Chapter 5

Ecosystem Conditions and Human Well-being

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*This appears in Appendix A at the end of this volume.

Main Messages

Over historical time frames, human well-being has on aggregate improved by several orders of magnitude. Incomes have increased, populations have grown, life expectancies have risen, and political institutions have become more participatory. In the global aggregate, human well-being continues to expand, although there are variations across geographical regions.

Well-being is not distributed evenly among individuals, countries, or social groups. Inequality is high, and gaps between the well-off and the disadvantaged are increasing. A child born in sub-Saharan Africa is 20 times more likely to die before age five than a child born in an OECD country, and this ratio is higher than it was a decade ago.

The ecosystems as classified by the Millennium Ecosystem Assessment vary in the degree to which they harbor high values of human well-being. For example, cultivated systems and coastal ecosystems tend to be characterized by high human well-being, while drylands are characterized by low human well-being.

The degree to which well-being varies across ecosystems is not the same everywhere. Variance in human well-being is highest in Asia and sub-Saharan Africa and lowest in the OECD. For example, per capita incomes in Asia are 40% higher in the coastal zones than they are in the drylands, while in OECD countries there is no significant difference between incomes in the two systems.

Populations are increasing in ecosystems characterized currently by low well-being. Whereas historically populations have tended to shift from low-productivity ecosystems to high-productivity ecosystems or to urban areas, today there are signs that the relative concentration of people in less productive ecosystems is going up. The concentration of poor in less-favored lands of Asia and sub-Saharan Africa is an example.

These trends signify that there are a large number of people at risk of adverse ecosystem changes. Approximately 1.1 billion people survive on less than $1 per day of income, most of them in rural areas where they are highly dependent on agriculture, grazing, and hunting for subsistence. For these people, degradation and declining productivity of ecosystems threatens their survival.

Ecosystem changes affect human well-being in a variety of different ways. Often the impacts of ecosystem changes are shifted from the groups responsible for them onto other groups. Sometimes ecosystem change is embedded in distributional conflicts over resources, with one group improving at another group's expense. Often impacts are experienced differentially as a function of levels of coping capacity—such differences can manifest themselves at the individual, household, regional, or national level.

Among less poor populations, ecosystem changes affect well-being in more subtle but not necessarily less important ways. Declines in incomes, loss of culturally important natural resources, and increases in threats to health can be expected to accompany declining ecosystem health.

5.1 Introduction

This chapter provides an overview of the primary patterns and trends in human well-being and summarizes what is known broadly about the connections between human well-being and ecosystems. It does not substitute for the more detailed findings found in the other chapters of this volume, but rather provides an overarching empirical foundation for assessing human well-being and ecosystem change side by side.

5.2 Dimensions of Human Well-being

This section reviews how the different dimensions of human well-being are measured, the extent of our knowledge about them, and the primary measurement gaps. (See also Chapter 2 for further description of the measurement of human well-being.) The benefits of qualitative data and new approaches for assessing human well-being are acknowledged, but the use of this information is limited in this global assessment because of difficulties comparing data across countries and aggregating information within units of ecosystems. Five dimensions of human well-being are recognized in the MA: basic material for a good life, freedom and choice, health, good social relations, and security (MA 2003).

5.2.1 Basic Material for a Good Life

The basic materials for a good life include adequate income, household assets, food, water, and shelter. Considerable effort goes into measuring and monitoring these dimensions of well-being. Systems of national accounts generate regular estimates of gross national income and GNP; these estimates are made roughly comparable through calculation of purchasing power parity, estimates that correct for price differences across countries. Food production is measured by central governments and by international organizations such as the Food and Agriculture Organization. FAO also measures national per capita dietary energy supply for most countries. (See Chapter 8 for further information.) Micronutrient information on vitamin A, iodine, and iron is collected at the community level but is not as widely available as DES. National-level water estimates are available, though these tend to be less precise than income and food measures. Of all these measures, shelter is probably the most poorly measured. The distribution of the quality of substandard housing is not known with any confidence.

Increasingly, measures of these basic material dimensions of well-being are being carried out through detailed household surveys (Deaton 1997). Living standard measurement surveys began collecting standardized measures of well-being at the household level in 1985. Approximately 100 developing countries have carried out such surveys. Other large-scale household survey efforts include demographic and health surveys and national-level multiple indicator cluster surveys. Surveys such as these provide information about nutrition, housing type, household assets, and access to water, health care, and sanitation.

Although great effort goes into these measurement efforts, they do not provide a complete enough picture to support a full understanding of the distribution of well-being and its relationship to ecosystem services. Comparable measures of water and sanitation access, for example, are scarce, because terminologies, methodologies, and measurement priorities differ from place to place (Millennium Project 2004). Even the measurements that receive the greatest level of effort, the national income measures, are inadequate for many purposes. They imperfectly capture economic activity outside the formal sector and the value from subsistence activities, for example, which is often highly important among populations vulnerable to decline in ecosystem services.

Especially problematic is the concept of poverty. Although poverty is the focus of many local, national, and international policies, and although many countries measure it, there is little congruence of measurement efforts and, as a result, little ability to portray clear patterns and trends (Deaton 2003; Reddy and Pogge

2002). Some efforts to measure poverty do so strictly in terms of income. For example, the World Bank relies heavily on household survey data to estimate the number of people living on less than $1 per day, and this measure is a prominent component of the Millennium Development Goal targets.

However, measures of income poverty have been criticized because of problems of comparability and relevance. Comparability is difficult because of the challenges involved in comparing prices, which is quite important at such low thresholds of income. Relevance is a problem where human well-being is often heavily dependent on non-income factors such as household assets (stoves, bicycles, toilets, housing materials, and so on) and output from subsistence activities (cultivation, hunting, and fishing). In spite of such measurement and comparability difficulties, an attempt is made here to provide an overview of trends in selected human well-being indicators and ecosystems.

