livestock rather than the macro-decomposers. Due to the high metabolic needs of mammalian herbivores (compared with cold-blooded macro-decomposers), much of the organic carbon consumed by the livestock does not return to enrich the soil but is respired or extracted from the ecosystem as meat, hair, milk, and other animal products. In addition, while most of the excreta of macro-decomposers is deposited within the soil, much of the livestock waste on the surface is volatilized and removed from the soil nutrient pool. Thus, livestock have the potential to gradually deplete the rangeland nitrogen reserve and further exacerbate the nutrient limitations for primary production in arid and hyper-arid rangelands (Ayal et al. 2005). However, this depletion may be partially mitigated by biological nitrogen fixation and by dust deposition (Shachak and Lovett 1998).

When drylands are used for crops, tillage and excessive use of pesticides can reduce the role of soil-dwelling macro-decomposers. This, together with low root biomass of annual crops, can impair nutrient cycling and reduce soil organic carbon and its associated nutrients. Whereas wastes from subsistence cropping systems in drylands are locally recycled and only small proportions of crop products are exported, cropping systems that export products lose nutrients, hence their fertilizer inputs are high.

22.2.1.3 Primary Production

The net primary production for global drylands, based on satellite observations at an 8-kilometer and 10-day resolution from 1981 to 2000, was 703 ± 44 grams per square meter (Cao et al. 2004), significantly lower than the values for the MA's cultivated system (1,098 ± 48 grams) and the forest and woodland system (869 ± 34 grams). But averaging over all the dryland subtypes masks the effect of the aridity gradient.

The NPP of rangelands is mostly generated by the natural dryland plant community, in contrast to cultivated drylands, where the NPP is generated by agricultural crops and is often elevated due to two imported inputs—irrigation water and fertilizers. Whereas the NPP of monitored rangeland sites was 40–90% higher in non-dryland than in dryland countries, in the same years the yield of wheat in the croplands was more than three times greater in the non-dryland countries. (See Table 22.3.) Further analysis that includes wheat yield data for more countries and more years suggests a relative advantage of cultivation in non-drylands, but at the same time highlights the significance of socio-economic conditions, which apparently determine the amount of resources that can be mobilized for promoting the service of primary production. On average, industrial dryland countries produced wheat yields nearly as high as those produced by non-dryland developing countries. The yield of developing dryland countries was low compared with that of non-dryland countries; even among industrial countries, non-dryland ones did much better than dryland ones.

In order to distinguish between the relatively low NPP of drylands that is due to their inherent moisture deficit and the additional decline in primary production due to land degradation, rain use efficiency—the ratio of NPP to rainfall—can serve as a measure of primary production service condition (Le Houerou 1984; Le Houerou et al. 1988; Pickup 1996): it separates out reduced NPP due to reduced rainfall from declines in NPP driven by land degradation (Prince et al. 1998) and also separates increased NPP due to increased rainfall from the effects of added irrigation and fertilizer use.

Several global MA systems, drylands included, show a trend of NPP increase for the period 1981 to 2000 (Cao et al. 2004). The slope of the linear regression for drylands (regression coefficient = 5.2) does not significantly differ from those of cultivated and forest and woodland systems. However, high seasonal and interannual variations associated with climate variability occur within this trend on the global scale. In the drylands, this variation in NPP was negatively correlated with temperature and positively with precipitation (Cao et al. 2004)—two drivers that are expected to further affect dryland primary production through global anthropogenic climate change.

Table 22.3. Primary Production Expressed in NPP of Rangelands and Wheat Yield in Croplands. The first Table shows the relations between aboveground biomass in monitored rangelands[a] and total wheat yield in each country's croplands[b] for the same year,[c] with dryland countries compared with non-dryland ones. The second Table is a comparison of mean annual wheat yields for selected dryland countries (in which most of the area is categorized as dryland) and temperate non-dryland countries, industrial and developing.[b]

Area	Country (year NPP measured)	Mean Annual Rainfall in Rangeland	Mean Aboveground Biomass in Rangeland	Wheat Yield of Country
		(millimeters)	*(grams per sq. meter)*	*(tons per hectare)*
Dryland countries[d]	Mongolia (1990)	280	100	1.3
	Kazakhstan (1978, 1992)	351	83	1.3
Non-dryland countries[e]	Sweden (1968)	537	141	4.3
	United Kingdom (1972)	858	188	4.2

Area	Country	Mean of Yields 1994–2003	Mean Annual Yield for Country Categories
		(tons per hectare)	
Dryland, developing	Kazakhstan	0.9	1.3
	Morocco	1.2	
	Iran	1.8	
Dryland, industrial	Australia	1.8	2.0
	Israel	1.8	
	Spain	2.5	
Non-dryland, developing	Uruguay	2.2	2.2
	Belarus	2.3	
	Bangladesh	2.1	
Non-dryland, industrial	Japan	3.6	5.7
	Sweden	5.9	
	United Kingdom	7.7	

[a] Data from NPP in grasslands database of Oak Ridge National Laboratory: http://daac.ornl.gov/NPP/html_docs/npp_site.html.

[b] Data from FAOSTAT: http://apps.fao.org/faostat.

[c] Except for Kazakhstan, where latest NPP are from 1978 and first-wheat yield data are from 1992.

[d] NPP measured in cold temperate steppes of both countries (modified Bailey ecoregion classification).

[e] NPP measured in rangelands within humid temperate forests (modified Bailey ecoregion classification).

22.2.2 Regulating Services

22.2.2.1 Water Regulation

Water is the limiting resource for dryland biological productivity, and thus water regulation is of major significance. This regulation determines the allocation of rainfall for primary production (enrichment of soil moisture); for irrigation, livestock watering, and domestic uses (storage in groundwater and surface reservoirs); and for the occurrence of flashfloods and their associated damages (soil erosion, reduced groundwater recharge, excessive clay and silt loads in downstream water bodies). Vegetation cover modulates the water regulation service, and its efficiency in intercepting rainfall determines the fraction available for human use. In rangelands, vegetation removal and livestock trampling can increase soil water erosion through disintegration of the biological soil crust. Similarly, in croplands tillage increases the risk of sealing and crusting (Hoogmoed 1999). Water regulation may be augmented by landscape management (terraces, small dams, and so on), which slows down surface runoff, thereby promoting water infiltration and flood avoidance.

22.2.2.2 Climate Regulation

Dryland ecosystems regulate their own local climate to some extent as their vegetation cover determines the surface reflectance of solar radiation as well as water evaporation rates. Drylands are also involved in regulation of the global climate, through local carbon sequestration by their vegetation. Both these phenomena are described here in some detail.

22.2.2.2.1 Regulation of local climate through surface reflectance and evaporation

The vegetative cover of drylands depends on inputs of incident solar radiation and rainfall. Conversely, the outputs from drylands, the fraction of the incident radiation reflected by the surface (the albedo), and the fraction of soil water transpired and evaporated (evapotranspiration) drive atmospheric energy- and water-balance processes. The provision of this service becomes apparent when it has either been degraded, as in the Sahel drought (Xue and Dirmeyer 2004), or enhanced, as in the rainfall patterns in Israel (Steinberger and Gazit-Yaari 1996) and the U.S. Great Plains (Barnston and Schickedanz 1984). Vegetation cover in drylands can either reduce albedo, resulting in increased surface and near-surface temperatures, or shade the surface leading to low surface temperatures. Both contrasting effects may lead, through different paths, to an identical effect on rainfall. (See Figure 22.5.)

The overexploitation of vegetation (Xue and Dirmeyer 2004) and the removal of the crust by trampling in arid and semiarid drylands (Warren and Eldridge 2001) lead to increased albedo, lower surface temperatures, lower convective activity, and reduced rainfall (Charney et al. 1975). Albedo may also increase due to surface dust cover, a result of dust storms promoted by greater surface exposure after vegetation removal (Williams and Balling 1995). Thus, the conservation of vegetation cover promotes the service of local climate regulation directly through its effect on albedo and indirectly through arresting dust generation.

A degraded vegetation cover also leads to reduced shade, increased surface and near-surface temperatures, and a rapid decrease in soil moisture, which leads to reduced evaporation. This reduction in overall evaporation links to reduced rainfall generation—low evaporation, reduced water flux into the atmosphere, a decrease in the amount of energy used to evaporate or transpire

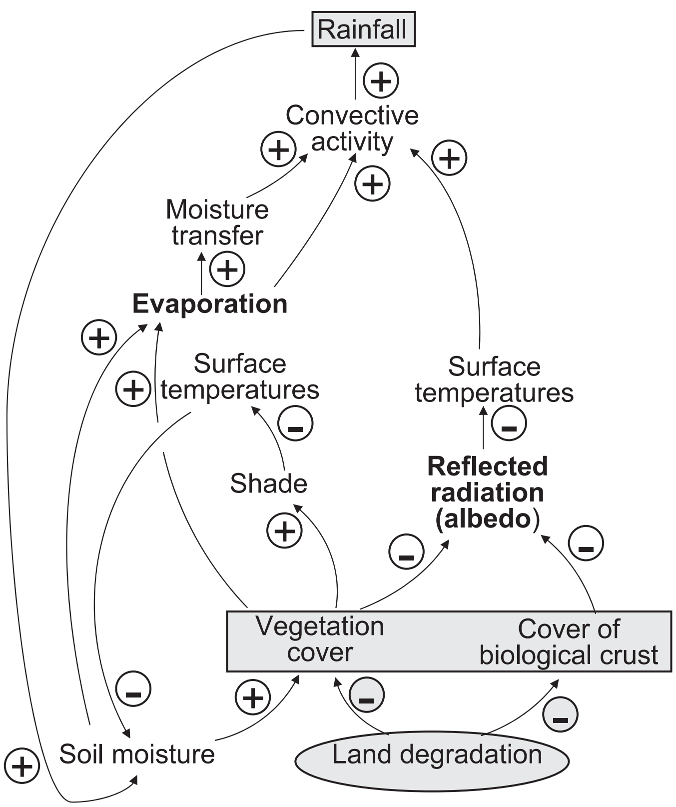


Figure 22.5. The Service of Climate Regulation in Drylands. The central grey box—the components of biodiversity involved in service provision—maintenance of soil moisture (bottom left) and modulation of rainfall (top). In bold—the major alternative/complementary function involved in the effect of live vegetation cover on rainfall; successive multiplication of signs along each trajectory generates an increase in rainfall (+) when service is ameliorated and a decrease in rainfall (–) when land is degraded. Land degradation (grey circle) degrades the service through affecting surface temperature; when surface temperatures increase along the albedo trajectory, it decreases along the evaporation trajectory; this trend is reversed when land is not degraded.

water, and reduced convective heating all combine to produce less rainfall (Williams and Balling 1995).

In climate modulated both by albedo and by evaporation, lower rainfall further reduces soil moisture and vegetation cover and induces further degradation in service provision. The prevalence of the climate regulation service is demonstrated by a few amelioration cases, such as the 10–25% increase in rainfall in the northern Negev of Israel attributed to reduced albedo resulting from controlled grazing, afforestation, and irrigated agriculture in a semiarid region (Otterman et al. 1990).

22.2.2.2.2 Regulation of global climate through carbon sequestration

Carbon sequestration (the uptake of atmospheric CO_2 by ecosystems and transformation into plant biomass) controls atmospheric CO_2 concentrations, which regulate the global climate through the "greenhouse effect." Part of the sequestered carbon is emitted back to the atmosphere through the respiration of plants and decomposers, but what is left—the live and the dead above- and belowground plant parts—constitutes the addition to the organic carbon reservoir. Some of the plant litter converts into recalcitrant humus, thereby enhancing the soil organic carbon pool and the formation of secondary carbonates through precipitation.

Plant biomass per unit area of drylands is low (about 6 kilograms per square meter) compared with many terrestrial ecosystems (about 10–18 kilograms). But the large surface area of drylands gives dryland carbon sequestration a global significance. Whereas organic carbon (in aboveground vegetation and soil) declines with aridity, inorganic soil carbon increases as aridity increases. (See Table 22.4.) Altogether, total dryland soil organic and inorganic carbon reserves comprise, respectively, 27% and 97% of the global soil organic and soil inorganic global carbon reserves.

22.2.2.3 Pollination and Seed Dispersal

Cases of tight associations between dryland plants and pollinators are known (such as Agava and its pollinator) (Arizaga et al. 2000), but the extent to which changes in land use in the drylands affect the pollination service and the dependence of dryland plant species on pollination has not been fully explored. Seeds of many dryland plant species are dispersed by fruit-eating birds, often prior to or after their cross-desert seasonal migration (for instance, in the Mediterranean basin) (Izhaki et al. 1991). Domestic and wild mammalian herbivores disperse seeds attached to their fur or through consuming them and then defecating, which promotes dispersal and enhances the chance of germination (as in African acacia trees) (Ward 2003). Livestock and other animals may also transfer seeds from improved pasture lands to neighboring non-managed rangelands (CGIAR 1997). Thus the services of pollination and seed dispersal are of significance, but assessment of their condition, importance, and trends requires more attention.

22.2.3 Provisioning Services

22.2.3.1 Provisions Derived from Biological Production

22.2.3.1.1 Food and fiber

The major dryland cereals and legumes (together with vegetable and fruits) constitute the main crops and basic food for 800 million farmers in drylands (CGIAR 1997). A large part of the dryland population depends on crop and livestock production as a livelihood and contributes significantly to the gross domestic product and trade. Livestock are raised mostly in rangelands or in agropastoral systems, and they constitute a major source of protein and income. Wool is provided by livestock and wild mammals

Table 22.4. Estimates of Dryland Carbon Reserves

	Biotic[a]	Soil Organic[b]	Soil Inorganic[c]	Totals	Share of Global
	(gigatons of carbon)				*(percent)*
Hyper-arid and arid	17	113	732	862	28
Semiarid and dry subhumid	66	318	184	568	18
Total in drylands	**83**	**431**	**916**	**1,430**	**46**
Global totals[d]	**576**	**1,583**	**946**	**3,104**	
	(percent)				
Share of global	14	27	97		

[a] Adapted from IPCC 2001.

[b] Means of data of Eswaran et al. 2000 and Allen-Diaz et al. 1996 adapted to the dryland subtype classification by J. Puigdefabregas.

[c] Adapted from Eswaran et al. 2000.

[d] Means of values assembled from various sources by Jonathan Adams, Oak Ridge National Laboratory, http://www.esd.ornl.gov/projects/qen/carbon2.html.

such as guanacos (*Lama guanicoe*) and vicunas (*Vicugna vicugna*) in South America (Fernandez and Busso 1997).

Fiber is produced by both croplands and rangelands. For instance, cotton (*Gossypium* spp.) and sisal (*Agave sisalana*) are widely cultivated, while timber and silk are produced on a smaller scale. Fiber, vegetable oil, vegetables, fruits, and nuts provisioned by dryland ecosystems are also exported to non-dryland countries. The food provision service of drylands may be impaired by soil erosion (in rain-fed croplands, a long dry season with no plant cover challenges the soil conservation service), salinization (in irrigated croplands with poor drainage), and nutrient depletion (the removal of commodity crops challenges the nutrient cycling service). (For more on the condition and trends of food provision, see Chapter 8.)

22.2.3.1.2 Woodfuel

Most woodfuel (the collective term for fuelwood, charcoal, and other wood-derived fuels) is provided by trees or bushes inhabiting natural dryland ecosystems that are also often used as range. Hence the exploitation of this service is often a trade-off with the provision of forage. Overexploitation for woodfuel harvesting impairs the soil conservation service, and it leads to soil erosion and hindered vegetation regeneration. This downward spiral of service degradation encourages reforestation and afforestation for woodfuel provisioning, using drought and salinity-tolerant tree species and strains (Sauerhaft et al. 1998). Fuelwood is used predominantly at the household level, for cooking and heating (Amous 1997), and may constitute a sizable proportion of the energy consumed in many dryland countries—for example, 57% in Senegal in 1999 (IEA 2001).

22.2.3.1.3 Biochemicals

Many species of dryland plants are used by dryland peoples for medicinal and cosmetic purposes and as spices, which highlights the significance of dryland plant biodiversity. However, excessive exploitation puts many of these species at risk of extinction and contributes to soil loss and consequent erosion. Attempts to cultivate such species in order to reduce the pressure on natural ecosystems often fail, because the production of the active compounds by these plants is rather low under stress-reduced cultivation regimes. The adaptations of dryland plants to varying and extreme conditions are often derived from unique biochemicals they produce that are the key to environmental tolerance or that act to deter herbivores and parasites. Further investigation into the generation and activity of these chemicals helps promote drought- and salinity resistance in cultivated crops (Wang et al. 2002) and can lead to development of novel medicines, such as anti-cancer (Haridas et al. 2001) and anti-malarial compounds (Golan-Goldhirsh et al. 2000). Biochemicals are also manufactured as part of dryland aquaculture, providing a source of alternative livelihoods, as described later in this chapter.

22.2.3.2 Freshwater Provisioning

The freshwater provisioning service is linked to supporting and regulating services—soil development (conservation and formation), water regulation, and, to a lesser extent, climate regulation. Vegetation cover and its structural diversity control much of the water provisioning service. This vegetation depends on water provisioning, but it is also instrumental in generating and maintaining the quality of the service. The resultant water is used to support rangeland and cropland vegetation and also livestock and domestic needs. The water provision service is also critical for maintaining wetlands within the drylands, to enable these ecosystems to provide a package of services of great significance in drylands.

However, the total renewable water supply from drylands is estimated to constitute only around 8% of the global renewable water supply (about 3.2 trillion cubic meters per year) (Vörösmarty et al. 2005), and only about 88% of this is accessible for human use. Thus, almost one third of the people in the world depend on only 8% of the global renewable water resources, which makes per capita availability in drylands just 1,300 cubic meters per year. It is substantially less than the average global availability and even lower than the 2,000 cubic meters regarded as a minimum by FAO (FAO 1993).

To mitigate this shortage, exacerbated by the large within- and between-years variability in rainfall, a variety of practices have been developed. From the least to the most technology-laden ones, these are:

- watershed management, including conservation and rehabilitation of degraded vegetation cover for generating and capturing surface runoff for deep storage in the soil (protecting it from evaporation) (Oweis 2000);

- floodwater recharge and construction of dams and weirs for minimizing impact of floods and water loss;
- irrigation, to circumvent the temporal variability in provision (often based on extraction from aquifers, with frequent overpumping leading to salinization)—however, the transportation of water from other ecosystems that may be severely affected and the salinization of the irrigated drylands often make this option unsustainable;
- mining of nonrenewable fossil aquifers (which are quite common in drylands), for cultivation that is otherwise impossible;
- treatment of wastewater, mainly from urban sources, and reusing it for irrigation—a promising practice provided that concerns about adverse impacts on human health, crops, soils, and groundwater can be overcome (Karajeh et al. 2000); and
- desalination of brackish water and seawater for all uses (which is safe and uses renewable sources but has a high energy demand and is relatively costly, and the accumulated brine often poses a salinization risk).

These interventions are critical for relieving pressure on the water systems of drylands.

22.2.4 Cultural Services

22.2.4.1 Cultural Identity and Diversity

Dryland peoples identify themselves with the use of their surrounding ecosystem and create their own unique ecosystem-inspired culture. (See Chapter 17.) Drylands have high cultural diversity, in keeping with the ecosystem diversity along the aridity gradient. One expression of this is that 24% of global languages are associated with the drylands' grassland, savanna, and shrubland biomes. Typical to drylands are the diverse nomadic cultures that have historically played a key role in development of dryland farming systems (Hillel 1991). Ecosystem functions and diversity generate cultural identity and diversity that in turn conserve ecosystem integrity and diversity. A negative feedback loop is therefore expected between land degradation and cultural degradation in drylands.