5.2.2 Freedom and Choice

Freedom is defined as the range of options a person has in deciding on and realizing the kind of life to lead. At a broad scale, only a few of the many specific phenomena that are relevant to this dimension of well-being are measured at all, and many of those that are measured are problematic.

The degree to which political institutions are participatory is not measured by any intergovernmental agency, chiefly because of disputes over what are appropriate measures. The most widely used measure in the scientific literature is the polity database, which provides annual measures of democratic institutions for 160 countries (Jaggers and Gurr 1995). The polity data, and similar efforts such as the Heritage Foundation's index of civil liberties, provide comparable, clear measures of national political institutions that emphasize electoral institutions and constraints on chief executives. There are no comparable data that measure citizen participation in decision-making at regional or local levels, although this dimension of freedom and choice has been well connected to ecosystem management and human well-being (Ostrom 1990; Ostrom et al. 2002).

Education is a clear aspect of well-being that enhances life prospects. Comparable international measures are poor. A frequently used measure is literacy, which is a component of the Human Development Index. Literacy is hard to measure accurately and comparably (Bruns et al. 2003). Moreover, it represents only a small aspect of education. Some countries collect comparable data on the percent of the population (often broken down by gender) enrolled in school, but this too is incomplete. More relevant for life prospects is the school completion rate, but this is not well measured.

5.2.3 Health

Human health is measured in a variety of ways, and knowledge about broad trends and patterns concerning health is good. Life expectancy, infant mortality, and child mortality are measured fairly intensively. Most central governments collect these vital statistics and publish them; international organizations such as the World Health Organization and World Bank collate and harmonize these measures. As a result, high-quality country-level time series on these measures are available. Some scholars have been able to construct time series going back several centuries by relying on a range of vital statistics collections (Maddison 2001).

Knowledge of health aspects of human well-being is more limited when it comes to more precise dimensions such as sub-national patterns or specific disease prevalences. There are no consistent monitoring or measurement efforts that measure health outcomes at a sub-national level. Infant mortality and child mortality are measured through a set of coordinated household survey efforts, including the DHS and MICS, and these can be used to generate estimates for sub-national regions, on the order of about 10 regions per country. Such surveys are not carried out in every country, however, and no more than about once per decade. As a result, it is difficult to portray the distribution of human health at a level of resolution more precise than national boundaries.

When it comes to measuring health outcomes in terms of specific diseases, monitoring and surveillance are also less complete than for vital statistics. Few disease incidence statistics are collected across a significant number of countries in a comparable enough fashion to permit robust tracking of patterns. The World Health Organization collects disease-specific data by country, but reports primarily at the level of six world regions because of limitations in comparability (WHO 2004).

5.2.4 Good Social Relations

Humans enjoy a state of good social relations when they are able to realize aesthetic and recreational values, express cultural and spiritual values, develop institutional linkages that create social capital, show mutual respect, have good gender and family relations, and have the ability to help others and provide for their children (MA 2003; Dasgupta and Serageldin 1999). This aspect of human well-being is not well measured, largely because it is more difficult to observe directly. Partly as a result of recent scholarship identifying the importance of social relations and social capital in explaining a range of important public policy outcomes (e.g., Putnam et al. 1993; OECD 2001), interest in measuring this dimension has increased considerably in the past decade. Although comparable quantitative measurements remain very primitive, there are case studies that illustrate the sensitivity of ecosystem changes on good social relations. (See Box 20.12 in Chapter 20, on North America's Great Lakes and Invasive Species.) Some research has noted that high levels of economic development are sometimes associated with poor social relations (Jungeilges and Kirchgässner 2002). Problems such as suicide and divorce are observed consequences of such dynamics.

5.2.5 Security

Humans can be said to live in a state of security when they do not suffer abrupt threats to their well-being. Chapter 6 indicates that people within the geographical region of a threat are differently susceptible to its negative effects. Those who are poor, sick, or malnourished generally have fewer assets and coping strategies and are more likely to be more severely affected.

Some of the most salient threats are organized violence, economic crises, and natural disasters. Comparable measures of organized violence are available for international warfare and civil war, but generally not for banditry and other forms of crime. One prominent collection of data on war is the Uppsala conflict database, which attempts to document all political conflicts resulting in 25 or more deaths for the period 1946–2003 (Gleditsch et al. 2002). It provides measures of the frequency of war as well as estimates of the magnitude of war, and rough information on geographical extent. Political violence is not evenly distributed across the world; it is especially concentrated in the poor countries of the world, though not all poor countries experience violence and not all violence takes place among the poor. Figure 5.1, showing the distribution of political conflict, maps the combined incidence of low-intensity (25 deaths or fewer), middle-intensity, and high-intensity (1,000 deaths or more) conflicts for the period 1975–2003. If a region had all three types of conflicts during each of

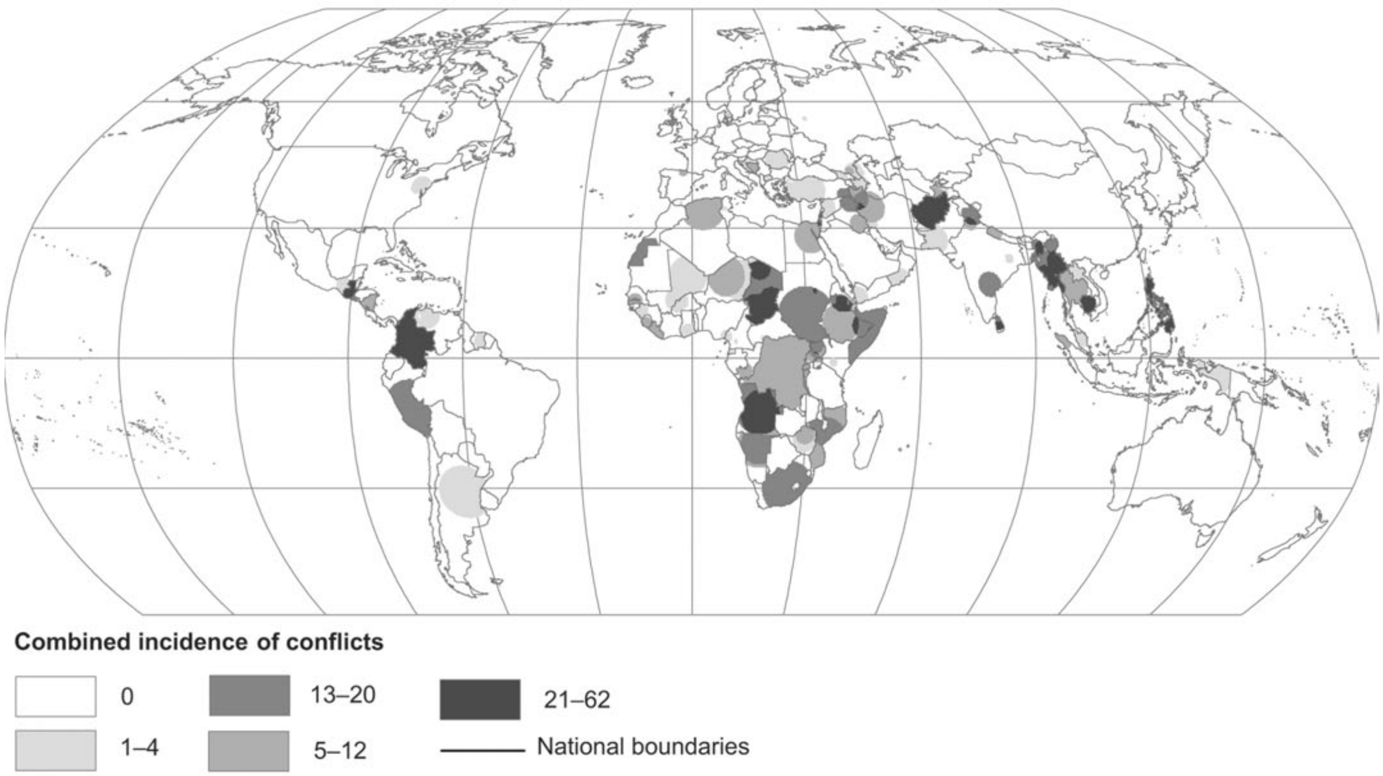


Figure 5.1. Distribution of Internal Political Conflict, 1975–2003 (Robinson Projection)

these 29 years, it would have a value of 87; the observed range is 0–62.

Economic crises—hyperinflation, depressions, exchange-rate shocks, and so on—are well measured by international financial institutions such as the International Monetary Fund, the World Bank, and various regional and national financial authorities. Yet the direct impact of such shocks on ecosystems have not been studied or documented adequately.

Natural disasters are not measured well, though various international organizations and research centers are seeking to improve measurement (Guha-Sapir and Below 2002). The most glaring deficiency in efforts to measure natural disasters is in the area of human impacts. Although some insurance companies undertake considerable efforts to quantify insured economic losses due to natural disasters, many of the grossest effects on human well-being are not insured economic losses, but rather loss of life and shelter in poor communities. (Further information on natural disasters can be found in Chapters 6 and 16.)

5.2.6 Aggregations

A wide variety of efforts to aggregate the multiple dimensions of human well-being have been attempted, the most prominent of which is the Human Development Index. The HDI is endorsed by the intergovernmental community through the U.N. General Assembly and widely used in policy assessments and the scholarly literature. A large number of countries now calculate their own HDIs, typically reporting at sub-national levels. (Other aggregations enjoy less support and are used less widely; see Chapter 2.) The HDI aggregates measures of economic well-being (per capita income), health (life expectancy), and education (literacy and enrollment). It does not take into account cultural or social aspects of well-being, and it considers security dimensions only insofar as they are reflected in economic and health outcomes. It is not meant to be an all-encompassing measure of well-being but rather a useful indicator of development consistent with the development-as-freedom approach pioneered by Sen (1999).

It is acknowledged that human well-being is not equally distributed among different social groups, including among men and women. In response, the U.N. Development Programme in 1995 began calculating the Gender-related Development Index (Prescott-Allen 2001).

Beyond measuring current well-being, there is the important question of sustaining well-being in the future. Asset accounting (an outgrowth of "green" national accounting) provides the necessary framework for assessing sustainability. As Hamilton and Clemens (1999) and Dasgupta and Mäler (2000) show, the change in real wealth—genuine savings—is equal to the change in the discounted future flows of well-being measured in dollars. The World Bank publishes figures on "adjusted net saving" that account for depreciation of assets; investment in human capital; depletion of minerals, energy and forests; and selected pollution damages (World Bank 2004). While ecosystem services are not directly valued in the published figures, the framework is robust enough to incorporate the economic value of the degradation of ecosystem "assets" where these values have been estimated.

5.3 Patterns and Trends in the Distribution of Human Well-being

5.3.1 Global Trends

In the aggregate, human well-being has improved dramatically since the advent of agriculture first made possible the accumulation of wealth. Incomes have risen, life expectancy has gone up, food supplies have risen, culture has become enriched, and political institutions have become more participatory. Two exceptions to this generalization have been the trends in warfare and hunger. Battle deaths (both combatant and civilian) peaked in the middle of the twentieth century, as a consequence of the intensity of the two world wars. Since 1945 they have declined. The second exception is the number of hungry people, which is now increasing. Although the size of world population is not a direct measure of well-being, it constitutes a fundamental background measure and is therefore included in this summary.

Of these trends, population growth shows clear signs of leveling off. (See Chapter 3.) Per capita incomes, life expectancy, and democratization do not yet show signs of leveling off, although they have increased historically at different rates. The absolute number of hungry people began to rise in 1995/97 (FAO 2003), as described in Chapter 8. Warfare patterns are not stable enough to identify clear trends, although the past 50 years have been comparatively peaceful in historical terms. Cultural trends are not susceptible to simple generalizations. Some observers have argued that the global reach of a relatively homogenous mass media threatens local cultural institutions, while others have argued that knowledge of cultural traditions has been able to spread globally; placing values on recent changes such as these is difficult.