22.2.4.2 Cultural Landscapes and Heritage Values

The term ''cultural landscape'' is a socioeconomic expression of the biophysical features of ecosystems that mutually contribute to the development of a characteristic landscape, and it signifies a heritage value. (See Chapter 17.) In drylands, the heritage value can be nurtured either by landscapes that reflect the human striving for ''conquering the desert'' or by ones reflecting aspirations to ''live with the desert.'' Transformation of rural to urban ecosystems is an expression of changed livelihoods that modify the landscape and its cultural values and often degrade cultural heritages. Actions to conserve outstanding Cultural Heritage Sites that are cultural landscapes are under way (UNESCO 2004), and 21 such sites have been identified, of which 8 are in drylands.

22.2.4.3 Servicing Knowledge Systems

Dryland ecosystems also contribute to human culture through both formal (''scientific'') and traditional knowledge systems. (See Chapter 17.) Drylands have generated significant contributions to global environmental sciences. Arid Cultural Heritage Sites (such as Lake Turkana National Park and Ngorongo Conservation Area) have generated knowledge of paleo-environments and of human evolution (UNESCO 2004); studies of desert organisms have revealed adaptations to extreme environmental stresses (e.g., Schmidt-Nielsen 1980); and studies of desert ecology have inspired modern community and ecosystem ecology (e.g. Noy-Meir 1973, 1974; Rosenzweig 1995).

Dryland traditional knowledge has co-evolved with the cultural identity of dryland peoples and their environment and its natural resources and has generated many unique systems of water harvesting, cultivation practices, climate forecasting, and the use of dryland medicinal plants. The degradation of this knowledge in many cases has often led to adoption of unsustainable technologies. The exploration, conservation, and integration of dryland traditional knowledge with adapted technologies have been identified as priority actions by the Committee of Science and Technology of the UNCCD (ICCD 2000).

22.2.4.4 Spiritual Services

Many groves, tree species, and individual trees have spiritual significance to dryland peoples due to their relative rarity, high visibility in the landscape, and ability to provide shade. In ancient times in the Middle East and North Africa, spiritually significant social and religious activities took place under tree canopies. The sites of individual trees have been used for anointing rulers, hosting legal hearings, burial of community and religious dignitaries, and religious rituals, and individual trees themselves have become sacred and named after deities. For instance, the Hebrew names of *Quercus* and *Pistacia* (the dominant species of the eastern Mediterranean shrubland and woodland biomes)—*Alon* and *Ela*—derive from the words for God and Goddess respectively. Protected from grazing and cutting, these sacred trees have reached dimensions far larger than they ever attain in their natural climax community (Zohary 1973: 505–07). These sacred groves often conserve islands of indigenous ecosystems in a transformed landscape and contribute to a unique cultural landscape. Similar services are also provided by other drylands, such as the religious, ceremonial, and historical sites of Native Americans (Williams and Diebel 1996) and aboriginal Australians. (See Chapter 17.) In hyper-arid drylands, trees are far rarer, and indigenous nomadic people do not generally identify individual trees as sacred, although they can have spiritual values.

22.2.4.5 Aesthetic and Inspirational Services

There are outstanding literary and historical examples for inspiration generated by dryland landscapes (such as the Old and New Testaments). The stark contrast between inland wetlands and surrounding dryland areas, linked with the significance of water bodies to the well-being of dryland people, could have generated the association of the Mesopotamian marshlands with the Garden of Eden (Hamblin 1987). Dryland ecosystems are also a source of inspiration for non-dryland people. The 1950s Walt Disney film ''The Living Desert'' brought desert ecosystems and biodiversity to the attention of millions prior to the television era and was declared ''culturally significant'' in the year 2000 by the U.S. Library of Congress.

The popular conception of dryland peoples among non-dryland groups is one of human struggle against harsh natural conditions producing rich cultures nurtured by strong moral values, as well as naive romantic notions of life in the desert (Fernandez and Busso 1997). However, while the media has largely promoted the conservation of desert heritage in recent years, others have responded by trying to ''green'' desert areas or make them ''bloom,'' which has often resulted in an aesthetically appealing landscapes of oasis-like patches of agricultural land set in sharply contrasting surrounding desert (Safriel 1992)—but with a loss of dryland biodiversity.

22.2.4.6 Recreation and Tourism

Large, sparsely populated, low-pollution arid and hyper-arid areas provide attractive holiday destinations for many. There are significant constraints to dryland tourism, however, including the general remoteness and isolation, which increases the cost of travel; lack of recreation amenities and security; the harsh climate, which means residential facilities have high energy demands; the high water demand of tourists, which places already scarce water under extra pressure; and often a direct competition with other livelihoods over the use of natural resources and energy. These issues are being addressed through various approaches, including treatment and reuse of local wastewater (Oron 1996), construction and architectural solutions for passive cooling and heating (Etzion et al. 1999), and the use of the dryland-abundant solar energy as a power source (Faiman 1998).

Drylands are also attractive for cultural tourism associated with historical and religious sites, for coastal tourism (such as Mediterranean beaches), and for health-related tourism (such as the Dead Sea). Dryland biodiversity is also a major draw for ecotourism. Paradoxically, this is because most drylands are devoid of woodlands and dense high vegetation and hence free of obstructions to view wildlife. For instance, African savanna safaris are generally designed around a few ''charismatic'' large mammal species and mass seasonal migrations of large herbivores, and many tourists pack resorts along the route of the spectacular seasonal trans-Saharan bird migration. The significance of the dryland cultural service to tourism is demonstrated by Kenya, where 90% of tourists visit a game park (White et al. 2000). Finally, although ecotourism generates income for dryland peoples, it often causes habitat degradation, as described later (White et al. 2000).

22.2.5 Biodiversity and the Provision of Dryland Services

22.2.5.1 Dimensions, Structure, and Composition of Dryland Biodiversity

Species richness declines with decreasing primary productivity (Rosenzweig and Abramsky 1993) and vice versa (Tilman et al. 2001); hence dryland species richness should decrease with aridity. Indeed, the low number of flowering plant species in the hyper-arid subtype rapidly increases with reduced aridity (in agreement with an increase of between-''broad biome'' diversity) and peaks in the dry subhumid subtype. However, contrary to expectation, species diversity declines in non-dryland temperate humid areas. But as might be expected, it is nearly half that of tropical areas. (See Figure 22.6.) The significance of biodiversity for each of the major dryland biomes is discussed in this section. (See also Chapter 4.)

22.2.5.1.1 Deserts

Some 7,000 terrestrial amphibian, reptile, bird, and mammal species live in the desert biome. This covers 25% of global terrestrial fauna of these groups—22% of which also live in other biomes and 3% are found exclusively in deserts. For comparison, the richest terrestrial biome—tropical and sub-tropical moist broadleaf forests—supports around 70% of global terrestrial fauna, 28% of which are species endemic to that biome. Thus species richness of desert vertebrates is as much as a third of the most vertebrate-rich biome on Earth, signifying that desert biodiversity may be quite high in spite of harsh conditions. Because functional groups in deserts may each have only a few species, however, the redundancy in service provision is low, and human pressure may reduce it further (Huenneke 2001). Indeed, in spite of the remoteness

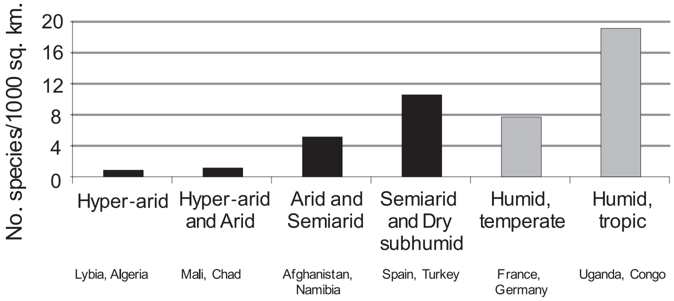


Figure 22.6. Number of Species of Flowering Plants in Selected Countries across the Aridity Gradient (per 1,000 sq. km). Each column represents a mean of two countries. Selected dryland countries are at least 95% dryland, either of one subtype, or two of roughly similar dimensions. Grey columns indicate non-dryland countries. (WRI 2004; CIA 2004)

and isolation, human impact on deserts in the form of settlements and infrastructure is mounting, and there has been a 6% loss of habitat between 1950 and 1990.

22.2.5.1.2 Grasslands

Grasslands (the temperate grasslands, savannas, and shrubland biome and the tropical and sub-tropical grasslands, savannas, and shrubland biome) occur in the semiarid and the dry subhumid dryland subtypes, and their biodiversity is richer than that of deserts (12% and 28% respectively of the global terrestrial vertebrate fauna are found in these two biomes). Much is known of the functioning of natural grasslands, many of which function as rangelands: plant diversity increases productivity (Tilman et al. 2001), and communities with many functional groups generate higher production than those with fewer groups. Yet within a grassland community a few abundant species account for a large fraction of grassland ecosystem functions, whereas the many rare species account for a small fraction of its functions (Sala et al. 1996; Solbrig et al. 1996).

It is important to note that the relationships between diversity and function are not linear, and a threshold in species richness has been identified below which ecosystem function declines and above which it does not change (Vitousek and Hooper 1993). Unfortunately, many natural grasslands have been transformed to croplands and most dryland cultivated lands are in these biomes. This transformation continues, and some 15% and 14% of the natural habitats in the semiarid and dry subhumid subtypes were transformed between 1950 and 1990.

22.2.5.1.3 Mediterranean forests, woodlands, and shrublands biome

The Mediterranean biome, comprising xeric woodlands and shrublands, occurs within semiarid and dry subhumid areas with a Mediterranean climate and is subjected to intensive human impact, especially in the Mediterranean basin, resulting in plant adaptations to clearing, grazing, fires, and drought (Davis et al. 1996). Species richness is high (Mooney et al. 2001), with the Mediterranean basin supporting 25,000 vascular plants (10% of global species), of which 60% are endemic; 10% of the global vertebrates species inhabit the Mediterranean biome.

The biome's biodiversity is threatened by its small geographic coverage, fragmentation, high human population density, abandonment of traditional practices, tourism, continued habitat conversion (2.5% of Mediterranean habitat was lost between 1950 and 1990), and invasive alien species (Mooney et al. 2001). Agriculture, grazing, and frequent fires have decreased dryland forests, converting many to grasslands (Solbrig et al. 1996). At the same time, the abandonment of rangelands in the Mediterranean basin has influenced secondary succession, which has eliminated open-habitat species and reduced diversity. Consequently, many endemic and rare species are currently restricted to protected areas surrounded by degraded or altered landscapes that act as a barrier to migration in response to environmental change.

22.2.5.2 The Role of Biodiversity in the Provision of Dryland Ecosystem Services

22.2.5.2.1 Involvement of biodiversity in packages of services

There are many dryland species that are directly involved in the provision of a range of ecosystem services. One such example is African acacia (Ashkenazi 1995), which provides for soil development and conservation (roots, canopy, and litter), forage (leaves and pods eaten by livestock), fuelwood (dead twigs), and food (edible gums). It is also involved in nutrient cycling (symbiosis with nitrogen-fixing bacteria) and generates cultural services (as described earlier). And it supports other biodiversity: a large number of animal species depend on it for shelter, shade, nest sites, and food. (Often this is of mutual benefit: wild and domestic mammals disperse the seeds, thus determining the spatial distribution of the species.)

The numerous dryland plant species of different growth forms jointly provide a package of services through their ground cover and structure, which provide the drylands' most important services of water regulation and soil conservation as well as forage and fuelwood provision and climate regulation. In arid and semiarid areas, clumps of bushes and annuals embedded in the matrix of a biological soil crust—which consists of an assemblage of several species of cyanobacteria (that provide the added benefit of nitrogen fixation), microalgae, lichens, and mosses—jointly generate soil conservation and water regulation (Shachak and Pickett 1997). In many arid and semiarid areas, this biodiversity of "vegetation cover" and biological soil crusts is linked to a diversity of arthropod species that process most of the living plant biomass, constituting the first link of nutrient cycling.

22.2.5.2.2 Involvement of dryland biodiversity in a single service

Individual species can also be important providers of a single service, such as individual dryland plant species serving as a "biogenetic resource" for cross-breeding and improvement of domesticated species to which they are genetically related. These species are either the progenitors of currently cultivated species that were domesticated millennia ago (Higgs and Jarman 1972; Harlan 1977) or they are relatives of those progenitors. It is estimated that 29–45% of the world's currently cultivated plants originated from drylands (FAO 1998). The progenitors and wild relatives of these originally dryland-cultivated plants (such as wheat, barley, rye, millet, cabbage, sorghum, olive, and cotton) are an important component of dryland biodiversity. However, only a few of them inhabit dryland protected areas and enjoy active in situ conservation, and much of their potentially useful genetic diversity has not yet been fully screened and may be under threat due to habitat loss (Volis et al. 2004).

Assemblages of dryland species can also jointly generate a single service, such as populations of large mammalian herbivores—from antelopes to elephants—providing for the cultural service of ecotourism, especially in the eastern and southern grasslands and savannas of Africa. These now occur mainly in protected areas and in ranches, and their management for the sustainable provision of this service is a scientific, legal, and sociopolitical challenge.

22.2.5.2.3 Trends in the involvement of dryland biodiversity in service provision

Evidence for human impacts on specific dryland biodiversity components that affect service provision is associated with livestock grazing. Livestock often impair the service of forage provision when prime forage species are replaced by non-palatable, often invasive species, leading to replacement of the grassland vegetation by encroaching bush or the reduction of the litter-decomposing termite populations, which impairs nutrient cycling, primary production, and carbon sequestration (Zeidler et al. 2002; Whitford and Parker 1989). Human-induced climate change may also alter the primary production and other dryland services, since plants of the three photosynthetic pathways (C3, CAM, or C4) co-occur in drylands and are expected to respond differently to climate change and to elevated atmospheric CO_2 (Huenneke and Noble 1996).

The loss of biodiversity from drylands is not likely to affect all services uniformly. Rather, primary production and the provisioning services derived from it, as well as water provision, will be more resilient than recreation and ecotourism. (See MA *Scenarios,* Chapter 10.) This is based on the observation that ecosystem services performed by top predators will be lost before those performed by decomposers. The service of supporting biodiversity (by generating and maintaining habitats of required value and ample size) is expected to be degraded faster than the service of provisioning biological products.

The direct threats to the service of supporting biodiversity include not only land degradation but also habitat loss and fragmentation, competition from invasive alien species, poaching, and the illegal trade in biodiversity products. Indirect threats include the losses of the drylands-specific "keystone" species (Paine 1966) and "ecosystem engineer" species (which modify the dryland environment for the benefit of other species) (Jones et al. 1994). Finally, not only losses but also addition of species may impair service provision. For example, Eucalyptus tree species introduced to southern Africa have invaded entire catchments of natural vegetation, causing large-scale changes in water balance and depriving water from lower catchments (Van Wilgen et al. 1998).

22.2.6 Integration: Services, Biodiversity, Livelihoods, and Aridity

Figure 22.7 highlights the interrelationships between major ecosystem services, between services and biodiversity, and between services and the livelihoods they support across the aridity gradient. Water regulation is the overarching dryland service, and its effect cascades through the interrelated supporting services of soil conservation and nutrient cycling to primary production and water provision. Whereas the service of water provision is the most significant one supporting the farming livelihoods prevailing in the dry subhumid and the semiarid subtypes, the primary production-dependent service of forage provision is the most significant service for pastoralists. Other primary production-dependent services are the provision of biochemicals and fuelwood, which serve both farmers and pastoralists but also generate independent, alternative livelihoods based on medicinal plants and biomass-generated energy. Forage, fuelwood, and biochemicals are goods produced by a diversity of plant species, which are both a product and a generator of primary production.

The structural diversity of the vegetation cover is the most significant dryland biodiversity component, since it is instrumen-

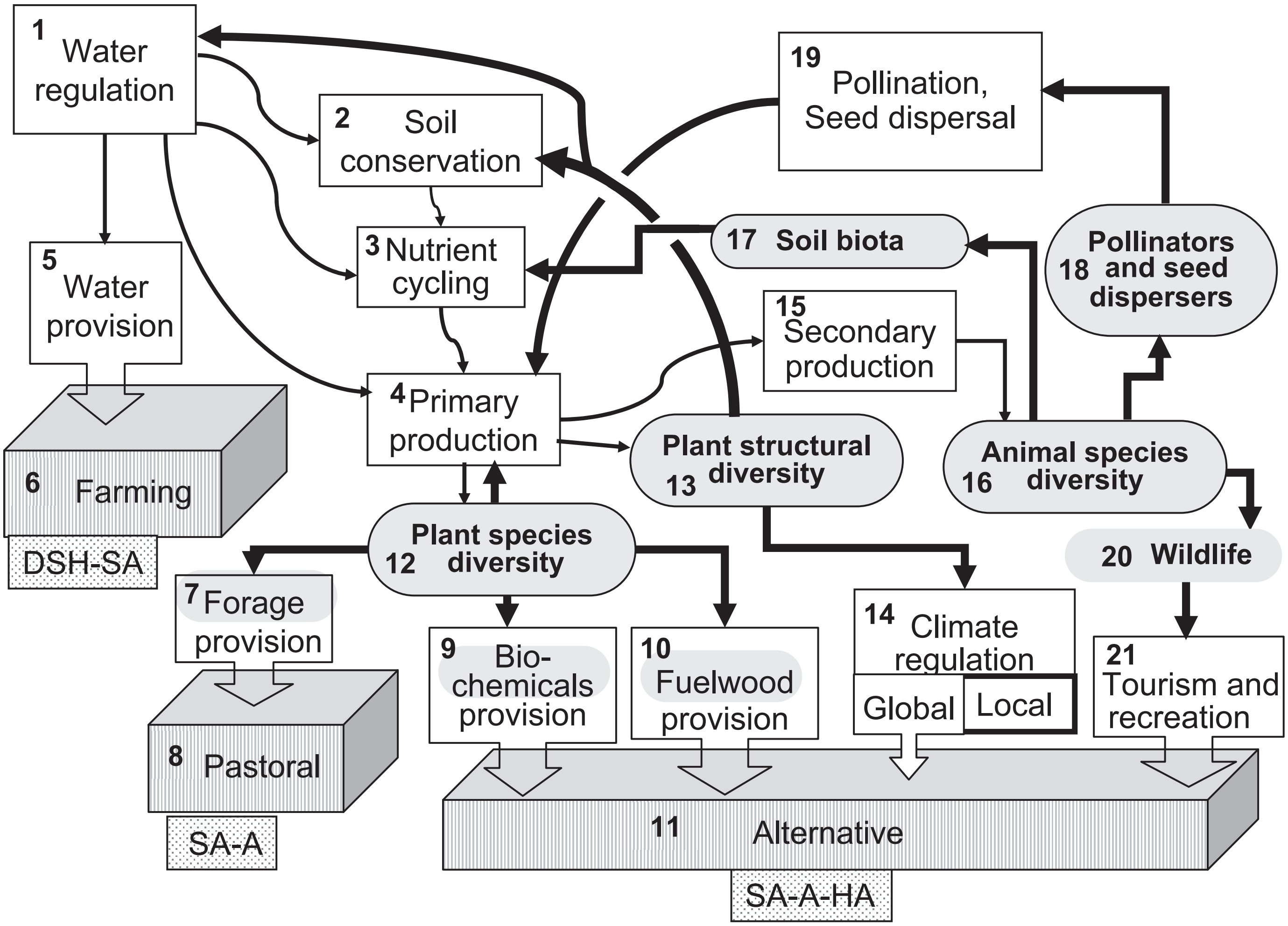


Figure 22.7. Linkages between Services, Biodiversity, Livelihoods, and Dryland Subtypes. Rectangular boxes—services; rounded boxes—components of biodiversity; three-dimensional boxes—livelihoods; dotted rectangles—dryland subtypes: DSH, SA, A, and HA—dry subhumid, semiarid, arid, and hyper-arid, respectively; thin arrows—direct effects of services; thick arrows—involvement of biodiversity. Follow the boxes in the order of their numbers, which streamlines with the text in section 22.2.6.

tal in the water regulation service. Plant structural diversity is also involved in soil conservation and water regulation, as well as in climate regulation. Plant biodiversity supports animal biodiversity since secondary production directly depends on primary production, and the diversity of animals is regulated by plant structural diversity through provisions of a diversity of habitats and shelters for animals. Critical components of dryland animal biodiversity are the diversity of surface and soil decomposers (supporting nutrient cycling) and larger wildlife (supporting the cultural service of tourism and recreation).