Many dimensions of human well-being that can be measured on a large scale, then, have increased considerably over the past 10 centuries and in the aggregate shows signs of continued expansion. Figure 5.2 shows estimates of human life expectancy and per capita income over the past 2,000 years, demonstrating the enormous improvements in basic material aspects of well-being over this long time frame. Figure 5.3 shows trends in the level of democracy and warfare since 1800 in 25-year increments; signs of progress are also visible in these more social dimensions of well-being. As Modelski and Perry (2002) demonstrate, the percentage of the world's population living under democratic institutions has increased steadily for several centuries and crossed the 50% mark in the 1990s. War deaths are lower today than they were in the first half of the twentieth century, but not low in longer historical comparison.

5.3.2 Distributional Patterns

Human well-being is not evenly distributed across individuals, social groups, or nations. Inequality across national boundaries is high by historical standards. Prior to the industrial revolution in the nineteenth century, national differences in economic output per capita were relatively low; as countries and regions accelerated at different rates of industrialization, they generated dramatic differences in economic growth rates (Maddison 2001; Baudrillard 1998). Cross-national income inequality has increased over the past decade (World Bank 2003). National inequality is apparent in other measures of well-being as well. A child born in sub-Saharan Africa is 20 times more likely to die before age five than a child born in an OECD country, and this ratio is higher than it was a decade ago.

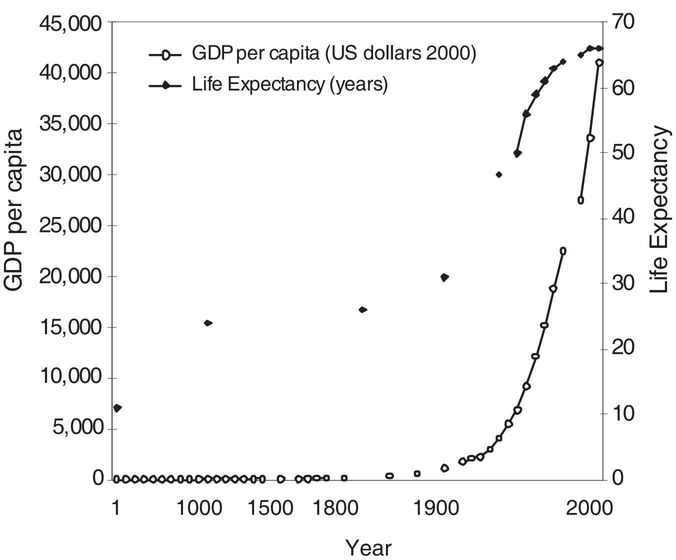


Figure 5.2. Trends for Life Expectancy and Per Capita Income, Past 2,000 Years (Maddison 2001; World Bank 2004; Kremer 1993; Haub 1995; United Nations 1953)

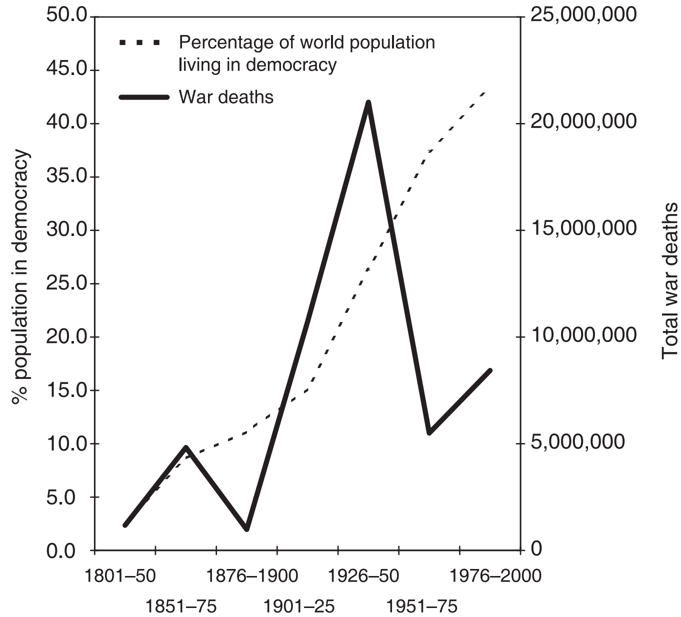


Figure 5.3. Trends in the Level of Democracy and Warfare since 1800 (Modelski and Perry III 1991 and 2002; Sarkees 2000)

At the individual level, the gap between the world's poorest and the world's richest individuals has increased over the past two decades, though whether this signifies a general increase in inequality among the world's population is the subject of debate (UNDP 2003).

Recent increases in human well-being have been most pronounced in East Asia, where income-poverty levels have been reduced by approximately half since 1990. However, there have been systematic decreases in human well-being in many countries over the last decade. Although differences in growth rates are common, absolute declines in well-being on this scale have been rare. During the 1980s only four countries experienced declines in their rankings in the Human Development Index; during the 1990s, 21 countries registered declines, 14 of which were in sub-Saharan Africa (UNDP 2003). Hundreds of millions of people are living in countries with economic growth rates too low to permit significant poverty reductions (UN Millennium Project 2004).

The overall global pattern of human well-being, therefore, is one in which aggregate levels are continuing to increase at historical rates, although a large number of individuals appear to be stuck at very low levels of well-being.

5.3.3 Spatial Patterns

Human well-being is not evenly distributed with respect to the world's ecosystems. At a global level, there are a limited number of measures of human well-being available through which to assess patterns across ecosystem boundaries. Population totals and densities, infant mortality rates, GDP, and GDP per capita can be calculated using spatial data derived from sub-national sources.

The primary indicators for the MA systems and subsystems are reported in Tables 5.1 to 5.4 and shown graphically in Figure 5.4. (These aggregations do not take into account the urban system; a separate set of aggregations is reported in Chapter 27.) Of these indicators, infant mortality is the most spatially representative measure of human well-being because it is available for most countries at a sub-national level. The global distribution of infant mortality rates is provided in Figure 5.5 (in Appendix A).

At the broadest level of generalization, it is clear that infant mortality rates are highest within drylands and that most of the world's population and GDP is located within cultivated systems. One way to assess well-being across ecosystems more precisely is to compare the fraction of the world's population found within each ecosystem to the fraction of the world's GDP within each ecosystem. If well-being were distributed randomly with respect to ecosystem boundaries, these two numbers would be approximately equal in each ecosystem. Where the ratio of population fraction to GDP fraction is much higher than one, people are less well off in relative terms; where it is much lower than one, people are better off.

Table 5.1. Human Well-being Indicators, by MA System

System	GDP	Infant Mortality Rate	Area	Population	Population Density
	(billion dollars)	*(deaths per thousand live births)*	*(million sq. km.)*	*(billion)*	*(people per sq. km.)*
Coastal	9,148	41.5	6.0	1.0	169.7
Cultivated	27,941	54.3	35.3	4.1	116.2
Drylands	10,395	66.6	59.9	2.1	35.2
Forest	11,406	57.7	41.9	1.2	28.4
Inland Water	10,215	57.6	29.1	1.4	48.1
Island	7,029	30.4	7.1	0.6	85.5
Mountain	7,890	57.9	31.9	1.2	38.2
Polar (Arctic)	96	12.8	8.1	0.0	0.7

Table 5.2. Population Growth within MA Systems, 1990–2000

System	Change in Population	Net Change in Population	Change in Population per Square Kilometer
	(million)	*(percent)*	
Cultivated	505.7	14.1	14.3
Dryland	329.6	18.5	5.5
Inland Water	203.5	17.0	7.0
Mountain	171.0	16.3	5.4
Forest	142.1	13.5	3.4
Coastal	140.3	15.9	23.3
Island	67.0	12.3	9.5
Polar	–117.9	–6.5	0.0

Table 5.3. Distribution of Dryland Population Growth, 1990–2000

Region	Increase in Dryland Population	Share of World Population Increase
	(million)	*(percent)*
Asia	180	54.5
Former Soviet Union	5	1.4
Latin America	21	6.4
Northern Africa	65	19.6
OECD	10	3.2
Sub-Saharan Africa	49	14.9
World	**330**	**100.0**

As seen in Figure 5.6, this ratio varies considerably across the MA systems, and this variation is correlated with differences in measured infant mortality rates. The drylands emerge as clearly an ecosystem characterized by low levels of human well-being. (See Box 5.1.) In each region, the dryland ecosystem shows higher infant mortality rates than the forest ecosystems, though the ratio of the two varies across regions. The ratio is highest in the former Soviet Union and lowest in Latin America. (See Table 5.5.)

The same comparisons can be performed for the MA subsystems. The results reveal even greater variation in patterns of human well-being than at the system level. As Figure 5.7 shows, infant mortality ranges from over 100 to under 10 in the MA subsystems, and some subsystems have a share of the world's population that is almost three times as large as their share of the world's GDP. At this level of resolution, the drylands do not emerge as clearly disadvantaged as they do in the system comparison. This is likely to be because the 56 MA subsystems are not distributed as evenly across geopolitical regions as the systems are, and therefore the strong effects of these geopolitical regions become more prominent in the subsystem analysis. For example, the MA subsystem with the highest infant mortality rate and the highest ratio of world population fraction to world GDP fraction is a forest subsystem: broadleaf, deciduous, open tree cover. Three quarters of this subsystem type are found within sub-Saharan Africa, where poverty rates in general are quite high, irrespective of ecosystem type.

It must be emphasized that none of these generalizations implies anything about causality. If infant mortality is high within a particular ecosystem, this does not mean that the ecosystem explains the high infant mortality. Rather, it indicates that the ecosystem is home to populations experiencing comparatively low levels of well-being and that these populations are therefore, other things being equal, potentially vulnerable to declines in ecosystem services.

Table 5.4. Human Well-being Indicators, by MA Subsystems. GDP and infant mortality rate estimates were not calculated for polar subsystems due to lack of appropriate resolution data.

MA System	Subsystem	Area	Population	Population Density	GDP	GDP Per Capita	Infant Mortality Rate
		(thousand sq. km.)	*(million)*	*(people/ sq. km.)*	*(bill. 2000 dollars)*	*(2000 dollars)*	*(deaths per thousand live births)*
Coastal	coastal	6,020	1,022	170	9,148	8,956	41.5
Cultivated	agriculture/ two other land cover types	630	91	145	932	10,202	49.6
	agriculture/forest mosaic	4,459	294	66	3,017	10,272	48.2
	agriculture/other mosaic	5,922	508	86	3,001	5,903	62.2
	agriculture with forest	2,170	247	114	3,003	12,154	38.2
	agriculture with other vegetation	2,884	288	100	2,160	7,492	47.7
	cropland	8,270	3,013	243	8,924	4,433	55.3
	cropland/pasture	2,612	152	58	2,515	16,528	45.1
	forest with agriculture	1,601	97	61	1,969	20,235	15.9
	other vegetation with agriculture	6,659	405	61	2,299	5,677	65.2
	pasture	108	7.6	70	120	15,790	32.8
Dryland	dry subhumid	12,689	910	72	3,886	4,271	60.7
	semiarid	22,270	855	38	4,773	5,580	72.4
	arid	15,325	243	16	1,135	4,677	74.2
	hyper-arid	9,635	101	11	601	5,928	41.3
Forest	mosaic: tree cover/ other natural vegetation	2,409	53	22	217	4,137	59.3
	tree cover, broadleaved, deciduous, closed	6,526	348	53	3,312	9,503	58.9
	tree cover, broadleaved, deciduous, open	3,776	88	23	232	2,645	103.7
	tree cover, broadleaved, evergreen	12,210	266	22	1,436	5,394	60.3
	tree cover, burnt	298	0.3	1.0	2.4	8,238	15.9
	tree cover, mixed leaf type	3,182	51	16	953	18,843	12.4
	tree cover, needle-leaved, deciduous	3,804	3.5	0.9	28	8,127	27.2
	tree cover, needle-leaved, evergreen	9,032	370	41	5,184	14,013	28.5
	tree cover, regularly flooded, fresh	562	3.6	6.3	20	5,531	73.4
	tree cover, regularly flooded, saline (daily variation)	89	7.9	89	22	2,794	90.0