While pastoralists control the exploitation of rangeland services through managing stocking rates and livestock species composition, cropland cultivation constitutes more-intensive management (tillage, irrigation, and so on) that often taxes biodiversity and does not always generate the expected increased provision of services. While cultivation intends to increase service provision, it sometimes impairs the provision of all three supporting services and affects the water regulation service. One way out may then be turning to alternative livelihoods, as described later. Whereas the prevalence of traditional livelihoods decreases with aridity, existing and emerging alternative livelihoods, each supported by a different service, are expected to augment or even replace traditional livelihoods and hence may increase with aridity.

22.3 Condition and Trends in Dryland Systems

This section assesses the issue of greatest concern—land degradation in the drylands. The condition of service provision to each of the three major dryland livelihoods—pastoral, farming, and "alternative"—is also considered. There is an overarching trend toward further water scarcity, exacerbated by aridity, with reductions of 11%, 13%, 15%, and 18% in the annual per capita supplies of surface runoff augmented by flows from outside each subtype expected for the period 2000–10 in the dry subhumid, semiarid, arid, and hyper-arid subtypes respectively (Vörösmarty et al. 2005).

22.3.1 Land Degradation

22.3.1.1 How Much of the Drylands Is Degraded?

The critical drivers of change in drylands are those leading to a degraded condition of primary production. The process by which this service is degraded, compared with its provision prior to human pressures, is called "land degradation." Land degradation in drylands is termed "desertification" and can be viewed as an expression of a persistent decline in the ability of a dryland ecosystem to provide goods and services associated with primary productivity. Thus, an indicator of the condition of drylands is the degree of "land degradation" or desertification. (See Box 22.2.)

Despite the global importance of desertification, the available data on the extent of land degradation in drylands are limited. To date, there are only two studies with global coverage and both have considerable weakness. But in the absence of anything better they have been widely used as a basis for national, regional, and global environmental assessments.

The best known study is the Global Assessment of Soil Degradation (Oldeman et al. 1991). Intended as an exploratory study, it did not include any remote sensing or field measurements and was based on expert opinion only. A more detailed assessment—Soil Degradation in South and Southeast Asia—also relied heavily on expert opinion (Middleton and Thomas 1997). A more thorough, measurement-based global follow-up has not been conducted. Additionally, these studies only considered soil degradation and placed a strong emphasis on erosion, which is extremely hard to measure. These studies also formed the basis of the data and maps presented in the *World Atlas of Desertification* (Middleton and Thomas 1997). A reported 20% of the world's drylands (excluding hyper-arid areas) suffer from soil degradation, mainly caused by water and wind erosion, which is presented as the prime cause for 87% of the degraded land (Middleton and Thomas 1997; Oldeman and Van Lynden 1997; Lal 2001a).

The second study with global coverage is that of Dregne and Chou (1992), which covers both soil and vegetation degradation. It was based on secondary sources, which they qualified as follows: "The information base upon which the estimates in this report were made is poor. Anecdotal accounts, research reports, travelers' descriptions, personal opinions, and local experience provided most of the evidence for the various estimates." This study reported that some 70% of the world's drylands (excluding hyper-arid areas) were suffering from desertification (soil plus vegetation degradation).

Recognizing the lack of adequate data on land degradation, the MA commissioned a desk study (Lepers 2003; Lepers et al. 2005) that compiled more-detailed (and sometimes overlapping) regional data sets derived from literature review, erosion models, field assessments, and remote sensing. This study found less alarming levels of land degradation (soil plus vegetation) in the drylands (including hyper-arid regions). Achieving only partial coverage, and in some areas relying on a single data set, it estimated that only 10% of global drylands were degraded. This includes 17% of drylands in Asia degraded, but in the Sahel region in Africa—an area reported as highly degraded by the Global Assessment (Oldeman et al. 1991) and by Dregne and Chou (1992)—few localities with degradation were found. The global number of people who live on lands determined by Lepers (2003) as degraded is about 20 million, much lower than the 117.5 million people living on lands defined as degraded by GLASOD.

All these assessments have their weaknesses. Due to the poor quality of the information sources, Dregne and Chou's numbers are most likely an overestimation. For example, they report figures as high as 80–90% for both rangeland and cropland degradation in the drylands of individual countries (such as Kenya and Algeria). Such high levels are hard to reconcile with data from the FAOSTAT database, which show that over the last 40 years the average per hectare yields of major cereals cultivated in Kenya and Algeria have increased 400–600 kilograms. Most likely the true level of degradation lies somewhere between the figures reported by GLASOD and those of Lepers (2003). This implies that there is *medium certainty* that some 10–20% of the drylands are suffering from one or more forms of land degradation. And the livelihoods of millions of people, whether they actually reside in the degraded areas or just depend on them, are affected by this degradation, including a large portion of the poor in drylands.

Even if the most conservative estimate of 10% is used, however, a total land area of over 6 million square kilometers is affected by desertification, an area roughly twice the size of India, the seventh largest country in the world. It should be borne in mind, however, that to determine the true extent of degradation and identify precisely where the problems occur will require a more in-depth follow-up to the three exploratory studies discussed here, combining analysis of satellite data with extensive ground-truthing. (See Box 22.3.) The ongoing Land Degradation Assessment in Drylands project, an international U.N. initiative to assess the status of land degradation in the drylands, is an appropriate response to this daring challenge.

22.3.1.2 Land Use, Land Degradation, and the Aridity Gradient

Human populations and land uses change across the aridity gradient. The best way to express the effect of the gradient on dryland peoples and their land use is through estimating the amount of water per capita available in each dryland subtype. As expected,

BOX 22.2

Desertification as Land Degradation

The UNCCD defines desertification as land degradation in the drylands ("'Desertification' means land degradation in arid, semi-arid and dry sub-humid areas"), yet the two terms are often used as if they are distinct (for example, "Land degradation and desertification in desert margins," in Reich et al. 2000). The UNCCD also defines "land" by its primary productivity service ("'land' means the terrestrial bio-productive system") and "land degradation" as an implicit loss of provision of this service ("'land degradation' means reduction or loss . . . of the biological or economic productivity").

The definition of biological productivity and economic benefit depends on users' priorities. Transforming woodland to cropland may decrease biological productivity and degrade the economic benefit of firewood production, for example, but increase the economic benefit of food production. With respect to the mechanisms of land degradation, changes in the properties of the land (soil, water, vegetation) do not correspond linearly to changes in productivity. Loss of productivity can also be attributed to non-human-induced factors such as rainfall variability and human factors such as low labor input. Thus a range of interacting variables that affect productivity should be addressed in order to assess land degradation objectively and unambiguously.

Commonly considered degradation processes are vegetation degradation, water and wind erosion, salinization, soil compaction and crusting, and soil nutrient depletion. Pollution, acidification, alkalization, and waterlogging are often important locally (Oldeman 1994; Lal 2001a; Dregne 2002). Field experiments, field measurements, field observations, remote sensing, and computer modeling are carried out to study these processes. The higher the aggregation level in each of these study approaches, the more problematic each of the methods becomes, either because of upscaling issues or because of questionable extrapolations and generalizations (Stocking 1987; Scoones and Toulmin 1998; Matthews 2000; Mazzucato and Niemeijer 2000b; Lal 2001a; Warren et al. 2001; Dregne 2002).

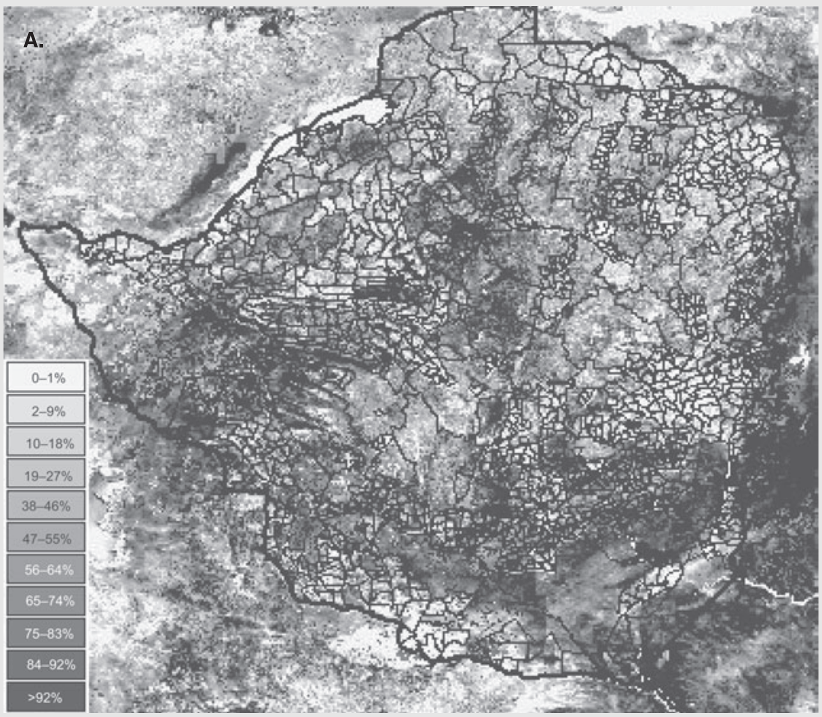
BOX 22.3

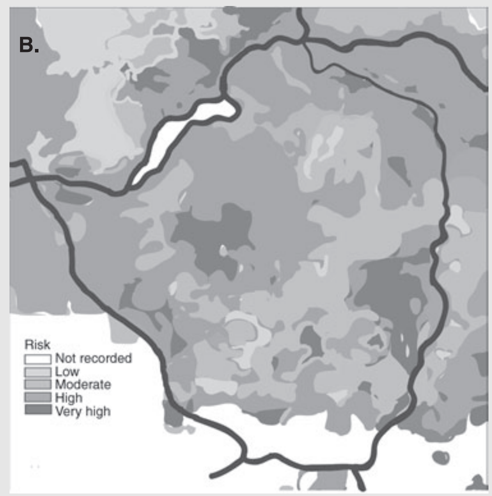
Satellite Remote Sensing and Desertification

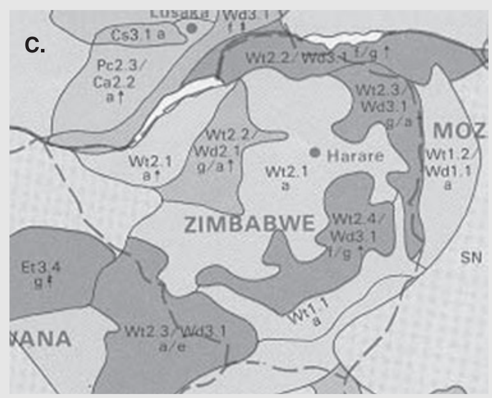
Attempts to map desertification are often unsatisfactory. A key requirement for mapping desertification is that the term is defined in a way that leads to objective and practical measurement criteria. Earth-observing instruments carried on satellites (Prince 1999) routinely map land surface variables that respond to desertification, such as albedo, surface temperature, and vegetation cover—all with appropriate spatial resolution and regular global coverage. Unfortunately, factors that are not related to desertification also affect these properties; for example, AVHRR data have been used to monitor interannual changes of vegetation cover in dry regions (Tucker et al. 1991; Nicholson et al. 1998), but these are frequently caused by rainfall fluctuations, not desertification (Prince 2002).

Persistent reduction in productivity is an expression of desertification (Prince 2002), and it is routinely measured using satellite derived vegetation indices (such as the normalized difference vegetation index). NDVI measures the amount of solar radiation absorbed by the vegetation, from which simple methods can be used to estimate net primary production (Prince 1991). Prince (2002) has suggested that a persistent reduction of NPP below its potential, a reduction that does not disappear during wetter periods, could identify areas that may be experiencing desertification, a measure that is both practical and based on the underlying mechanism.

In the absence of human impacts the NPP is set by climate, soils, vegetation productive capacity, and growing season weather conditions.







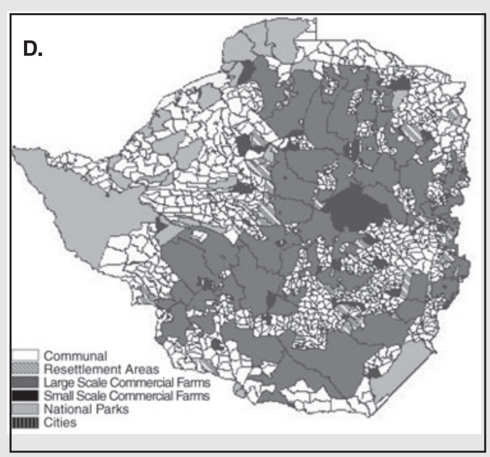


Figure A. Maps of Desertification in Zimbabwe. Map A. Local NPP Scaling (LNS) map. Gray scale indicates the LNS value, from white (LNS = 0–1%, i.e., desertified) to dark gray (LNS > 92%, near potential productivity). Note correspondence with fourth level administrative boundaries (See Map D) and the correlation of low LNS with the overcrowded communal lands that are known to be seriously degraded. LNS was calculated using NPP estimated from SPOT VEGETATION 1 sq.km. satellite NDVI data, 1998–2002. Map B. Desertification Risk Map (Eswaran and Reich 2003). This map is a combination of the NRCS global desertification map and a global population density map. Note that the spatial resolution is much less than in Map A and the values of "risk" unfortunately cannot be validated. Map C. Zimbabwe, excerpted from the Global Assessment of Soil Degradation (GLASOD) map (Oldeman et al. 1990). Letter symbols: Wt-loss of topsoil by water erosion; Wd-terrain deformation/mass movement by water erosion; Pc-physical deterioration by compaction/crusting; f-deforestation and removal of the natural vegetation; g-overgrazing; a-agricultural activities; e-overexploitation of vegetation for domestic use. Key to numeric symbols: x.y, where x indicates degree of degradation (1-light; 2-moderate; 3-strong; 4-extreme) and y indicates percentage of mapping unit affected (1-less than 5%; 2–5 to 10%; 3–10 to 25%; 4-more than 50%); ↑-medium rate. As in Map B, the resolution is low and hard to validate on the ground. Map D. Zimbabwe land tenure classes. Note the correspondence of communal lands (white) and commercial farms (dark) to low and high LNS in Map A, respectively.

BOX 22.3
continued

Unfortunately these cannot be measured at an adequate resolution in most desertification-prone regions. An alternative, however, is to use the NPP maps themselves and to employ a statistical method to estimate the NPP of non- or less-degraded areas (Prince 2004). A large region can be classified into homogeneous areas that consist of land having the same climate, soils, and vegetation structure, in which only the human impacts vary. The NPP of the grid cells (pixels) measured by the satellite instrument that fall in each area can be normalized, and the highest NPP values can be used to estimate the potential NPP. All other pixels in that area can then be represented as a percentage of the potential NPP for the same area.

In the example (Figure A), Zimbabwe was stratified into regions in which the principal natural characteristics and existing vegetation types are uniform, based on maps of land cover and rainfall. The regions varied in area but were typically 1,000–10,000 square kilometers. Following the earlier outlined procedure, a percentage reduction from potential NPP was calculated for each pixel. This method is known as the Local NPP scaling method. Other methods are possible, based on closer study of desertification and NPP; under development is Local NPP Ranking, which depends on the recent observation (Wessels et al. 2004) that the NPP of some long overused land in South Africa differs from non-degraded land by a constant proportion. (See Figure B.)

Satellite data are able to detect changes in the productivity of the vegetation; hence, future synoptic primary production mapping is likely to identify regions with persistent reductions in NPP, indicating changes that need closer investigation and ground verification. The definition of desertification used here is land that has suffered a shift to a reduced NPP, even when rainfall is not limiting or is equally limiting on desertified and non-desertified land. This newly emerging procedure detects shifts to reduced NPP relative to the potential NPP. Its validity, utility, and practicality, however, have yet to be demonstrated for global-scale desertification monitoring.

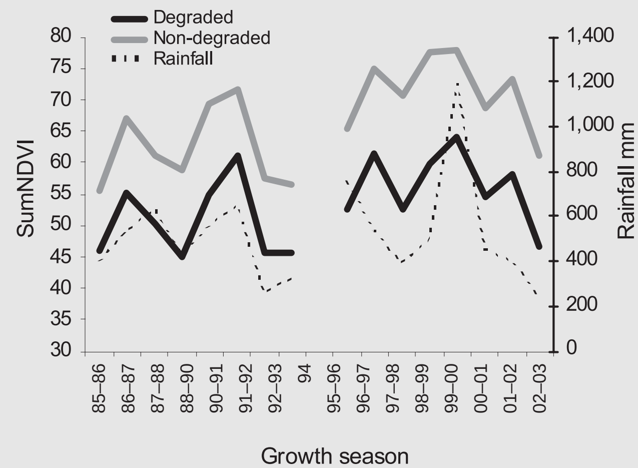


Figure B. Interannual Variation in Net Primary Production of Neighboring Non-degraded and Degraded Areas within the Same Land Potential Class in South Africa. Primary production was estimated using satellite measurements of the Normalized Difference Vegetation Index summed over the growing season. SNDVI is generally positively related to average rainfall. The SNDVI in the degraded areas relative to the non-degraded was reduced by a near constant proportion. Also, in wetter years, the SNDVI in degraded sites exceeded that of non-degraded sites in dry years (Wessels et al. 2004)

human population decreases with aridity. (See Figure 22.8.) It is also expected that annual runoff (as well as surface flows from non-drylands into drylands) will decrease with aridity. However, water supply per person also decreases with aridity (Vörösmarty et al. 2005 Figure 20.8b). Namely, the rate of decrease in water supply with aridity is greater than the rate of decline of the human population with aridity. This suggests that as aridity increases, the ability of the ecosystem to provide the water required by the local population decreases. Thus not only does water supply become low with increased aridity, but there is a mismatch between the supply and the number of people, and the increased aridity-linked gap between supply and demand creates water scarcity. This provides added insight into the decline of human population, cropping, and urbanization with aridity.

However, the most pronounced decrease of population and cropland occur from the semiarid to arid drylands. This may be partly due to the larger spatial extent of the global semiarid dryland compared with other subtypes. On the other hand, use of rangeland peaks in the arid subtype; drier areas are not attractive to livestock, and in areas with higher productivity pastoralism gives way to farming. Thus other than urban areas (2%), most of the world's dryland area is divided by land cover and land use between rangelands (65%) and croplands (25%), although some of these are actually interwoven rangeland and croplands, supporting a mixed, integrated agropastoral livelihood. Both pastoralism and farming and their combination are often implicated as drivers of degradation.