If the geopolitical regions are brought into the analysis explicitly, additional detail can be seen. Figure 5.8 (in Appendix A) shows that the differences across geopolitical regions are by and large more significant than the differences across ecosystem boundaries. Sub-Saharan Africa is less well off within each ecosystem than all other world regions, for example. There is also significant deviation from global averages within Asia: the Asian cultivated system contains 44% of the world's population, for example, but only 20% of the world's GDP.

By looking simultaneously at world geopolitical regions and the MA subsystems, the world is divided into 274 overlapping units. The basic patterns are seen in Figure 5.9 (in Appendix A). Well-being disparities across ecosystem types are lowest in the OECD countries and highest in Asia and sub-Saharan Africa. The very low variation within the OECD countries probably reflects the fact that high incomes and advanced infrastructures eliminate the kind of gross sensitivity to ecosystem effects that would influence infant mortality. This figure also shows the fundamentally

Table 5.4. *continued*

MA System	Subsystem	Area	Population	Population Density	GDP	GDP Per Capita	Infant Mortality Rate
		(thousand sq. km.)	*(million)*	*(people/ sq. km.)*	*(bill. 2000 dollars)*	*(2000 dollars)*	*(deaths per thousand live births)*
Inland Water	50–100% wetland	2,157	13	6.3	454	33,623	6.1
	bog, fen, mire	2,305	7.4	3.2	98	13,243	25.1
	freshwater marsh, floodplain	4,606	403	87	1,123	2,789	68.5
	intermittent wetland/lake	4,946	128	26	558	4,355	68.2
	lake	9,538	522	55	5,390	10,329	45.5
	pan, brackish/saline wetland	619	11	18	59	5,279	59.8
	reservoir	649	37	57	278	7,504	47.1
	river	2,382	258	108	2,174	8,426	52.3
	swamp forest, flooded forest	1,902	21	11	82	3,993	76.7
Island	island state	3,949	375	95	1,787	4,767	36.0
	non-state island	3,125	230	74	5,242	22,794	11.8
Mountain	dry boreal/subalpine	997	10	10	46	4,436	85.2
	dry cool temperate montane	2,936	145	49	761	5,259	54.2
	dry subpolar/alpine	315	1.2	3.7	5.1	4,347	5.8
	dry subtropical hill	2,078	47	23	292	6,246	58.3
	dry tropical hill	467	16	33	56	3,595	73.8
	dry warm temperate lower montane	1,364	45	33	272	6,034	60.5
	humid temperate alpine/nival	1,605	4.4	2.8	33	7,381	51.1
	humid temperate hill and lower montane	3,888	373	96	3,101	8,321	42.8
	humid temperate lower/ mid-montane	1,591	91	57	1,232	13,512	29.8
	humid temperate upper montane and pan-mixed	5,143	54	10	357	6,659	39.1
	humid tropical alpine/nival	151	1.3	8.8	28	21,093	39.7
	humid tropical hill	942	57	60	198	3,487	55.4
	humid tropical lower montane	5,673	348	61	1,344	3,858	73.3
	humid tropical upper montane	212	16	74	99	6,253	35.1
	polar/nival	4,574	11	2.5	66	5,723	48.1
Polar	barrens and prostrate dwarf shrub tundra (includes rock/lichens and prostrate tundra)	2,628	0.5	0.2	8.5	18, 805	10.9
	forest tundra (includes low shrub tundra)	1,435	0.7	0.5	16	22,537	7.0
	graminoid, dwarf-shrub, and moss tundra	3,356	1.0	0.3	23	22,017	6.8
	ice	444	0.0	0.0	1.2		0.2
	lakes	595	4.0	6.7	48	12,019	10.7

different situation that sub-Saharan Africa is in with respect to well-being patterns. Almost all of its IMR values are higher than those found in any other region. Significant exceptions are the Asian dry boreal/subalpine subsystem and the Asian arid subsystem, where IMR values are much higher than the Asian average and well within the sub-Saharan African range.

5.3.4 Temporal Patterns

Most global socioeconomic indicators that are available in spatially disaggregated (sub-national) formats are not available in time series, and therefore it is difficult to say much about broad trends within the MA system boundaries. The exception to this generalization is

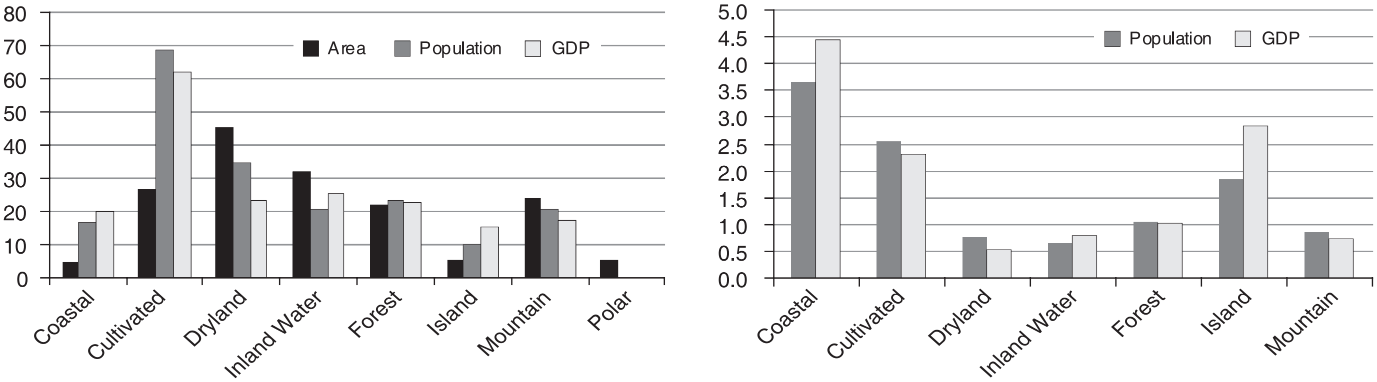


Figure 5.4. MA System Attributes as Percentage of World Total and Share of World Population and GDP as Ratio of Share of World Area (CIESIN 2004)