It is likely that the sensitivity of dryland ecosystems to human impact increases with aridity—a little human pressure may not destabilize a dry subhumid ecosystem, but it will degrade the productivity of a semiarid one. And even less pressure will destabilize an arid dryland, in which the capacity of the inherent resilience mechanisms is lower than in less arid drylands. On the other hand, human population pressures and the associated pressure of livestock decrease with aridity, as Figure 22.8 indicates.

Much of the drylands have traditionally been used as rangelands, but with the increase in dryland human populations, a gradual transformation of rangelands to croplands has occurred. Although a large proportion of the hyper-arid dryland is used as range, the value of this range is low and so is livestock density. In the dry-subhumid, the extent of rangeland is low since much of it has been converted to cropland, but grazing pressure is reduced, possibly due to the higher potential profitability of croplands. (Note that human density is greater than livestock density only in this subtype).

Unlike sensitivity to human pressure, which increases with aridity, and human pressure, which decreases with aridity (from 70.7 persons per square kilometer in the dry subhumid to 10.4 persons in the hyper-arid drylands), land degradation—at least as presented by GLASOD—follows a hump-shaped curve, with a maximum in the arid and semiarid drylands. (See Figure 22.9.)

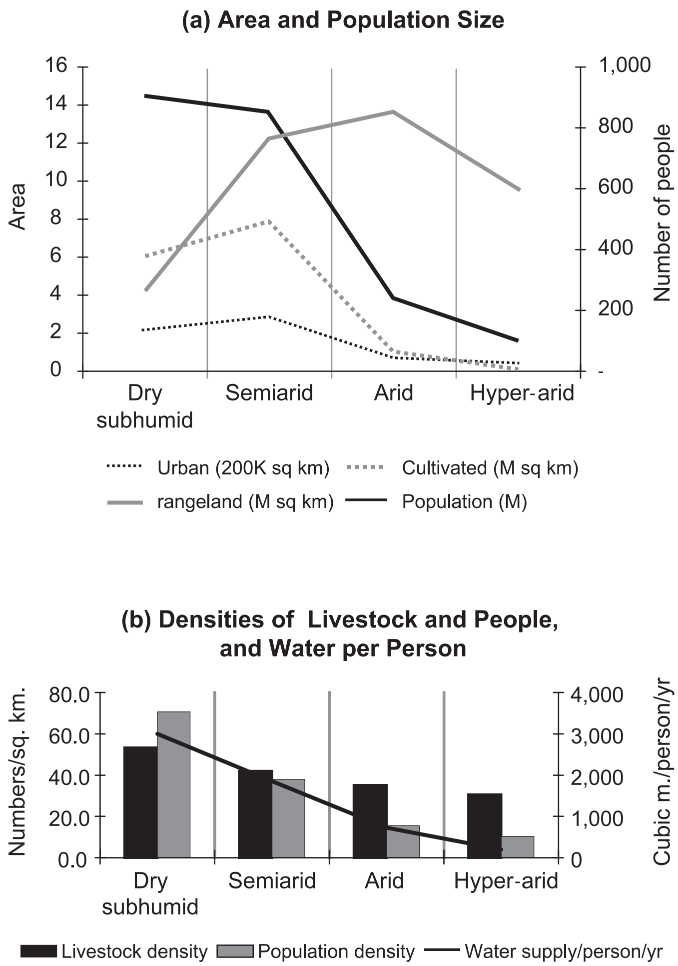


Figure 22.8. Land Use, Human and Livestock Populations, and Water Availability across the Aridity Gradient. Land use and human population size (a) note the different scale for size of urban area). Rangeland figures are based on available data on rangelands in drylands of developing countries (Reid et al. 2004; Thornton et al. 2002) and estimates of rangeland areas in the remaining drylands based on the assumption of uniformity in the rangeland's share of each dryland subtype. Human population densities (b) (CIESIN 2004) and livestock averages of mean densities for developing countries only (Thornton et al. 2002). Line-water supply per person: total runoff generated by a dryland subtype and augmented by inflows (e.g., rivers) from other subtypes or other MA systems, divided by the number of people living in the subtype but taking into account the position of humans along river corridors, in areas of higher (or lower) runoff, etc. Thus, the points represent population-weighted means in terms of the flows per person based on the populations served. (Fekete et al. 2002; Vörösmarty et al. 2005)

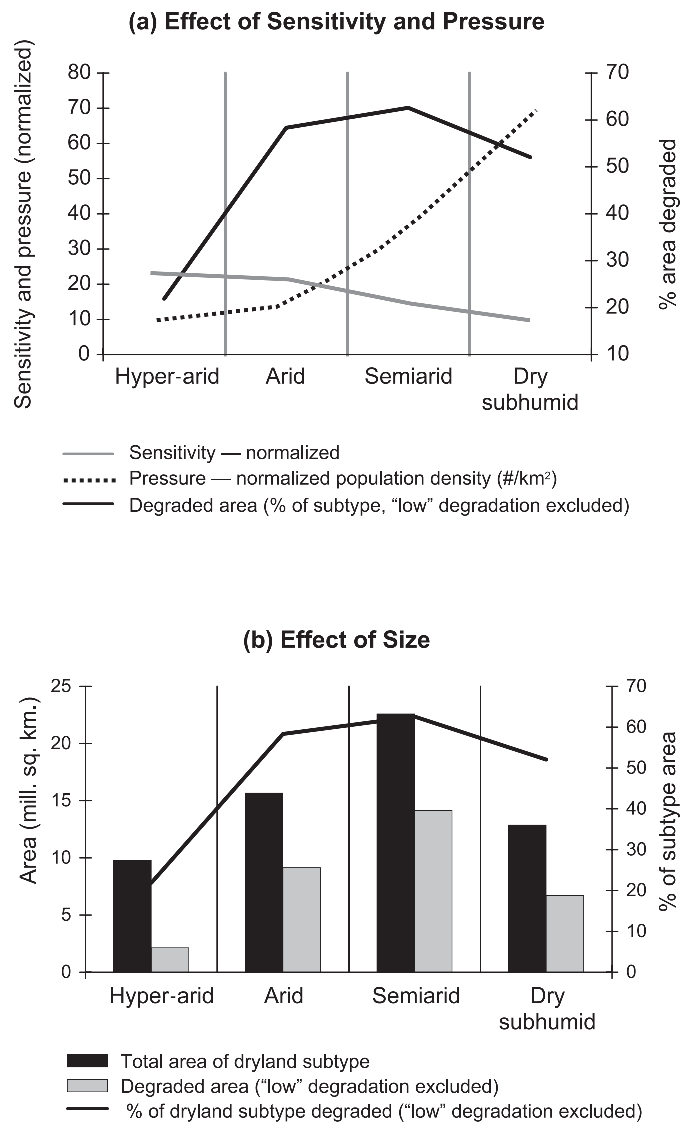


Figure 22.9. Dryland Degradation across the Aridity Gradient. Effect of aridity (a) and effect of subtype global size (b). Sensitivity to human pressure is 1-median of Aridity Index; sensitivity and pressure are normalized, lowest values set to 10; land degradation is from GLASOD (1990), excluding "low" degradation category, which may be hard to distinguish from "no degradation." (Population density data from CIESIN 2004)

This distribution of land degradation fits a model in which degradation is a function of the product of sensitivity and pressure: when sensitivity is linear but pressure increases exponentially with aridity, the degradation curve is biased to the lower aridity section. The peak is closer to the semiarid than to the arid section of the gradient, and the value for the dry-subhumid subtype is higher than that for the hyper-arid subtype.

These relationships between degradation, sensitivity, and pressure emerge when sensitivity is expressed as an inverse function of aridity and when pressure is a function of population density. The peak in percentage degradation coincides with the peak in global dryland size, however—the semiarid dryland has the largest global extent and the highest degradation percentage. Thus the most extensive degradation occurs in the central section of Figure 22.9, which also happens to be the most extensive global dryland subtype—the semiarid drylands. This subtype and the arid ecosystems subtype—and especially the transition between the two—have medium sensitivity and are driven by a medium anthropogenic pressure, a combination that generates the highest vulnerability and may result in desertification.

22.3.2 Condition and Trends of Rangelands

Dryland rangelands support approximately 50% of the world's livestock and also provide forage for wildlife (Allen-Diaz et al. 1996). Global data on the extent of rangelands within drylands are available only for developing countries. Based on Reid et al. (2004), rangelands occupy 69% of the drylands of the developing world. Their greatest extent is in the semiarid subtype (14 million square kilometers) and the proportion of dryland they occupy increases with aridity—from 34% in the dry-subhumid subtype to 54% in the semiarid, 87% in the arid, and up to 97% in the hyper-arid subtype. Data on livestock numbers in drylands are available only for industrial countries, where densities are calculated according to land units, mostly administrative units (Thornton et al. 2002).

Combining data from Reid et al. (2004) and Thornton et al. (2002), it is possible to estimate livestock densities per dryland sub-type as well as for just the rangelands within those dryland subtypes. Livestock densities for rangelands within the subhumid, semiarid, and arid subtypes are relatively uniform (32–35 animals per square kilometer of rangeland) but drop to a low 15 animals in rangelands within the hyper-arid subtype. The combined densities of sheep, goats, and cattle per dryland subtype area unit steadily decline with aridity (53 animals per square kilometer in dry subhumid to 31 animals in the hyper-arid subtype). The number of animals per unit area of a dryland subtype is greater than those per rangeland unit area, especially in the hyper-arid and the dry subhumid subtypes. This suggests that many animals (especially cattle) do not range freely in the dry subhumid areas, probably due to competition with cultivation, and are kept in fertile areas within the low-productivity hyper-arid rangelands, such as desert oases and along desert rivers—areas not classified as pastures.

22.3.2.1 Semiarid Rangelands

Most of the arid drylands are used as rangeland, but during the second half of the nineteenth century large-scale commercial stockbreeding spread over the semiarid drylands of North and South America, South Africa, and Australia. Both the type of herbivore and the grazing management applied (including fire prevention) were new to these semiarid ecosystems. The resulting disturbance created a ''transition trigger'' that, combined with drought events, led to a progressive dominance of shrubs over grass (Scholes and Hall 1996), a process that may have been facilitated by increasing atmospheric CO_2 levels that differentially favored C3 shrubs over C4 grasses (Archer et al. 1995; Biggs et al. 2002). The transition of grasslands to shrublands (see Figure 22.10) is widely reported around the world. This transition generated a mosaic of plant clumps within a ''matrix'' devoid of much vegetation, which encourages surface runoff, topsoil erosion, and exposure of rocky surfaces (Abrahams et al. 1995; Safriel 1999).

Eventually, the degradation due to overstocking and range mismanagement led to a decline in livestock numbers after peaking at the beginning of the twentieth century—40% loss in New Mexico (Fredrickson et al. 1998), 45% loss in western New South Wales (Mitchell 1991) and 60% loss in Prince Albert District *karoo* (Milton and Dean 1996)—and to substitution of sheep for cows, as they are better adapted to graze on tussock grasses.

22.3.2.2 Dry Subhumid Rangelands

Two opposing trends in the global area of temperate grasslands are evident: expansion at the expense of woodland and contraction due to the encroachment of cultivation. Examples of the first process are the expansion at the expense of forests in North America following European colonization (Walter 1968) and, in the Caucasus, a 27% increase in the last century at the expense of oak forest (Krenke et al. 1991). Grasslands' natural primary production generates high biomass of many species of herbaceous forage plants, and the second transformation involved redirecting the grasslands' primary production service for maximizing the production of seeds of a few species of domesticated grasses. The conversion of grasslands to grain crops occurred some millennia ago in the loess region of north-central China, in the last three centuries in the Russian Federation (162 million hectares), and during the last century in the United States (121 million hectares) (Ramankutty and Foley 1999). However, though temperate grasslands are fairly resilient to grazing, fire, and tillage that maintains the topsoil (Lavrenko and Karamysheva 1992), more-intensive cultivation dramatically reduces the provision of supporting services.

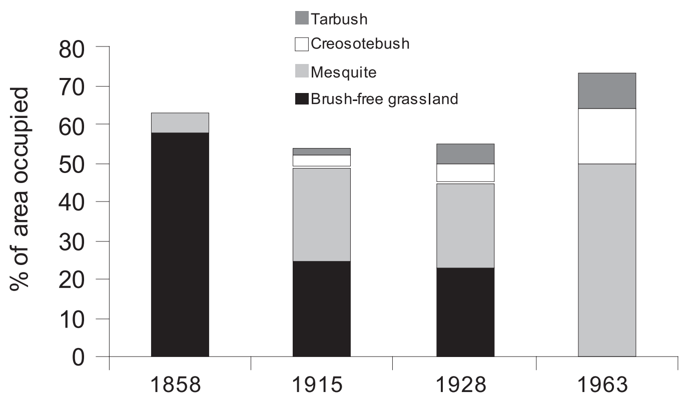


Figure 22.10. Transition of Grassland to Shrubland due to Stockbreeding in Semiarid Rangelands. The figure shows the percent of area occupied by dense (≧55% of perennial plant composition) brush cover of the major shrubs at various dates on the Jornada Plain of the Jornada Experimental Range in New Mexico. (USDA-ARS 2003)

Population increase is the main driver of the tropical savanna-cropland transition, and the dry subhumid African savannas north of the equator represent barely 14% of the original cover and are retreating at an estimated rate of 0.15% (or 340 square kilometers) per year (WRI 2004). Where human population in tropical savanna is relatively low but soil fertility high, fire is excluded, and grazing is heavy, however, range degradation occurs due to topsoil erosion driven by bush encroachment (Scholes and Hall 1996).

Rangelands of the Mediterranean xerophytic shrubland and woodland are relatively resilient to human impact. The Mediterranean landscape is of a fine-grained spatial heterogeneity, with mosaics of cultivated fields and stands of different vegetation succession stages that result from the combined effect of fire, grazing, and cropping. This dynamic mosaic of land uses maintains the soil conservation service, though frequent and extensive alterations may reduce it (Naveh 1991).

22.3.3 Condition and Trends of Cultivated Drylands

22.3.3.1 Oases in Hyper-arid and Arid Drylands

In the hyper-arid and arid drylands (the desert biome), most cultivation is either in oases or in croplands, where crops are irrigated by fluvial, ground, or local water sources or by a combination of these. Traditionally, oases were carefully managed by combining crops and water regulations. Since the middle of the twentieth century, oases have borne increasing demographic and investment pressures resulting in larger water abstraction, which has led to soil salinization and huge loss of surrounding vegetation through overgrazing and fuelwood exploitation followed by soil erosion.

Two examples are indicative of these trends. Recent indirect drivers of change in the Maghrebian oasis (northern border of the

Sahara) have been population increase, policies to settle nomadic populations, investments generated by migrants working abroad, and transformation of self-sufficiency to open-market economies in countries of the Maghreb. The expansion of cultivated areas irrigated by water from deep aquifers and a lack of drainage (de Haas et al. 2001) led to spreading shallow water tables and subsequent soil salinization (Mtimet and Hachicha 1995). In the Nile delta, traditional water management of the summer flood kept the water table at 5–7 meters below the surface during the low flow season. But nineteenth- and twentieth-century water management policies and practices, including construction of the Aswan dam, enabled year-round irrigation and the growth of out-of-season crops, such as cotton. These reduced the water table depth, however, resulting in soil salinization and a dramatic decline in crop yield (Ruf 1995).

22.3.3.2 Semiarid and Dry Subhumid Agriculture

Where massive agricultural encroachment into temperate grasslands has occurred, and where drylands are exposed to freezing and thawing and suffer a relatively high recurrence of drought and strong winds, topsoil is at risk of being lost and with it all the provisioning services. This happened in the Chinese loess plateau south of the Yellow River bend millennia ago and in North American central plains in the first quarter of the twentieth century. Once the topsoil is lost to wind, the underlying layers—rich in calcium carbonate and poor in organic matter—develop crusts that impede infiltration and foster further soil loss through gully erosion (Mainguet 1996). In the United States, temperate grassland soils can lose up to 50% of their original carbon within the first 50 years of cultivation (Conner et al. 2002). In parallel to carbon loss, conversion of grasslands to croplands can result in loss of fertility, increased soil erosion, and decreased water quality through larger sedimentation and non-point chemical pollution by salts, nutrients, and pesticides.

When agricultural encroachment of tropical savannas occurs, there is a risk of soil impoverishment through erosion and nutrient depletion (Stoorvogel and Smaling 1990; Drechsel et al. 2001) unless nutrients and water are carefully managed. Subsequent erosion may leave the subsurface soil horizon with its limited water infiltration capacity exposed, resulting in further soil loss by gully erosion. However, if land husbandry practices are properly adjusted, the increased crop production required to meet a growing population does not necessarily have to lead to nutrient depletion (Scoones 2001; Niemeijer and Mazzucato 2002; Mortimore and Harris 2004).

The long, traditional agricultural use of Mediterranean shrublands and woodlands in the Mediterranean basin has prevented soil loss through sophisticated terrace systems used across hill slopes. But the pulse of rural population increase that started at the end of the nineteenth century occurred too fast to allow widespread land conditioning, and it triggered extensive soil losses. The outcome was large upstream areas of exposed rock (Roquero 1990) and accretion pulses in river deltas (Hoffmann 1988).

22.3.4 Condition and Trends of Alternative Livelihoods

Rather than grappling with drylands' low biological productivity, dryland peoples have explored ways to exploit other ecosystem functions that can serve them better, even better than if they exploited the same functions in non-drylands. Such emerging ''alternative livelihoods'' do not depend on traditional land uses and are generally undemanding on land and natural resource use. Alternative livelihoods have minimal dependence on land primary productivity for producing subsistence products; do not impair the provision of other services of dryland ecosystems; generate more income per investment from local dryland resources, compared with the traditional, land biological production-dependent livelihoods; and provide people with a competitive edge over others who follow the same practices outside drylands. Five major alternative livelihoods are discussed, in order of decreasing dependence on land primary productivity and hence decreasing desertification risk and increasing likelihood of sustainability.

22.3.4.1 Dryland Afforestation

Silviculture and rain-fed horticulture are not very common in drylands and depend on labor-intensive construction and maintenance of runoff-harvesting structures (Evenari et al. 1982; Droppelmann et al. 2000). However, dryland silviculture and horticulture provide better soil protection than agriculture because tree canopies are denser and tree root system deeper and more extensive than those of agricultural crops and because trees continue to provide soil conservation after harvest, unlike agricultural crops, where very little is left to cover the soil after harvest.

Dryland afforestation for firewood production is a livelihood that depends on the biological production service. Unlike grazing or cropping, afforestation provides a superb soil conservation service for an area greater than that occupied by the forest itself since flashfloods are not generated by dryland forests. Dryland afforestation will qualify as an alternative livelihood if it generates more income than a traditional dryland land use and, even better, if it can generate more income than non-dryland silviculture.

Carbon sequestration by forests and their contribution to above- and belowground carbon reserves and the recent emergence of ''carbon trading'' under the Clean Development Mechanism may make the required difference. This is because most non-dryland ecosystems with good provision of the biological productivity service are already either cultivated or afforested. On the other hand, though the global drylands are less efficient than non-drylands in carbon sequestration, their potential for further carbon sequestration is high and has not yet been developed, while non-dryland capacity is already close to the maximum. Experiences in Israel have shown that a mean annual addition to the carbon reserve of drylands of 150 grams of carbon per square meter per year is possible, generated mainly during winter (rather than during summer in non-drylands), thus storing twice as much carbon as the adjacent nonforested rangeland (Gruenzweig et al. 2003).

Dryland afforestation only counters desertification in those cases where it is used as an alternative for unsustainable cropping and grazing practices. It is not a suitable alternative for rangelands, agroforestry systems, and areas under natural plant cover, as these offer equal or better protection against desertification. Also, in the case of degraded croplands, the benefits are quickly lost if trees are watered through irrigation (with its potential for salinization and water resource depletion) rather than through runoff harvesting.

22.3.4.2 Controlled Environment's Cash Crop Agriculture

There are dryland agriculture practices that can qualify as alternative livelihoods by employing plastic covers in agrotechnology. The plastic cover allows nearly full light penetration and at the same time offers options for locally manipulating many other crop-relevant environmental factors (Arbel et al. 1990). This practice ranges from covering individual rows of low-stature crops, with no additional intervention and for only a part of the growing season (mainly in the least dry drylands), to covering plots within "growth houses" or "greenhouses," within which several of the internal environmental conditions are artificially manipulated to the extent that the crop is virtually separated from the outer dryland environment (mainly in the driest drylands). The plastic enclosure reduces evapotranspiration and thus maximizes water use efficiency (Pohoryles 2000); it reduces insecticide use and makes CO_2 fertilization feasible.

Often the crops are grown on artificial substrates, with nutrients supplied and water provided by irrigation that incorporates fertilizer application ("fertigation"), and pollination may be provided by commercially raised and marketed pollinators (BioBee 2000). Together these enable intensification of biological productivity while economizing on land resources. This approach uses the dryland's abundant incident light and winter warmth, but it is otherwise nearly independent of local ecosystem services. Provided that it does not deplete local water resources and that salinity is controlled and not allowed to leach into groundwater, this practice does not generate desertification.

However, this livelihood requires investment in infrastructure, such as energy for ventilation and cooling, making it more suitable for industrial countries. The intensification of crop growth generates more yield per unit of investment, but the crops need to have high market value—namely, cash crops. The production of cash crops in drylands may be more profitable than in the non-drylands, on account of two physical/climatic features of most (but not all) drylands: high irradiation due to relatively infrequent cloud cover and higher ambient winter temperatures relative to those in the nearest non-dryland areas. Indeed, the gross value added and the cash generated per unit area from that part of the hyper-arid dryland of Israel in which intensive greenhouse agriculture is widely practiced is higher than those of all other types of Israeli agriculture, including those of the least dry areas of the country (Portnov and Safriel 2004).

22.3.4.3 Aquaculture in Drylands

Dryland aquaculture is inherently advantageous to dryland agriculture because although aquatic organisms live in water they do not transpire it, so water losses from aquaculture are predominately from evaporation rather than raised evapotranspiration. Furthermore, many more aquatic species than terrestrial crop species are tolerant of salinity and even thrive in it. Thus, dryland aquaculture can prosper on fossil aquifers (quite common in drylands) whose high salinity greatly curtails their use by dryland agriculture.

When dryland aquaculture borrows the technology of dryland greenhouses (as just described), water conservation is even greater than it is in agricultural greenhouses due to zero transpiration of aquatic organisms. At the same time, dryland aquaculture does not compete for water with dryland agriculture due to the divergent salinity tolerances of terrestrial plants and aquatic organisms (Kolkovsky et al. 2003). Since dryland aquaculture is always more economic on land than dryland agriculture, land use as well as water use efficiencies are high. Thus dryland aquaculture, like dryland controlled-environment cash crop agriculture, does not depend on local ecosystem services and need not cause desertification.

Dryland aquaculture is based on aquatic animals and plants (mostly micro-algae) or some combination of these. The productivity of aquatic animals is not light- and CO_2-dependent, hence the costs of feeding the animals are greater than those of fertilizing the plants. There is, however, an added cost of water filtration due to the enrichment of the water by the surplus organic load of animal feed and animal excretions. This cost can be reduced by integrating animal and plant aquaculture, in which algae thrive on the animal waste-enriched water, or the enriched water can be used for irrigation of crops. Plant aquaculture is advantageous on animal aquaculture in that feeding is not required and organic load is not a problem. Also, given that most aquatic plants are either very small or unicellular, their growth is much faster than that of terrestrial plant crops, and the ratio of harvested to nonharvested biomass of the crop is much higher than that of terrestrial plants.

Dryland aquaculture of both plants and animals is more advantageous than aquaculture elsewhere due to the abundance of light for aquatic plants (Richmond 1986) and of winter warmth for both plants and animals (Kolkovsky et al. 2003). An added benefit is the higher availability and hence the lower price of land in drylands than in non-drylands and the reduced competition with agriculture on land in the drylands. Most of the products of dryland aquaculture are cash crops, such as ornamental fish, high-quality edible fish and crustaceans, and industrially valuable biochemicals produced by micro-algae, such as pigments, food additives, health food supplements, and pharmaceutical products.

22.3.4.4 Urban Livelihoods

Though "dryland development" and "rural development" are often used synonymously, dryland cities as an alternative to dryland villages may be a sustainable option for settling more people in drylands because the cities consume, and hence affect, fewer land resources than dryland farming and pastoral livelihoods do. However, this depends on the potential of dryland cities to provide livelihoods as well as living conditions that are advantageous compared with those provided by other cities.

A combination of appropriate building materials, architectural design (Etzion et al. 1999), and urban planning (Pearlmutter and Berliner 1999) can provide living conditions in drylands that are as comfortable as and much cheaper than those provided by non-dryland cities. This is because drylands are endowed with two climatic features that are highly conducive to "passive" (energy-saving) climate control. The very low air humidity in the driest drylands makes summer evaporative cooling very efficient and cost-effective, and the low dryland cloud overcast means that solar radiation (aided by appropriate positioning, dimensions, and technological design of glass windows) provides efficient and cost-effective winter warming (Etzion and Erell 2000).

Thus the use of fossil fuels for cooling, and of fossil or biomass fuels for warming, can be much lower in driest dryland cities than elsewhere. Furthermore, fossil fuels can be nearly completely replaced by solar energy-generated power (Faiman 1998) due to the high year-round intense solar radiation coupled with the low overcast of many drylands. Given the potential (though rarely realized) advantages of living in dryland cities and their relatively low impact on dryland services, a policy of encouraging urban livelihoods in appropriately designed and functioning dryland cities could significantly contribute to sustainable dryland management. Dryland tourism may be one such livelihood.

22.3.4.5 Dryland Tourism

Dryland tourism is driven by the increasing affluence, free time, and mobility of a relatively large segment of the global population coupled with the growing craving for uncongested, unpolluted, pastoral, pristine landscapes. Drylands offer many unique scenic, wildlife, biodiversity, historical, cultural, and spiritual services. Hence employment in the tourist industry may become an increasingly important alternative dryland livelihood for both rural and urban dryland people.

Though urban and tourism-related dryland livelihoods are economic on land use, their impact on dryland water resources requires attention. Given the large water demand of dryland agriculture, the per capita water demand of a dryland city is likely to be lower than that of a rural dryland village. However, the tourist industry is a significant consumer of water. Irrespective of dryland urban versus dryland rural development, the growing demand versus the diminishing supply of renewable water in drylands has catalyzed the improvement of technologies for recycling and reuse of wastewater and for water desalination in drylands (NRC 1999). These are also helping to address the water demand incurred by the dryland tourist industry.

22.3.5 Condition and Trends of Dryland Biodiversity

22.3.5.1 Species Endangerment and Extinction in the Drylands

Most available information on species threat status and extinctions is listed by country, and no assessment has been made on overall species status for drylands, let alone for specific dryland subtypes. However, to gain some insight on the situation we selected three relatively large countries (each more than half a million square kilometers in size) that are virtually 100% drylands and are geographically isolated from each other as to minimize species identity: Kazakhstan in Central Asia (semiarid and arid), Mali in north equatorial Africa (arid and hyper-arid), and Botswana in south of equatorial Africa (semiarid and dry subhumid). The combined number of terrestrial threatened and non-threatened vertebrate species for these countries totals 1,593 species (IUCN 2004), occurring over an area of more than 4.5 million square kilometers. Only one species is known to be globally extinct (a mammal in Kazakhstan), and 69 species (4.3%) are threatened (see Table 22.5), which appears to be much lower than global species endangerment (12–53% for different groups; see Chapter 4).

No correlation exists between the species richness of each group and its proportion of threatened species, and it is likely that threat status is more related to body size. The dryland birds and mammals of these countries are more prone to extinction than amphibians and reptiles are, and though there are many more bird than mammal species, the highest proportion of threatened species is among mammals. It is likely that this is because, on average, mammals are larger than other vertebrates, have larger home ranges, and hence are more affected by habitat loss or are subject to greater hunting pressure or persecution by humans.

Analyzing a single country—Israel—by dryland subtype reveals 3% of the desert biome vertebrate and plant species (hyper-arid and arid subtypes combined) are threatened, compared with 7.7% of the Mediterranean biome species (semiarid and dry subhumid subtypes), which suggests that, at least in Israel, threats decline with aridity. These figures also include locally and globally extinct species: five freshwater fish and one amphibian species lost in Israel are globally extinct. Furthermore, 57% of the breeding birds associated with wetlands and inland waters in Israel have become locally extinct or are threatened (compared with only 27% of non-wetland birds) (Nathan et al. 1996). This is in agreement with the global situation, whereby species of freshwater habitats are at greatest risk of extinction (see Chapter 4), and it demonstrates the intense pressures on wetlands in drylands.

22.3.5.2 Conservation of Biodiversity in Drylands

Protected areas occupy 8% of global drylands, which is close to the global average for all systems (10.6%). The fraction of each subtype area within protected areas declines with aridity: 9% of dry subhumid drylands, 8% of the semiarid drylands, and 7% of arid drylands, although the figure for the hyper-arid subtype is the highest at 11%, just above the global average. The high degree of protection provided in the dry subhumid subtype has two explanations. First, greater political attention is focused on the conservation of less-arid areas and, second, due to the high population pressure in dry subhumid areas, there is a greater awareness of conservation needs there. At the same time, the negligible population pressure and low competition for dryland services make hyper-arid drylands ideal for designation of protected areas, which explains the high degree of protection there. Protected areas in drylands are managed for three different reasons: to support biodiversity, to promote the provision of their cultural services, and to promote biodiversity's role in provisioning all other services.

Of the 25 global ''biodiversity hotspots''—terrestrial areas where at least 0.5% or 1,500 of the world's 300,000 plant species are endemics and with habitat loss expressed in the decimation of 70% or more of their primary vegetation (Myers et al. 2000)—8 are in drylands. These are the Succulent Karoo and Cape Floristic Province, both in southwestern Africa; the Brazilian Cerrado; Central Chile; the California Floristic Province; the Mediterranean Basin; the Caucasus; and parts of southwest Australia. (Note, however, that most of these hotspots represent the Mediterranean type biome only.) Of the 134 terrestrial ''ecoregions'' (200 global ecoregions defined by Olson and Dinerstein 1998) identified as priority conservation targets, 24 are within drylands. Almost 30% of the global Centers of Plant Diversity (WWF/IUCN 1994) contain, at least partially, drylands. Using the IUCN Protected Area classification, dryland protected areas that are managed to support biodiversity, and with the highest degree of protection and least access to people, occur mainly in the semiarid drylands and occupy 11.4% of all dryland protected areas.

Table 22.5. Endangerment of Vertebrate Species in Three Dryland Countries. Data for all IUCN categories of endangerment combined. (Data from IUCN 2004)

	All Species		Amphibians	Reptiles	Birds	Mammals
	Total	Threatened	Threatened within Each Group			
	(number)	(number and percent)	(percent)			
Mali	340	20 (6)	0	1	3	9
Kazakhstan	462	35 (8)	7	4	4	10
Botswana	349	14 (4)	0	0	4	4
Total	**1,593**	**69 (4)**	**2**	**1**	**3**	**8**

In protected areas maintained primarily for the provision of cultural services, human exploitation and occupation are restricted, but visitors are welcome and tourism is encouraged and hence they offer potential economic benefits to local people. In total, these account for 44.7% of all dryland protected areas combined and are most common in the arid subtype. Many of these are national parks or (officially non-protected) private game farms, which provide many of the same cultural services. In many of the national and private parks, especially in Africa, management is geared to maximizing the number of large game species for visitors, which may lead to trampling and overgrazing due to overpopulation of game.

It is increasingly difficult to set aside formally protected areas that largely exclude human populations, especially in dryland countries with high poverty levels. In some regions, historically protected areas have been associated with oppressive political regimes and the exclusion of local inhabitants, where wildlife conservation goals have been put ahead of human needs. This image of protected area use has been challenged over the past decade, especially through increased efforts to promote community-based natural resource management. Protected areas managed for their provisioning services, which allow for controlled exploitation of ecosystem goods, account for 43.9% of dryland protected areas and are most common in the semiarid drylands.

22.4 Drivers of Change

22.4.1 Conceptual Framework of Dryland Drivers: The Desertification Paradigm and Its Counterpart

The overarching change in drylands is land degradation defined as a persistent decrease in provisioning of ecosystem services—also frequently termed desertification, as described earlier. A number of phenomena are tied in through various links, interactions, and feedbacks, which jointly make up the ''desertification paradigm.'' This section assesses the validity of the desertification paradigm by presenting the relevant direct and indirect drivers, including both biophysical and socioeconomic drivers. More-recent research has led to the development of an alternative ''counter-paradigm'' concerning drylands processes; this approach identifies interventions that prevent the occurrence of desertification. Between the two paradigms there is general agreement on the role of the direct biophysical drivers discussed in the next section. Where the common ''desertification paradigm'' and the emerging ''counter-paradigm'' differ is in the proposed role of indirect drivers. This is the subject of the subsequent two sections.

22.4.1.1 Direct Bioclimatic Drivers

The relatively low productivity and low soil moisture content of drylands are often exacerbated by the uni-modal pattern of rainfall, resulting in a long period during which soil moisture falls. Low and infrequent precipitation patterns and radiation-induced evaporation jointly and directly drive a linear sequence of biophysical processes. In this cycle, low soil moisture leads to low plant productivity, poor soil development, and high runoff, resulting in a high susceptibility of drylands to soil erosion.

The same two bioclimatic factors that are drivers of vulnerability to erosion are also drivers of vulnerability to salinization. Low rainfall does not leach the surface salts into deeper soil layers, down below the root zone of plants, hence the dryland topsoil is vulnerable to salinization. These natural conditions make dryland ecosystems vulnerable to land degradation, while both drought and human activities can further exacerbate existing vulnerabilities.

22.4.1.2 The Desertification Paradigm

The desertification paradigm holds that bioclimatic drivers and anthropogenic drivers that traditionally maintain dryland ecosystems in a stable state become drivers of change, pushing the transition from sustainable exploitation of ecosystem goods and services to a new ecosystem state of much lower level of service provision. Extremes of direct bioclimatic drivers, rainfall fluctuations leading to droughts, and extensive, intensive, and frequent fires, when coupled with indirect anthropogenic drivers, jointly become drivers of change that through an intricate chain of processes lead to a downward spiral of productivity ending in irreversible land degradation—that is, desertification.

Human population growth in drylands, which increased 18.5% between 1990 and 2000, has been the highest of any MA system (CIESIN 2004). Increased aspirations for raised standards of living are driving an increase in the exploitation of ecosystem services, often accompanied by an increased use of labor and new technologies. This is expressed as a proliferation of livestock and expansion of agriculture and through the adoption of intensive farming practices. The adverse impacts are further amplified when intensification of human activities coincides with droughts, which temporarily but drastically reduce soil and plant productivity.

Cropland in drylands has lower productivity than ''wetter'' croplands. Farmers attempt to address this through supplements such as additional water, fertilizers, and pesticides. If they cannot afford these, rain-fed dryland croplands are left fallow, but land shortages reduce fallow length, often leaving the land insufficient time to recover. Irrigation increases productivity, maintains vegetation cover, and helps protect soil from erosion. However, dryland irrigation accelerates soil salinization due to the often high salinity of available irrigation water and high evaporation. Salinization in croplands directly affects plant growth, dramatically impairing the provision of the soil's productivity service. Over time, soil erosion and salinization reduce productivity to the point where cropland has to be abandoned. In a similar way, rangelands may be degraded due to overgrazing.

The indirect anthropogenic drivers of change in drylands are diverse and act on several scales. They include demographic drivers, such as local population growth or immigration resulting from regional population growth; economic drivers, such as local and global market trends; and sociopolitical drivers, such as local and regional land tenure policies as well as scientific and technological innovations and transfer. According to the desertification paradigm, these combined drivers intensify pressure on drylands (in areas already in use and ''virgin'' territory) in anticipation of increased provision of ecosystem services. However, this pressure for increased productivity frequently fails and, worse, can lead to decreased productivity.

The impact of reduced land productivity is manifest through reduced income, malnutrition, and poor health, culminating in famine and increased mortality rates. People frequently abandon degraded land in order to avoid this impact and either intensify the use of other intact but lower-quality land or transform more rangeland to cropland, practices that may delay but not avoid further land degradation. Since alternative livelihood opportunities are few, migration from rural to urban areas and transfrontier migration often follows. These migrations often create environmental refugees, a situation that exacerbates poverty and urban sprawl and can bring about internal and transboundary social, ethnic, and political strife. These may encourage foreign intervention, which has the potential for destabilizing local, regional, and even global political and economic systems. This chain of processes driven by anthropogenic drivers of change leads to a downward spiral of productivity loss and increasing poverty.

Furthermore, the paradigm implies that since soil degradation and vegetation degradation are linked to increased aridity as part of a negative feedback loop, desertification is practically irreversible, and its inevitability increases with aridity (Cleaver and Schreiber 1994). And since desertification takes place mainly where agriculture is the major source of local livelihoods, agricultural practices are often blamed for desertification and the associated decline in the provision of ecosystem services and rise of poverty. Finally, the paradigm claims that investments are usually required to make dryland agriculture sustainable, but these are generally in short supply due to poverty. Thus poverty is not only a result of desertification but a cause of it.

22.4.1.3 The Counter-paradigm

According to the counter-paradigm, the drivers, processes, and events described in the desertification paradigm do exist, but the chain of events that leads to desertification and the chain-reaction cycle of reduced ecosystem productivity and poverty are far from inevitable. This section identifies the conceptual weaknesses of the desertification paradigm and presents the counter-paradigm approach.

The ''desertification narrative'' dates back to the 1920s and 1930s, when concerns about a presumed extension of the Sahara began to be raised and when claims of harmful African farming practices coincided with reports about the American ''Dust Bowl'' experience (Anderson 1984; Swift 1996). So even before the term ''desertification'' was coined, the narrative or paradigm already existed (Swift 1996). Although large-scale drought-related famines in drylands are not a new phenomenon (Nicholson 1979), however, there has always been a recovery after each drought rather than the irreversible collapse implied by the desertification paradigm. This suggests that the desertification paradigm does not fully describe what is happening on the ground. In particular, as described in this section, there are problems with the knowledge and understanding of dryland systems that form the basis for the theoretical foundation of the paradigm; the evidence for degradation on which the paradigm builds; and its assumptions about human response to changes in the natural and socioeconomic environment.

22.4.1.3.1 Inherent instability of drylands

The desertification paradigm assumes that natural dryland ecosystems are in a stable state that can be disrupted by population growth induced by overcultivation and overgrazing leading to a degraded condition of the service of primary production. Based on this assumption, measured deviations from a theoretical natural stable state are considered degradation, so human and livestock populations above calculated carrying capacities indicate degradation (Leach et al. 1999).