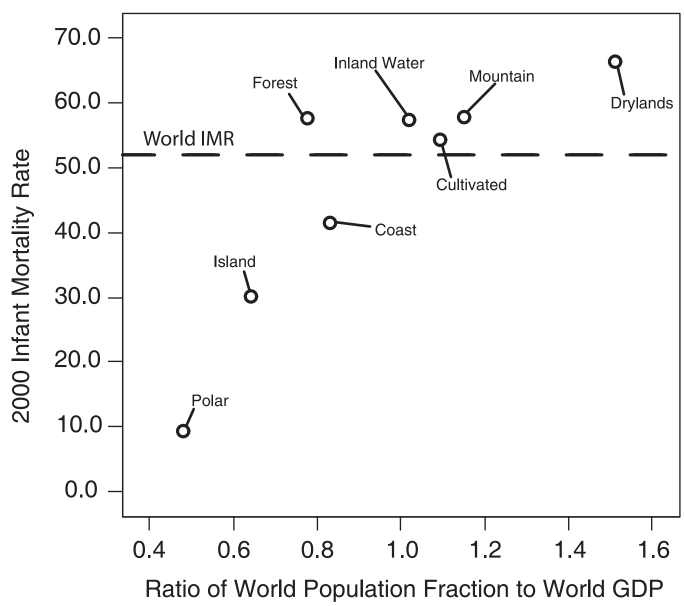


Figure 5.6. MA Systems and Relative Measures of Well-being

population. Because most countries carried out censuses both around 1990 and around 2000, and since these have been geo-referenced and integrated into a consistent grid, it is possible to estimate changes over the 1990–2000 period within the MA systems, as in Table 5.2.

Considering the global MA systems, the fastest growth rate during the 1990s occurred in the drylands, where population increased by 18.5%. The MA system with the greatest increase in total population is the cultivated system, where population increased by 506 million. If population growth is divided by land area, the highest value is observed in the coastal zone, where over the 1990s population grew by 23.3 people per square kilometer.

The fact that the highest growth rates are in an especially vulnerable ecosystem is significant. As the World Bank (2003) has pointed out, historically populations have migrated out of marginal lands to cities or to agriculturally productive regions; today the opportunities for such migration are limited due to poor economic growth in many African cities and much tighter immigration restrictions in wealthy countries.

Table 5.3 showed how the increased population in the drylands is distributed across world regions. More than half the people are located in Asia, but significant portions are also in Africa.

5.4 Sensitivity to Ecosystem Change

This section briefly reviews the state of knowledge about the degree to which the various dimensions of human well-being are sensitive to ecosystem change. In assessing the level of sensitivity, several issues arise that make an isolated understanding of the exact effect of a change in ecosystems on human well-being difficult. The affects of appropriating an ecosystem service today may have a different effect in the future on the appropriating social group. For example, the consumption of water today for irrigation will raise current crop productivity for the consuming population, but the impact on the future population is unknown, and so the net effect cannot be determined. Another difficulty in isolating the human well-being impact of ecosystem change is the distribution of ecosystem services. These may be derived from one geographical location but consumed in another one. Devising the net impact needs to take into account the costs and benefits to groups in all affected geographical locations.

5.4.1 Basic Material for a Good Life

The assessment of changes in the ecosystems on access to the basic needs for a good life has been one of the two dimensions of

BOX 5.1

Drylands and Human Well-being

Dryland ecosystems are characterized by extreme rainfall variability, recurrent but unpredictable droughts, high temperatures, low soil fertility, high salinity, grazing pressure, and fires. They reflect and absorb solar radiation, maintain balance in the functioning of the atmosphere, and sustain biomass and biodiversity. (This section is derived from World Bank 2003.)

Of the 500 million rural people who live on arid and dry semiarid land (see Table), most live in Asia and Africa, but there are also large pockets in Mexico and Northeastern Brazil. The low volume and extreme variability of precipitation limit the productive potential of this land for settled farming and nomadic pastoralism. Many ways of expanding agricultural production in the drylands—shifting cultivation from other areas, reducing fallow periods, switching farming practices, overgrazing pasture areas, cutting trees for fuelwood—result in greater environmental degradation.

Rural Population Living on Arid Lands (World Bank 2003)

Land Characteristics	Number of People *(million)*
Aridity only	350
Arid, slope	36
Arid, poor soil	107
Arid, slope, poor soil, forest	25
Total	518

The Southern Plains of North America, Africa's Sahel, and the inner Asian grasslands face similar climatic and soil characteristics but different political, financial, and institutional constraints. The result is differing patterns of resource management, with different impacts on human well-being.

The Southern Plains of North America

The European settlers in the Great Plains converted prime grazing land into intensive agricultural uses (monocropping, usually wheat). This pattern was badly suited to the lighter soils of the Southern Plains. Deep plowing dislodged soils, and monocropping mined soil nutrients. Large-scale farming in the 1920s pushed the expansion of wheat cultivation further onto native grasslands. By the next decade overgrazing, overplowing, and monocropping were exacerbated by the worst drought in U.S. history. An area of about 50 million hectares was affected each year in the Dust Bowl of the 1930s. (This section is based on Worster 1979.)

The response to the Dust Bowl included zoning laws for the most fragile areas, repurchases of submarginal private land, cash payments for leaving land fallow, and farm loans tied to approved land practices. In addition, there was planting of shelterbelts, adoption of soil and water conservation techniques such as the introduction of contour plowing, small dam and pond construction, mixed cropping, replanting of grasses, and state and federal protection of the remaining open grasslands.