The notion of this ''balance of nature'' has been increasingly challenged by twentieth century ecologists, however, and an increasing number of studies in the last two decades have shown that dryland systems exhibit large variability in space and time and that many of them are far better described in terms of non-equilibrium systems (Ellis and Swift 1988; Behnke et al. 1993; Leach et al. 1999). A lot of this work has focused on African savanna systems, but the principles are likely to apply to other dryland regions. The basic premise is that irregular droughts prevent the establishment of a stable equilibrium between plants and livestock (Ellis and Swift 1988). Droughts, disease, and social upheaval have had similar disruptive impacts on many dryland farming systems, introducing elements of non-equilibrium systems there as well. Misinterpreting these systems as in equilibrium leads to an overestimation of land degradation because each (temporary) shift in the balance of vegetation versus human and livestock populations is interpreted as a sign of degradation.

22.4.1.3.2 Problems defining and detecting degradation of an unstable system

Recent remote sensing studies (see Box 22.4), using multiyear analyses of rain-use efficiencies and vegetation indices, have revealed that the widely claimed land degradation in the Sahel may have been a temporary phenomenon caused by the droughts of the 1980s (Nicholson et al. 1998; Prince et al. 1998; Eklundh and Olsson 2003). In contrast, traditional desertification assessments have tended to be simple snapshots in time that have extrapolated observations and measured rates of change linearly into the future. To some extent that may be appropriate for equilibrium systems undergoing a transition, but such linear extrapolations are not justifiable for non-equilibrium systems that undergo continuous change (Niemeijer 1996).

While the understanding of the basic principles of the individual biophysical processes underlying the desertification paradigm is essentially correct, the methods of assessing and quantifying the processes have been problematic. Evidence for degradation has been based on the assessment of vulnerabilities using national, regional, and continental soil surveys and models of carrying capacity, as well as experimental plot studies, expert opinion, and nutrient balance models. While each method is sound in its own right, findings cannot simply be extrapolated in time and space to map out an essentially dynamic and spatially heterogeneous phenomenon such as desertification (Stocking 1987; Mazzucato and Niemeijer 2000b; Scoones 2001). To take just one example, erosion, which is rightfully a major concern in the desertification paradigm, is extremely difficult to measure accurately, let alone to extrapolate to large areas given the high spatial variability of rainfall, geomorphology, and soils in most dryland environments. Due to difficulties in measuring and extrapolating wind and water erosion accurately, landscape-level erosion figures based on plot measurements can lead to overestimation of the actual erosion by a factor of 10 to 100 times (Stocking 1987, 1996; Warren et al. 2001).

22.4.1.3.3 Responses to keep ahead of degradation

The desertification paradigm is grounded in simplistic, mechanistic thinking about human responses to the dryland environment and the processes of desertification. This section presents the crux of the counter-paradigm. An understanding of the dynamism of human responses helps explain why degradation estimates based on carrying capacity concepts of the desertification paradigm can be somewhat misleading.

It is important to note that the paradigm has its root in the environmental sciences (soil science, agronomy, and to a lesser degree forestry) and is strongly influenced by Malthusian thinking on the population-environment nexus. The sciences that deal with human behavior have been largely ignored; as Swift (1999) noted: ''Soil science has been brilliantly informed by reductionist physics and chemistry, poorly informed by biology, ecology and geography and largely uninformed by the social sciences.'' The premise of the desertification paradigm is that land users, in response to their needs, increase pressure on the land in unsustainable ways, leading to decreasing productivity and a downward spiral of poverty and further degradation.

However, there is increasing evidence that these negative feedback loops need not occur. Rather, dryland populations, building on long-term experience with their dynamic environments as well as active innovation, can stay ahead of degradation

BOX 22.4

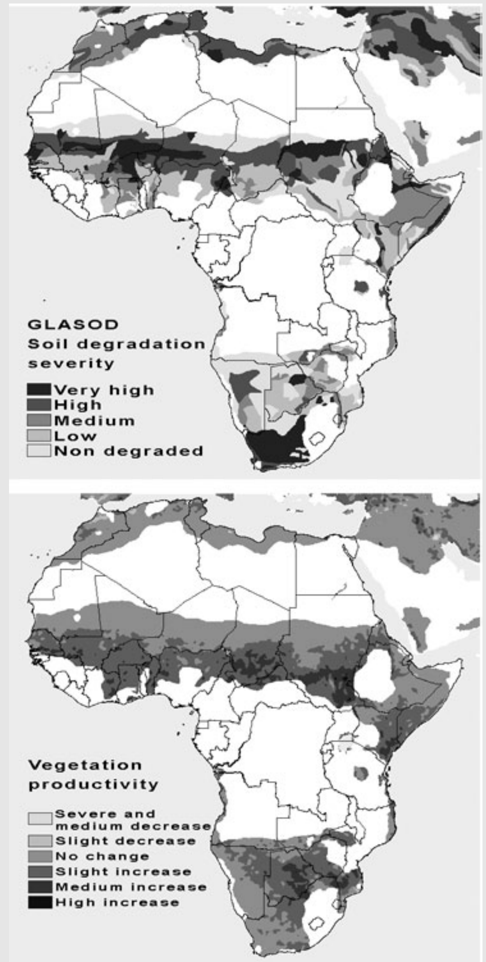
How Much of the Dryland Is Degraded?

The top Figure shows the severity of soil degradation as it was reported in the late 1980s by experts for the Global Assessment of Soil Degradation (Oldeman et al. 1991). Darker tones indicated more severe land degradation. A band of high to very high soil degradation severity can be seen across the Sahel, as well as similar degradation severity in northern and southern Africa.

The bottom Figure shows a map of the trend in primary production between 1982 and 2000. It was based on temporal analysis of satellite imagery (as described below). Dark tones indicate an increase in vegetation productivity, medium tones a no-change situation, light tones a decrease in productivity over time, and white areas are non-drylands and hyper-arid areas left out of the analysis. This Figure suggests a vegetation recovery since the Sahelian droughts of the 1970s and 1980s. Such a recovery would not be expected in areas of severe soil degradation, because soil degradation reduces the capacity of the soil to absorb and store rainwater, reduces soil nutrients for plant growth, and creates less suitable conditions for seed germination.

It is difficult to reconcile the "greening" of Africa (bottom Figure) in often the very same parts of dryland Africa reported as severely degraded in the 1980s (top Figure). What is more, areas of high degradation in the top Figure do not necessarily coincide with similarly located and shaped areas of decreasing vegetation productivity in the bottom Figure. While these Africa-wide results are preliminary, they are corroborated by more detailed studies for the Sahel region (Nicholson et al. 1998; Prince et al. 1998; Eklundh and Olsson 2003). These results suggest that desertification may be much less pronounced than the GLASOD map suggests, but more detailed analysis of the remote sensing material will be needed, especially in relation to the correlation between rainfall dynamics and vegetation cover response.

Methods: For the bottom Figure, 18 years of continental normalized difference vegetation index data (1982–2000, 1994 excluded) from the NOAA Pathfinder program were analyzed and compiled into a single image. Yearly vegetation productivity (calculated as the sum of NDVI values across the year: iNDVI) was calculated, resulting in a temporal linear regression of productivity over time for each pixel. The result was subsequently smoothed to improve legibility. Hence the image illustrates the general trend in vegetation productivity. Assuming that many areas in the drylands of Africa in the analyzed period experienced an increase in rainfall, some of the slightly darker tones may indicate a no-change situation, and medium-toned areas may indicate a decrease in vegetative response to rainfall. (Nielsen and Adriansen 2005; Nielsen in prep)



by intensifying their agricultural practices and enhancing pastoral mobility in a sustainable way (Prain et al. 1999; Niemeijer and Mazzucato 2002; Mortimore and Harris 2004). In these scenarios, population growth does not lead to degradation and poverty but to a Boserupian-style intensification and improved environmental management. (Esther Boserup (1965) analyzed different trends of technological development of countries and continents over centuries and concluded that population growth provides the impetus for technological change. She found that the increased need for food and land scarcity caused by population growth was commonly countered by an intensified use of technologies in which more labor was used in conjunction with land improvement technologies.)

There is, for example, a mounting body of evidence that in the African Sahel region, once considered the centerpiece of the desertification paradigm, land users are achieving higher productivity by both intensifying and improving their land management practices—capitalizing on improved organization of labor, more extensive soil and water conservation, increased use of mineral fertilizer and manure, and new market opportunities (Scoones 2001; Niemeijer and Mazzucato 2002; Tiffen and Mortimore 2002; Mortimore and Harris 2004).

These studies have shown that yields per hectare and food output per capita and livestock sales are largely determined by policies and market opportunities within the constraints posed by the natural environment. It is also argued that population growth is not the overriding driver of either desertification or sustainable land management, but that the impact of population growth is largely determined by the rate of change and the way in which people adjust to their increasing numbers, mediating the effect on the environment and their own well-being through adaptations of local informal institutions, technological innovations, income diversification, and livelihood options and strategies (Mazzucato and Niemeijer 2002; Mortimore and Harris 2004).

The message of the counter-paradigm is that the interacting direct and indirect drivers combined with the local situation can create a range of different outcomes and that raising a general alarm based on questionable scientific evidence in the end is much less effective than identifying individual problem areas where large influxes of refugees or other complicating factors have led to an unsustainable local response. It is also crucial to distinguish between problems originating from the natural harsh and unpredictable conditions of dryland ecosystems and problems caused by unsustainable management of the environment, since the remedies will often be different.

Figure 22.11 shows the interrelationship between the two paradigms. The desertification paradigm focuses only on the negative interactions (left side of figure), whereas the counter-paradigm allows for both negative (left side of figure) and positive interactions (right side), depending on how humans respond to the direct and indirect biophysical and anthropogenic drivers. The counter-paradigm offers a much more flexible approach in

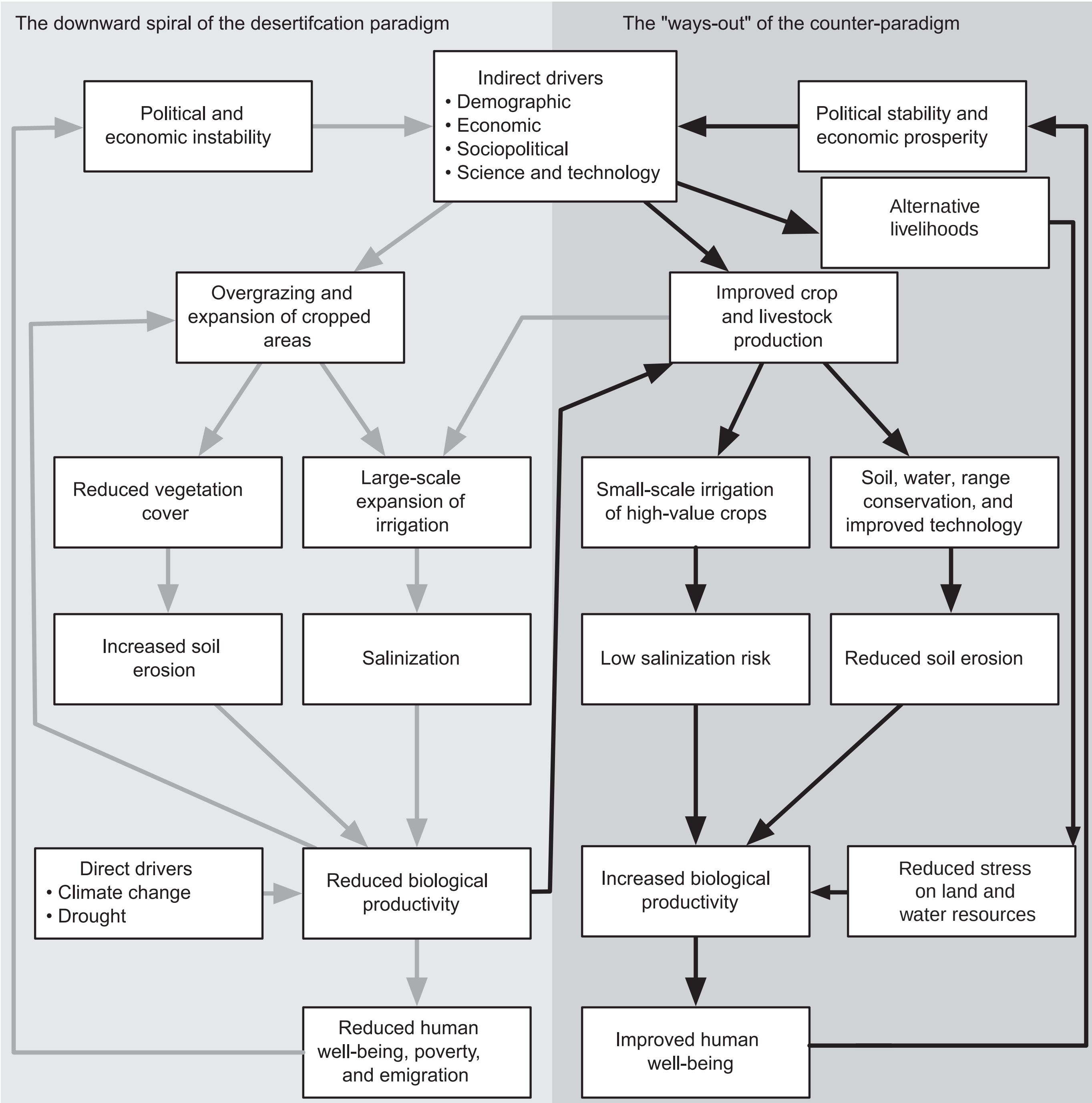


Figure 22.11. Desertification Paradigm and Counter-paradigm. The schematic shows the inter-relationships between the two paradigms: The desertification paradigm focuses only on the negative interactions (left side of figure), leading to a downward spiral of desertification. The right side shows the counter-paradigm, which entails developments that can help avoid or reduce desertification. In the counter-paradigm, land users respond to stresses by improving their agricultural practices on currently used land. Both development pathways occur today in various dryland areas.

that it allows for multiple sustainable development pathways and does not impose a single, intervention-based development model as the only way out.

22.4.2 Socioeconomic and Policy Drivers

22.4.2.1 Policy Drivers—Successes and Failures

Top-down policies with minimal participation of local communities often lead to land degradation, whereas policies encouraging participation and local institutions can induce a sustainable intensification of primary production. For example, a study of eight countries in West Asia and North Africa (Hazell et al. 2002) revealed that past agricultural policies favoring only rich farmers promoted agricultural growth that led to environmental degradation. On the other hand, policies that emphasize risk-reducing strategies, that secure property rights, and that take into account both technical and socioeconomic constraints do ensure adequate incentives for participation in resource management and can thus avoid degradation (Sanders et al. 1996; Pender et al. 2001; Hazell et al. 2002). Community-based land use decision-making and social networks also contribute to the success of non-degrading agriculture in drylands (Mazzucato et al. 2001).

There are also examples for the Boserupian "induced innovation" triggered by increasing needs and sustained by the community's investments in agricultural infrastructure, markets, and conservation practices; in the Machakos (dry subhumid Kenya), demand from the nearby growing city of Nairobi since the 1930s has motivated farmers to restore degraded lands by terracing, penning, and feeding livestock; manuring croplands; planting high-value trees; adopting labor-saving plows and new maize varieties; and creating small-scale water harvesting and irrigation structures. In Gombe (semiarid to dry subhumid north-central Nigeria), farmers repeatedly changed their livelihoods base from livestock to sorghum/groundnut, to cotton, and to maize as market access and prices shifted and as fertilizer and new cultivation technologies became available through government programs since the 1940s (Tiffen and Mortimore 2002). In these two cases, market demand increased returns on agricultural production, which stimulated development toward a more labor-intensive system in which labor-intensive soil and water conservation practices paid off through higher yields and better prices at the market.

However, there are other situations where induced innovation has not occurred and higher population has increased pressure on the land, which has not been compensated for by more investment in soil and water conservation measures (Lopez 1998; Kates and Haarmann 1992). A comparison of these successes and failures suggests that critical drivers for successful indigenous dryland rehabilitation include access to technologies that can increase labor and land productivity faster than population growth and access to markets (Pender and Kerr 1998; Pender et al. 2001).

Next to intensification, diversification away from a small list of regular crops or mono-cropping systems provides economic sustainability as well as maintenance of service provision. Trees interspersed with crops provide year-round ground cover and livestock feed, protecting soils from the degradation spiral. A greater diversity of crops also provides a more consistent stream of employment and income to the farm year-round, reducing the incentive for out-migration and hedging against short-term drought risk. Higher-value products provide farmers with the income needed to reinvest in soil nutrient replacement, in turn building soil organic matter. In some areas, such practices have traditionally been an integral part of the system; in other areas, they are currently being stimulated through development interventions.

22.4.2.2 Demographic Drivers

Population is an important driver; however, population growth projections for drylands can be confounded by the impact of socioeconomic and health problems, like HIV/AIDS. For example, in Botswana, which is mostly semiarid and where one in three adults is reported to be HIV-positive, a 20% decline in population is predicted between 2000 and 2050 (UNFPA 2003). This situation could also apply to other dryland countries in Africa. Rapid demographic changes—increases or decreases—make planning resource management more problematic.

Migrating populations can be a source of additional pressure on dryland environments and on resource management when livestock temporarily concentrate at key resources such as water points. Under these circumstances, conflicts over water often arise between nomads and farmers (as in the dry subhumid part of Tanzania) (Mbonile 2005). A transition between migration as a temporary livelihood strategy to permanent migration creates additional pressure on drylands, as described later.

Nomadism can be described as a rangeland management practice that over the centuries has proved to be sustainable and within the carrying capacity of drylands. Sedentarisation of nomads and other policies and infrastructure that promote farming in rangelands at the lower limit of cropping viability can act as drivers of land degradation. The concentration of human and livestock populations in particular areas can reduce the ability of nomads to adjust their socioeconomic activities in the face of stresses such as droughts, and a Convention on Nomadic Pastoralism to protect pastoralists' rights and empower them economically, socially, and politically has been suggested (CENESTA 2002). Sedentarization under the Tribal Grazing Land Policy in Botswana has not yet caused large-scale environmental degradation, but it has reduced the resource base and options for both environmental and societal resilience to natural environmental variability (Thomas et al. 2000). Similarly, in Kenya's semiarid Laikipia District, sedentarization of the previously nomadic population in a dryland wetland placed the people in an escalating human-wildlife conflict (Thenya 2001).

22.4.2.3 Land Tenure Policies

Land tenure practices and policies in drylands can also act as indirect drivers of land degradation. When farmers and herders lose control or long-term security over the land they use, the incentives for maintaining environmentally sustainable practices are lost. Problems of water scarcity, groundwater depletion, sedimentation, and salinity can all be symptoms of deeper policy and institutional failures, including a lack of well-defined, secure, tradable property rights (Ahmad 2000). According to this argument, it is essential that people perceive that they have secure ownership over local natural resources for management to be effective. However, security of tenure need not imply systems of private property rights. For instance, long-established collective and community-based management of village tank systems has been more effective than the current proliferation of privately owned boreholes (Gunnell and Krishnamurthy 2003).

22.4.2.4 Water Policies

Water policies are relevant to many provisioning and supporting services in dryland areas. These policies include allocation systems, pricing, government investments in water resource development, and priorities in conservation measures. Water allocation for irrigation has caused degradation in some dryland areas where flows in semiarid rivers used for irrigation, such as the River Ord in Western Australia, are highly variable and unpredictable. Therefore the proportionate water release strategies have been found to be unsuitable and to cause detrimental effects to the riverine ecosystem (Dupe and Pettit 2002). Irrigation policy decisions also depend on other factors, such as water availability and pricing and anticipated crop prices (Norwood and Dumler 2002).

Increasing water scarcity and degradation of quality are also linked to water sharing between upstream-downstream riparian users (Lundqvist 1999). A frequent policy focus on the aggregate availability of water—more specifically, the ratio between the number of people in a country or region and the amount of water that is naturally available—hides how much of that water can and is withdrawn and used by different people (Lundqvist 1999). Therefore, a shift from the mindset of resource development to one of resource management and conflict resolution is more useful (Shah et al. 2001).

Institutional reforms such as pricing of water have been slow to materialize due in part to strong political interest groups resisting policy changes in the water sector (Ahmad 2000). The National Water Act of South Africa is an example of legislative innovation attempting to address these issues (Kamara and Sally 2003).

22.4.2.5 Governance Approaches

Central or local government investments in infrastructure and accessibility to credit can also influence sustainability or vulnerability of dryland livelihoods as well as determine human well-being in these areas. Large-scale government-driven projects can facilitate the sustainable development of drylands, as seen in developed dryland areas in Israel, California, and Australia. But if inappropriately designed, implemented or managed, they can lead to desertification, as in the Aral Sea region. Around the Mongolian-Chinese borderland, increasing cooperation with the Chinese government through development projects has led to both economic benefits for the Mongol population and to changes and homogenization of land forms, increasing sand dune encroachment and vulnerability (Jiang 2004; Brogaard and Zhao 2002).

The failure of African governments to devolve power to affected people and to link environmental degradation to economic policy has been seen by some as a significant drawback in combating desertification and drought (Darkoh 1998). As a result of these failings, many programs lack local support or are undermined by conflicting trade and agricultural policies pursued by governments.

22.4.2.6 Economic Drivers: Local Markets and Globalization

International, national, and local market dynamics and private and public-sector financial flows are treated as indirect drivers of pastoral and agricultural practices of dryland people, driving either sustainable use of dryland natural resources or desertification. Regarding globalization, the increasing focus on raising production for exports in Ghana (mostly semiarid) and Mexico (more than half of the country arid to dry subhumid), for instance, has led to increasing degradation (Barbier 2000). The negative impacts from increased access to markets challenge the conclusion of Zaal and Oostendorp (2002) that much of the explanation for the successful intensification in the Kenyan Machakos may be attributed to access to enlarged markets.

As far as local markets are concerned, these drive livestock management decisions and determine the effects that land degradation and droughts have on human well-being (Turner and Williams 2002). Local markets for off-farm labor also influence farm-level resources and resource management decisions, particularly regarding the use of fertilizers and land improvements (Lamb 2003; Pender and Kerr 1998).

22.4.3 Biophysical Indirect and Direct Drivers

22.4.3.1 Water Use

Freshwater resources like lakes, rivers, and aquifers are essential to the transition of rangelands to croplands by providing fresh water for irrigation. The intensity of this driver decreases with distance of the dryland from the source. The proximity of fresh water generates interventions in water transportation infrastructure, which accelerate the use of the provisioning services. These interventions can cause a degradation of several dryland services.

22.4.3.2 Global Climate Change

Anthropogenically induced global warming has been detected in the last 50 years (IPCC 2001). Dryland-specific and comprehensive information and predictions for the dryland system are not readily available, but it can be inferred that global warming has driven climate changes that have also affected many drylands. These may include the 0.3% rainfall decrease per decade during the twentieth century between 10° N to 30° N; the 2–4% increase in the frequency of heavy precipitation events in mid-latitudes of the Northern Hemisphere over the latter half of the last century; the more frequent, persistent, and intense warm episodes of the El Niño-Southern Oscillation phenomenon since the mid-1970s; and the increased frequency and intensity of droughts in parts of Asia and Africa in recent decades. These trends are expected to continue, whereas precipitation will either decrease or increase in different regions (IPCC 2001).

The combination of global climate change induced by anthropogenic emissions of greenhouse gases and the fact that carbon dioxide is both the most significant greenhouse gas and an important ingredient for primary production constitutes a potential driver of dryland services. The service of biological productivity, on which so many dryland peoples directly depend, is most sensitive to this combined driver.

The water deficit by which dryland primary production is constrained is caused by low precipitation but also high evaporative demand of the dryland atmosphere, which makes plants lose water each time they open their stomata to let in carbon dioxide, a raw material for primary production. With increased CO_2 concentration in the air, plants shorten the time of stomatal opening, thus reducing water losses, or they maintain transpiration rate but increase overall production, made possible by the increased CO_2 concentration. Furthermore, rainfall may locally increase due to climate change, which too may promote primary production. However, increased temperatures may be above the optimum for dryland plants and may also increase evaporation from soil surfaces, hence reducing soil moisture and even negating possible increases in rainfall. Should plant cover decline, the service of water regulation and hence also primary production will be disrupted. Modeling projects decreases in grain and forage quality in the drylands (IPCC 2001).

Climate change is also likely to drive changes in the water provision service through reduction of water quality and due to increased solubility of minerals with the temperature increase. Since global climate change is expected to increase the intensity of rainstorms, this together with the reduced plant cover will increase the incidence of flashfloods. These increased freshwater flows (Mirza et al. 1998) may offset the water quality degradation but increase soil erosion. Also, the projected higher frequency of dry spells might encourage dryland farmers to increase water withdrawals for irrigation. Since sea level rise induced by global warming will affect coastal drylands through salt-water intrusion into coastal groundwater, the reduced water quality in already overpumped aquifers will further impair primary production of irrigated croplands.

Rangelands will be affected too, by projected changes in grassland/shrubland boundaries due to climate change driving changes in plant community composition (Sala et al. 2000). On the other hand, dryland scrublands and woodlands, used mostly for livestock grazing, will be affected by a greater frequency and extent of fire (Howden et al. 1999). Climate change will also increase habitat fragmentation and thus detrimentally affect dryland biodiversity (Neilson et al. 1998).

Overall, climate change is expected to exacerbate desertification (Schlesinger et al. 1990). Furthermore, it is conceivable that it might amplify the potential negative effects of an existing management regime on the services of interest, increase the risks of land degradation, and raise the cost of intervention and reversal

(Fernandez et al. 2002). However, climate change is expected to have different effects on the various dryland subtypes; Canziani et al. (1998) suggested that since plants and animals of fluctuating environments are better adapted to environmental change, the adaptability of biodiversity to climate change will increase with aridity, since the drier dryland subtypes are also environmentally less stable than the less dry subtypes.

22.4.3.3 Floods

Drylands are characterized by low, unpredictable, and erratic precipitation. The expected annual rainfall typically occurs in a limited number of intensive, highly erosive storms. This produces overland flows that usually develop into violent floods. These floods can be a major driver of soil erosion and soil loss, and the dry spells between storms increase the risk of crop failure. However, these floodwaters can also replenish freshwater resources, deposit fertile minerals and organic debris, and recharge groundwater or the soil profile.

The prevalence of flash floods in drylands typically leads to a number of responses from farmers directed at storage of runoff and flood water, mainly for increasing crops and forage. These include using catchments of up to several hectares (Pacey and Cullis 1986) with or without mechanical or chemical treatment to reduce infiltrability (UNEP 1983); creating micro-catchments of several square meters around a single bush or tree; cultivating wadis that are naturally flooded following rainstorms; spreading the water over extensive tracts to reduce the kinetic energy and enhance infiltration; constructing diversion channels, stone or earth bunds, and even wood bunds to irrigate farmlands of hundreds or even a few thousands hectares; and combinations of several of these techniques (Reij et al. 1988; van Dijk 1995; Niemeijer 1999). Runoff farming is suitable in arid and semiarid areas where direct rainfall is too low for cropping, but in dry subhumid areas it would lead to extensive periods of waterlogging, causing yield reduction. In many of the drier areas floodwaters are also used to recharge wells and fill basins used for drinking water for livestock and humans or for some dry season gardening.

22.4.3.4 Fires

Natural and induced fires are drivers of land cover, soil condition, and biodiversity, especially in the dry subhumid and semiarid dryland subtype. With respect to soil condition, nitrogen and organic carbon are largely lost to the atmosphere or converted to inert forms (charcoal) by fire, while soil erodibility increases for a period after the event. Thus highly recurrent fires can lead to soil degradation.

Historically, land use and management changes have modified the temporal and spatial patterns of fire occurrence and intensity, with strong consequences on soil fertility and the composition of the vegetation it supports. In general, traditional land users maintained a fine-grained spatial pattern of small fires with low on-site recurrence, such as the aboriginal fire management in Australia (Griffin and Friedel, 1984a, 1984b, 1985), which could be extrapolated to other semiarid and dry subhumid dryland.

Dryland fires are often controlled by grazing and browsing of either wild herbivores or livestock. The twentieth-century commercial agricultural and stock breeding systems as well as wildlife management regulations led to widespread fire prevention together with overstocking of rangelands. The outcome has been a new pattern of larger patches of higher-intensity fires, which is claimed to be one of the triggers for grass-shrub transition (Scholes and Hall 1996). World carbon emissions from savanna burning are estimated at 0.87 billion tons of carbon per year (Scholes and Hall 1996). In the northern Mediterranean basin, the burned area has been increasing at an annual rate of 4.7% since 1960 due to vegetation regrowth after agricultural abandonment (Le Houerou 1992).

22.5 Trade-offs, Synergies, and Interventions

This section compares and contrasts the major options available for drylands management. Each category of options is assessed in terms of trade-offs, as far as gains and losses of services with regard to their impact on human well-being; synergies, where one type of management option leads to multiple benefits; and vulnerability (losses greater than gains and no synergies) and sustainability (losses are equal to or smaller than gains).

22.5.1 Traditional Dryland Livelihoods

22.5.1.1 Woodland-Rangeland-Cropland Trade-offs and Synergies

Historically, dryland livelihoods have been based on a flexible combination of hunting, gathering, cropping, animal husbandry, and fishing. Archeological records and anthropological studies have revealed shifts in livelihood strategies over time in the same location and often involving the same cultures. As a consequence, land use changes both in time and space as an adaptation to new economic possibilities, in response to environmental or climatic changes, or as a result of war or drought-induced migration (Robbins 1984; Berry 1993; Niemeijer 1996). Land use changes are thus both responses to changes in the provision of ecosystem goods and services and drivers of changes in this provision.

Population increase drives a growing tension between pastoral rangeland and cultivated land use. This can lead to intercultural conflicts and service degradation as herders and farmers claim access to and use of the same land (van Driel 2001). Depending on annual rainfall, supplemental or full irrigation may be introduced for conversion to cultivated systems, often requiring capital investment by governments or farmers. In the long run, trade-offs between the two land uses can also lead to a tighter cultural and economic integration, with herders cultivating more land, farmers holding more livestock, and an increased exchange of services (Breusers et al. 1998; Mazzucato and Niemeijer 2003).

Woodlands are a source of wild fruits, edible plants, and wildlife that can be important sources of food and off-farm income—vital during years of drought. Woodlands also often have cultural and religious significance for the local population, which protects them to some degree against overexploitation. When woodlands are transformed to croplands, the tree volume decreases. In many traditional systems, however, certain trees and shrubs are not removed because their fruits, leaves, or other products are used for consumption or medication or are traded, as described earlier. The species composition changes and the soil cover decreases following clearance, especially during the dry season, when no crops are grown. The transformation negatively affects regulation and cultural services and reduces biodiversity, but at the same time it increases food production and creates multiple livelihood opportunities.

Woodlands that are increasingly used by livestock (and often managed with fire) may develop into rangelands with a reduced tree cover and increased grass or shrub cover. Over time, the species composition changes as a result of grazing, browsing, and fire (more fire-resistant species become dominant, for instance). For herders, economic productivity increases, but for hunters and gatherers the changes in species composition and the reduced habitat for wildlife negatively affects their livelihood. On a larger scale, the disappearance or transformation of woodlands reduces the service of supporting biodiversity by eliminating corridors for migration and refuge from predation and disturbances.

In semiarid and dry-subhumid areas, different land uses meet and there is the greatest potential for both trade-offs and synergies. Afforestation, silvipastoral, and agropastoral systems develop in response to population growth, environmental changes, and economic and political developments. Natural biodiversity is replaced by agrobiodiversity, where different species and landraces of livestock and crops are introduced. Synergies are found in mixed farming practices, where a single farm household combines livestock rearing and cropping (Slingerland 2000).

Synergies are also found where different households or communities engage in either livestock herding or farming and trade food and services. Such interactions can decrease livestock pressure on rangelands through fodder cultivation and provision of stubble to supplement livestock feed during forage scarcity. At the same time, cultivated systems benefit from manure provided by livestock. Many West African farming systems are based on this kind of integration of pastures and farmland (Prudencio 1993; Steenhuijsen 1995; Mazzucato and Niemeijer 2000a; van Driel 2001). Growing crops in the most fertile areas and grazing livestock on the less fertile land can optimally exploit spatial and temporal variability in service provision.

When used infrequently and controlled, fire plays an important role in the management of most pastoral and cropping systems. Pastoralists use controlled fire to get fresh shoots that are more digestible for their livestock. Farmers use fire to clear new land or old fallows for cultivation and in some cases also to remove the remaining crop residue at the onset of the wet season. In both cases, the use of fire promotes nutrient cycling essential for maintaining the productivity of rangeland and cultivated land. Although fire provides a temporary boost to the provisioning services, carbon and nitrogen are lost to the atmosphere, and the excessive and improper use of fire can also lead to land degradation.

22.5.1.2 Use of Water Resource for Cultivated Drylands

The relative scarcity of dryland water dictates trade-offs in land use and often creates competition and conflicts between different riparian users, as well as upstream-downstream conflicts. For example, dryland-crossing rivers provide drinking water, irrigation, and navigational uses for multiple countries. Water abstracted for irrigation often conflicts with the downstream needs of wetland areas of coastal or inland deltas. On a more local scale, farmers and pastoralists may compete for use of water between irrigation and livestock use. These competitive uses of water resources pose political, economic, and ecological conflicts and trade-offs that sometimes go back to ancient time.

Effective water harvesting and water conservation practices reduce runoff and erosion and increase crop performance, but they also reduce downstream water supply. This reduction in runoff and erosion generally reduces flooding and siltation of fields and water ways. More significant trade-offs need to be considered when runoff farming and water harvesting include intentional clearing of the catchment areas, by removing vegetation and sometimes using artificial coatings to seal the soil. This helps increase the amount of runoff that can be harvested from the catchment, thereby increasing water availability in the run-on area for crop production or livestock watering. However it leads to a loss of ecosystem services for the catchment area itself. Such catchment clearing is labor-intensive and not common in traditional runoff farming and soil and water conservation practices, except in the arid and hyper-arid regions (Pacey and Cullis 1986; Reij et al. 1996; Bruins et al. 1987).

22.5.2 Drylands and Other Systems

Six MA-defined systems overlap with the dryland system, some of which overlap with each other. Cultivated systems (44% of dryland area), inland water systems (rivers and wetlands, 28%), coastal systems (9%), mountain systems (32%), forests (12%), and urban systems (2%) are all embedded in drylands. These systems generate services for the drylands in which they are embedded, and often feedback loops and even synergies develop between the drylands and the systems embedded in them. The trade-offs and synergies between cultivated systems in drylands and other land uses are discussed in previous sections. The linkages of dryland systems with coastal and mountain systems are important and are discussed in the related chapters. Inland waters and urban systems are assessed in this section.

22.5.2.1 Inland Waters and Wetlands

Inland water systems—rivers, canals, lakes, and wetlands—are an integral component of the dryland system and relate to provision of many services, including freshwater provision and supporting biodiversity. Rivers in drylands often feed dryland freshwater lakes (such as the Aral Sea and Lake Chad), landlocked salty lakes (the Dead Sea and Salt Lake in Utah), or end up in dryland deltaic (such as the Mesopotamian marshlands) or landlocked marshes (the Okavango, for example). There is a major trade-off and potential for conflict here: increasing abstraction of water from rivers is essential for agricultural production but it reduces the quantity and quality of water reaching lakes and marshes, leading to reduction in surface area and increase in water salinity.

For example, the Aral Sea lost about 60% of its 68,000 square kilometers between 1960 and 1998, a figure expected to rise to about 70% by 2010, and its salinity increased from 10 to 45 grams per liter (DFD 1996). This resulted in the total collapse of the 44,000 annual tonnage of the lake-based fishing industry and in wind transport of the salt and pesticide-laden soil particles to other parts of the Aral Sea basin, with severe health effects on the population (DFD 1996).

The large-scale abstraction of water for irrigation is directly expressed in shrinkage of wetlands; for example, the Mesopotamian marshlands lost 89% of 20,000 square kilometers between 1970 and 2000, which also affected fisheries of the Persian Gulf (UNEP 2001). Similarly, Lake Chad lost 95% of its 25,000-square-kilometer area from 1963 to 1997 due to irrigation appropriation and climate (USAID/FEWS 1997; ITAP 2003). Such changes could have a significant impact on the 180 fish species in Lake Chad, which are the second most important source of household income in the Nigerian drylands (Sarch and Birkett 2000).

Water abstraction also affects the provision of other services of dryland wetlands, including nutrient cycling, primary production, soil formation away from wetlands, provision of food (both animal and wild food plants) (Brouwer and Mullié 1994), provision of fuelwood and biochemicals, climate regulation through evaporative cooling, and removal of several pollutants from water. Many dryland wetlands are critical for survival of cross-desert migratory birds. Wetlands also provide cultural services (spiritual services and tourism, for instance, as described earlier).

22.5.2.2 Urban Systems

The proportion of the global population living in urban areas is expected to increase following a historical trend, with the urban fraction increasing to around 52% by 2010 (see Chapter 27) and to 60% by 2030 (UN 2002). This projection implies that nearly all the population growth over the next three decades will occur in urban areas. Such growth has consequences for drylands, depending on whether it is undertaken with proper planning and provision of services, infrastructure, and facilities. In hyper-arid drylands, a much larger fraction of the population is urbanized. (See Figure 22.12.) This may be a result of concentration of livelihood opportunities and better living conditions in otherwise harsh settings (CIESIN 2004). Overall urban population density increases with decreasing aridity, accompanied by a decreasing per capita income (expressed by GNP, calculated as dollars per capita). Such correlations with aridity can be linked to the reduction of provision of services with increasing aridity. On the other hand, the ''ecological footprint'' or impacts of dryland urban centers on adjoining rangelands and cultivated systems cannot yet be assessed.

22.5.2.3 Systems Away from Drylands—Dryland Dust

Drylands also affect non-dryland areas, indirectly at the sociopolitical level (through environmental refugees, for example, or immigration), and in various direct ways, such as the dust particles carried by winds from the drylands. Dust from the Gobi desert is carried to the Pacific coasts of America, and Saharan dust is carried to the Caribbean islands (Prospero and Nees 1986) and the Amazon basin (Swap et al. 1992). Chemical contaminants and bacterial and fungal spores adhere to the surface of these dust particles, which can be hazardous to people and are suspected to have already affected organisms of the Caribbean coral reefs (Smith et al. 1996). It is hypothesized that this and other recently emerging coral reef degradation episodes are coincidental with the desertification-driven increased frequencies of Saharan dust storms (Shinn et al. 2000).

22.5.3 Climate Change and Carbon Sequestration

During the last century, global drylands have experienced anthropogenically induced climate changes that are predicted to continue and even to accelerate during the present century, as noted earlier. Drylands ecosystems contribute carbon emissions to the atmosphere (0.23–0.29 billion tons of carbon a year) as a result of desertification and related vegetation destruction, through increased soil erosion and a reduced carbon sink (Lal 2001b). This latter effect is expected to intensify with climate change, but if they are properly managed, dryland systems have the potential to function as a carbon sink.

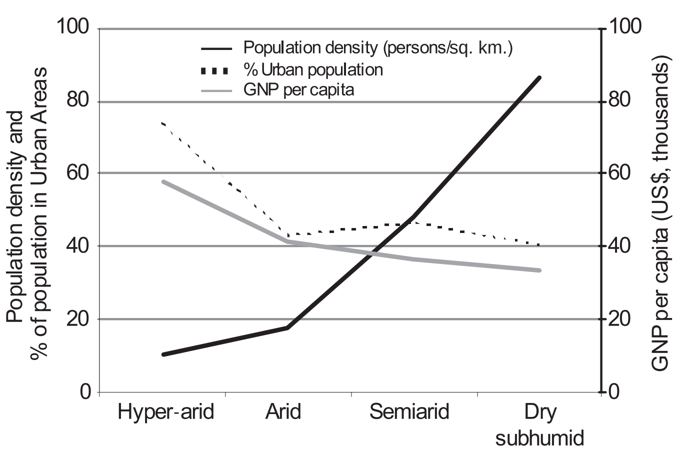


Figure 22.12. Impacts of Urbanization and Population Density on Income Levels in Drylands (CIESIN 2004)

Lal (2001b) estimated the potential of dryland ecosystems to sequester up to 0.4–0.6 billion tons of carbon a year if eroded and degraded dryland soils were restored and their further degradation were arrested. Furthermore, Lal also pointed out that through active ecosystem management, such as reclamation of saline soils and formation of secondary carbonates, carbon sequestration can be further enhanced. This will add sequestration of 0.5–1.3 billion tons of carbon a year; similar magnitudes of potential carbon sink capacity of dryland ecosystems have been estimated by Squires et al. (1995) on a global scale. This restoration and enhancement of dryland condition, if undertaken at a global scale, could have a major impact on the global climate change patterns.

A significant change in the direction of national and local policies would be needed to implement such restoration and enhancement in the carbon sequestration service. Knowledge gaps also need to be filled by collecting information on credible rates of the extent and severity of soil degradation at different spatial scales; biotic and soil carbon pools and fluxes; the impact of land use changes and desertification on the carbon sequestration dynamics; and the cost-benefit ratio of soil improvement and carbon sequestration practices for small landholders and subsistence farmers in dryland ecosystems.

However, there are also numerous hidden costs of enhanced soil carbon sequestration that must be considered (Schlesinger 1999). Such enhancements require the addition of mineral or organic fertilizer (especially nitrogen and phosphorus) and water, which would need significant capital investment. An incentive to further enhance the natural condition of the service even with the costs involved and at the expense of other services is that drylands can be instrumental in counter balancing the increased anthropogenic emissions of carbon dioxide to the atmosphere. In the context of the Clean Development Mechanism proposed by the Kyoto Protocol, developing countries can attract investments from industrial countries and multinational industries. Such projects are expected to generate income through emerging international carbon trading (World Bank 2003a, 2003b), which may offset the expenses. The long-term impact of such projects in developing countries depends on the future of the Kyoto Protocol and the Clean Development Mechanism.

22.6 Human Well-being in Dryland Systems

22.6.1 Indicators of Human Well-being in Drylands

In general, the human well-being of dryland peoples is lower than that of people in other MA systems (see Chapter 5). Dryland peoples have the highest infant mortality rates, and their economic condition (as expressed by the GNP per capita) is the lowest. (See Figure 22.13.) Though the two factors may be linked, the question remains as to what drives the relative and absolute low human well-being in drylands.

The MA defines human well-being as a composite of the basic materials for a good life, freedom and choice, health, good social relations, and security (MA 2003) and implies that these are directly or indirectly linked to the availability of ecosystem services. One hypothesis is therefore that HWB in drylands is low because the natural rate of provision of ecosystem services is inherently low. Hence, the relatively low rate of water provision not only reduces biological productivity on which most dryland peoples depend, it also restricts people's access to clean drinking water and adequate sanitation, thus worsening their health.

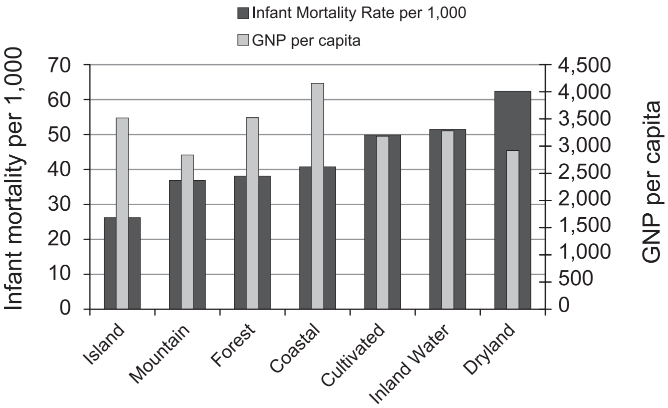


Figure 22.13. Comparison of Infant Mortality Rates and GNP per Capita across the MA Systems in Asia (CIESIN 2004)

Another hypothesis is that land degradation in drylands further reduces the natural rate of service provision, which either drives or exacerbates HWB in the drylands. The degree to which these dryland communities are reliant on dryland ecosystems to sustain them (Webb and Harinarayan 1999; Nyariki et al. 2002) and the extent to which their relatively low HWB is linked to services' failure can be assessed by extending the analysis to subtypes of drylands, with the underlying assumption that the level of aridity is associated with the quality of ecosystem services as well as to the level of stress or degradations observed in drylands. (See Figure 22.14.)

This correlation manifests itself when observable well-being indicators are measured. The hunger rate in children under the age of five and infant mortality rates in drylands demonstrate a clear linkage to the level of aridity. It can be argued that semiarid areas are worse off in terms of human well-being as a result of a high degree of sensitivity and high degree of pressure, which also generate the highest degree of land degradation. The region-to-region variability is also significant, with drylands in sub-Saharan Africa and Asia lagging well behind drylands in the rest of the world, whereas the GNP per capita in OECD dryland countries exceeds that of dryland countries in other regions almost by an order of magnitude. This is not surprising, considering that economic performance relates to many other governance and macro- and microeconomic factors. Thus the economic status of dryland societies is not entirely linked to the low availability of basic ecosystem services such as water and biological productivity. This section assesses the contribution of ecosystem services versus socioeconomic factor to components of HWB in the drylands.

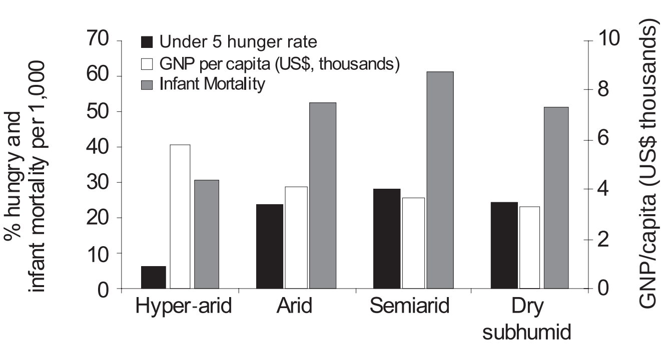


Figure 22.14. Human Well-being Statistics by Dryland Subtypes (OECD countries excluded)

22.6.2 Human Well-being Components in Drylands

The MA conceptual framework (MA 2003) broadly identifies five key components of human well-being.

- *Basic materials for a good life.* The low biological production of drylands, constrained by water, is the ecosystem condition that limits the provision of basic materials for a good standard of living. This also limits the livelihood opportunities in drylands and often leads to practices, such as intensified cultivation, that cannot be serviced due to low and further impaired nutrient cycling and water regulation and provision, requiring adjustments in management practices or the import of nutrients and water provided by services of other ecosystems.
- *Health.* The two key factors contributing to poor health in drylands are malnutrition and limited access to clean drinking water, again reflecting their low biological production and water provision. In Asia, for example, the fraction of children under the age of five facing hunger is 36% in drylands compared with 15% in the forest and woodland system (averaged for the different subtypes of each of these systems) (WHO 2004). However, poor health is also exacerbated by poor health-related infrastructures.
- *Good social relations.* The quality of social relations can be gauged in terms of social strife (wars and political upheavals) and refugees. Environmental refugees leave their homes due to environmental degradation and lack of viable livelihoods. And the sale of stock, wage labor, borrowing of cash for food, and the sale of valuables all precede their migration (Black 2001). Other categories include people displaced for political reasons that may affect the availability of services in drylands to which they have been relocated. Thus demography and sociopolitical drivers, more than the direct condition of ecosystem services, contribute to the quality of social relations.
- *Security.* Food security is an essential element of human well-being in drylands and is related to socioeconomic marginalization, lack of proper infrastructure and social amenities, and often the lack of societal resilience. Climatic events like prolonged droughts and excessive floods also drive insecurity in drylands. But sociopolitical drivers like land tenure practices that relate to sharing and conservation of natural resources or that generate land cover change that may limit traditional pastoral livelihood opportunities can greatly affect food security. Snel and Bot (2002) proposed a list of socioeconomic indicators of land degradation, including indicators to reflect insecurity caused by land degradation. Other security attributes, however, can be only indirectly related to the condition of the ecosystem.
- *Freedom and choice.* Dryland people are not affected just by the unique condition of the ecosystem but are also further restricted by local and global political and economic factors, which can exert major limitations on their freedom and life choices. With the exception of OECD countries, dryland peoples are mostly politically marginalized; that is, their role in political decision-making processes is perceived as being insignificant. Consequently, market factors that determine dryland farmers' decision-making and the effects on their well-being are often critical (Turner and Williams 2002).

This discussion demonstrates that provisioning of ecosystem services is not the only driver of low HWB in drylands. The lack of a strong HWB-service correlation can be attributed to a number of exogenous factors, including political marginality, slow growth of health and education infrastructure, facilities and services, and so on. What needs to be assessed, though, is whether or not there are thresholds in the provision of services that either independently or together with the exogenous factors cause human well-being to drop to a level that crosses the poverty threshold.

22.6.3 The Relative Dependence of Human Well-being on Ecosystems and Socioeconomic Drivers

Natural climatic fluctuations can move the level of service provision to the point of crossing a threshold from a relatively high, stable rate of provision to a lower yet relatively stable state of provision. This can be a temporary transition, but a prolonged drought or overexploitation can exert a persistent impact, resulting in a permanently reduced rate of service provision that does not regain the previous level even when the impact is removed (e.g., Puigdefabregas 1998).

The grassland/scrubland transition is an example of a dryland ecosystem that moves from one relatively stable state with a high provision of forage to a different relatively stable state with a lower provision of forage due to human impact. Even when the impact is removed, the lower-service state persists, as described earlier. Whether such a threshold is associated with a threshold in socioeconomic and political drivers and a resulting significant change in human well-being is not certain. The Sahel drought of the 1980s, for example, produced a devastating reduction in HWB, yet the region reverted to its former state once the prolonged drought terminated. Thus it is likely that the issue of concern is not that of thresholds but of vulnerability to a persistent ecosystem change, coupled with concomitant, resultant, or driving socioeconomic and political changes.

The relative contribution of the condition of the dryland ecosystem and of socioeconomic drivers to poverty attributes—such as per capita rural cereal production, the time spent by household members collecting water and fuelwood, the quantity of annual household consumption that is derived from common lands, the percent of children under five who are underweight, wasted, or stunted, and the percent of the rural population below the poverty line (Shyamsundar 2002)—has not yet been adequately assessed.

22.6.4 Responses to Improve Human Well-being in Drylands

The section explores the response interventions that can mitigate or reverse the effect of degraded ecosystem and service condition on the well-being of dryland people. Experience has shown that locally appropriate interventions can introduce dynamics of sustainability and can improve human well-being by interrupting the vicious circle of poverty leading to overexploitation of services and to environmental degradation and desertification.

Traditionally, dryland societies have been able to cope with their harsh environment through livelihood adaptations over extended periods. A number of commentators have explored the "failure" of dryland farmers in sub-Saharan Africa and elsewhere to develop as quickly as farmers in non-dryland regions during the Green Revolution (Singh 2004). Analyses conducted at the smallholder level have concluded that while overall progress has been compromised by widespread insecurity, significant achievements have been made by dryland farmers due to social resilience, the evolution of knowledge over time, and successful farmer adaptation (Bird and Shepherd 2003; Mortimore 2003). These achievements are contrasted with the failures of non-dryland farmers at comparable poverty levels (Mehta and Shah 2003). This section assesses the relative role of traditional practices and modern technologies in building capacities and public participation for improving HWB in the drylands.

22.6.4.1 Traditional Knowledge

Traditional response options combine tested approaches for resource management based on insights into the local natural and socioeconomic environment with continuous experimentation to deal with changes in that environment (Prain et al. 1999). Such approaches have enabled communities to live in the harsh dryland environments for millennia. In oases, for example, traditional management approaches are based on the appropriate usage of the physical and geomorphological factors. These include production and distribution systems for water management, architectures that regulate micro-climate, cultivation of salinity-tolerant fruit species such as the date palm, waste recycling systems, and sand dune stabilization techniques.

Traditional methods of water harvesting allow the replenishment of the resource and its long-term availability. They make effective use of local topographic and soil characteristics. In some cases, horizontal underground tunnels drain water from the surface of the groundwater table. Vertical ventilation shafts augment supplies by capturing night-time humidity. Locally adapted architectural innovations are also used to facilitate water conservation by condensing atmospheric water, including stone heaps, dry walls, little cavities, and depressions in the soil, thus allowing the plants to overcome periods of high drought.

Contrary to the literal implication of the term, however, "traditional" knowledge is not static but evolves over time, incorporating elements of local experimentation and integrating new ideas and technologies brought from outside or observed during seasonal or temporary migrations (Mazzucato and Niemeijer 2000b). Local knowledge can significantly contribute to human well-being because it has the benefit of integrating the multiple constraints posed by the natural and social environment in ways that are often lacking with introduced technologies. Where local approaches are failing, it is important to distinguish cases where the technologies themselves are fine but need a more enabling political or socioeconomic environment from those cases where a technological solution is needed in the form of improved local technologies or the introduction of new technologies.

22.6.4.2 Adaptation of New Technologies

The gradual introduction, trial, and development of new technologies have allowed considerable progress to be made in some dryland farming communities (Chapman et al. 1996). The adaptation of new techniques is entirely dependent upon the skill and environmental awareness of dryland farmers (Twomlow et al. 1999). Integration of new technologies with tested management approaches is a measure that can improve human well-being at various levels. Three such examples are:

- Integrated water resource management approaches include consideration of the full extent of water resources available within a catchment. Even in hyper-arid areas, opportunities can often be identified to use additional water sources, such as rainwater, seasonal floodwaters, and wastewaters, to supplement over-reliance on groundwater or variable rainfalls. Cumulative uses of water in a catchment are also considered in order to prevent overuse of water by multiple users over time and the resulting depletion of aquifers.
- Integrated water and farming approaches highlight the importance of considering water management in relation to other factors in the dryland production system. For example, the potential to economically irrigate a crop of turnips to provide

an additional source of nutritional value for lactating dairy cows is considerably affected by sowing dates, soil type, and insect damage (Jacobs et al. 2004).

- Farming systems approaches (e.g., Singh 1998) look into the whole production and farming system for synergies among its components, such as arable cropping, livestock management, alternative land use systems, and management of village commons or degraded lands.

22.6.4.3 Capacity Building and Public Participation

Dynamically evolving local and "traditional" practices into which adapted new technologies are integrated have the potential to build capacity for improving HWB in drylands. However, this potential is not always realized. For example, the Indian National Demonstration Programme, which was coupled to training and visiting system (beginning in the 1960s), was unsuccessful in the drylands of India (Singh 1998). This was in contrast to the Green Revolution that occurred elsewhere, with the instant adoption of the technology package over large areas in high-capacity irrigated regions. Singh (1998) concludes that this was because the dryland farmers were less willing to take risks and invest in the new technologies since they were poorer to start with and suffered from water-related constraints and uncertainties in the production process and because the demonstration approach could not convince them that the technologies were appropriate to their needs. Following such experiences, more-recent approaches to capacity development in drylands have adopted a more participatory approach to capacity development, working with farmers as they develop their knowledge, according to their needs and perceptions, rather than demonstrating to them what they could or should do.

Similarly, participatory learning approaches have been used to facilitate the transfer of technologies. In Australia, for example, increasing use is being made of on-farm experiments for capacity development (e.g., Foale et al. 2004; Lawrence et al. 2000). Public participation in resource-use decision-making in drylands is increasingly seen as a key to demand-management for scarce water resources (Kulkarni et al. 2004) and biodiversity conservation (Solh et al. 2003). Participation in dryland decision-making is generally structured according to the prevailing system of land and water rights. For instance, "community-based" projects in Sudano-Sahelian West Africa have often attempted to improve resource management by spatially delimiting appropriate land uses, strengthening the community's exclusionary powers, and clarifying specific claims to village resources. However, such moves can also increase social conflicts (Turner 1999). Thus, further experimentation and experience in merging "traditional" with advanced knowledge as a tool for capacity building for increasing HWB in the drylands may still be required.

22.6.5 Services, Degradation, and Human Well-being

This chapter is an attempt to present "drylands" and "dryland peoples" not as homogenous entities but as a continuum of ecosystems and their human inhabitants arranged along a global aridity gradient in which life and livelihoods are constrained by water. The magnitude of this constraint determines the makeup of the suite of services provided by the ecosystems and, accordingly, the land uses by people and their respective livelihoods. The chapter also examines the mutual interactions between ecosystems and people across this gradient and explores the degree to which the services provided by the ecosystems are used sustainably or are overexploited.

The findings are that both sustainable use and overexploitation occur, but they depend more on socioeconomic drivers than on the degree of water constraint and the resulting dimensions and qualities of the provided ecosystem services. Thus the greatest pressure on ecosystem services takes place at intermediate aridity and not, as might be expected, in the least arid drylands where population density is highest, or in the most arid areas, where population is lowest. The high overexploitation of services is inferred by physical, biological, and social phenomena—soil erosion and salinization, reduced biodiversity and biological productivity, and reduced income expressed by reduced human well-being—and it is reflected by the highest rate of infant mortality and hunger among children. It can therefore be suggested that where aridity is intermediate, on average, there is a mismatch between the rate of service provision and the intensity of exploitation. But there are deviations from this average, expressed in sustainable use of the ecosystems.

Two interlinked drivers are involved in generating this sustainability. The first one is a selective use of services depending on their divergent condition in different areas. For example, in areas where the quality and provision of cultural services are high, local people choose livelihoods served by cultural services (such as ecotourism in the African savanna). And in areas where the quality of provisioning services is high, people choose livelihoods served by these services (such as food crops in natural or managed desert oases). The second factor that promotes sustainability is the adaptation of sociocultural institutions and practices to the prevailing natural condition of the services and the implementation of policies that recognize the natural constraints and create economic instruments that provide for sustainability of the use of services, combined with the promotion of good human well-being.

This assessment also highlights the significance of dryland biodiversity as a whole rather than just individual, selected species in the provision of every single dryland service. It is therefore implied that livelihoods and human well-being depend on biodiversity just as they depend on services. Thus in addition to protected areas, most dryland management, land uses, and livelihoods that maintain biodiversity in drylands will contribute significantly to the well-being of dryland peoples. Also, the chapter suggests that some natural attributes of the drylands have the potential, already realized in some places, to provide dryland peoples with a competitive edge economically (through "alternative livelihoods," for example). Together with policies based on sociocultural and socioeconomic considerations, all dryland livelihoods—pastoral, farming, and "alternative"—can contribute to alleviation of the current high relative poverty and low human-well being of dryland peoples.

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