Beginning in 1940, normal rainfall patterns resumed, while outmigration reduced the farm population and increased farm sizes (about 1 million people left the area between 1930 and 1970). But in the 1950s Dust Bowl II hit, followed in the 1970s by Dust Bowl III. Conservation practices had helped, but to achieve reliable production the United States needed to achieve a "climate-free" agriculture on the plains. In response, a striking feature has been the reliance on fossil fuel–intensive agricultural production with deep pumping of underground aquifers (up to 600 feet), and heavy reliance on chemical fertilizers and mechanization. In the Texas High Plains Region, irrigated land area shrunk by 34% between 1974 and 1989 because the cost of overpumping the Ogallala aquifer exceeds the value of crops grown there. This vast aquifer is now being pumped faster than replenishment rates, with a net depletion rate of 3.62 million acre-feet (4.5 billion cubic meters) a year (Postel 1993).

The African Sahel

Throughout much of Africa the plowing and monocropping on fragile soils adopted in colonial times continued after independence (Swearingen and Bencherifa 1996). Inappropriate land use can rapidly lower soil quality, and intensive cultivation can deplete soil nutrients. Deforestation can cause erosion, washing away the layers of soil most suitable for farming. Two patterns are typical in Africa (note, however, that population growth in low density areas can be positive for resource management; see Tiffen et al. 1994):

- Growing populations convert high quality pastureland to grow cash crops. Herders lose the better grazing land, their security against drought. Migratory movements for herders are reduced, lower-quality land is more intensively grazed, and overgrazing leads to degradation.
- Poor subsistence farmers reduce fallow periods in order to grow more food to feed growing families. The reduction in fallow increases vulnerability to drought and without sufficient inputs, depletes soil nutrients. Degradation and soil erosion get worse.

In the Sahel, favorable rainfall from the 1950s to the mid-1960s attracted more people to the region. However, rainfall reverted to normal low levels after 1970, and by the mid-1970s many people and their livestock had died. The possibility that the Sahel could enter another period of favorable rainfall poses the risk of repeating the same tragedy as poor people are drawn back to the land. The Intergovernmental Panel on Climate Change (IPCC 2002) reports that Africa is highly vulnerable to climate change. Although the equatorial region and coastal areas are humid, the rest of the continent is dry subhumid to arid. Global warming scenarios suggest that soil moisture and runoff will be reduced in subhumid zones. Already, water storage has been reduced to critical levels in some lakes and major dams, with adverse repercussions for industrial activity and agricultural irrigation.

The poor quality of soils in the Sahel is another constraining environmental factor. Phosphorus deficiency, low organic content, and low water infiltration and retention capacity on much of African soil have been limiting factors in agriculture. Unlike climate variability, this problem can be addressed: soil quality can be augmented through careful management and soil nutrient supplementation. More difficult to address are the recurrent droughts.

The Asian Drylands

Population pressure on arable land in Asia is considerable and growing. Severe land degradation affects some 35% of productive land. The result has been to put more population pressure on the Inner Asian drylands. Most affected are Afghanistan, China, India, and Pakistan (FAO et al. 1994; ESCAP 1993), as well as Inner Asia's high steppe, the largest

(continues over)

BOX 5.1
continued

remaining pastureland in the world, which includes Mongolia, northwestern China, and parts of Siberia. Over thousands of years, these grasslands have been home to nomadic herders of horses, camels, goats, sheep, and cattle who practice elaborate systems of seasonal pasture rotation across wide stretches of land in response to climate fluctuations. Herd rotation has helped sustain the fertility and resilience of grassland ecosystems and improve the health of livestock (Ojima 2001).

Over the past decade, population pressures and competing uses on these fragile lands have made it hard to find the right balance between traditional land management and demand for higher agricultural productivity. Government policies that discouraged a nomadic lifestyle, herd movement, and temporary use of patchy grasses led to dependence on agricultural livelihoods and sedentary herds, which created greater pressure on local ecosystems and degraded fragile grasslands. The contrasting experiences of Mongolia and northwestern China illustrate some of the problems.

Mongolia has retained many traditional herding customs and customary tenure with land management as a commons. (This section is drawn from WRI 2000 and from Mearns 2001, 2002.) Herders rely on local breeds (which are stronger and more resilient) that graze year-round on native grasses. These customary practices were effectively supported by collective agriculture between the 1950s and 1980s. Policies allowed people and herds to move over large areas and provided the possibility of sustainable grasslands management under controlled-access conditions.

The economic transition since 1990 has not been conducive to sustainable management. Livestock mobility declined significantly. Many public enterprises closed. Having few alternatives, people turned to herding—often for the first time. The numbers of herders more than doubled from 400,000 in 1989 (17% of Mongolia's population) to 800,000 in the mid-1990s (representing 35%). Poverty also increased to 36% of the population by 1995 from a very low base in the 1980s. Herd size grew from the traditional 25 million head to about 30 million. Today, an estimated 10% of pastureland is believed to be degraded, causing noticeable increases in the frequency and intensity of dust storms.

This problem is considered manageable in Mongolia because population pressures are not very high. Rural population increased by about 50% from 1950 to 2000 (compared with a 700% increase in neighboring northwestern China).

As in Mongolia, the grasslands in China are state-owned. (This section is drawn from Mearns 2001, 2002.) But settled pastoralism and the conversion of grasslands to arable cultivation were more common in northwestern China than in Mongolia, beginning in the 1950s, when state-owned pastureland was allocated to "people's communes." The concentration of people in villages meant declining pasture rotation and expanding agriculture. Policies encouraged conversion of prime pasturelands into arable cropland, leading to salinization and wind erosion in some areas.

Common policies were applied to highly diverse circumstances, resulting in perverse outcomes and higher degradation in some places. Subsidies encouraged mixed farming systems, which put more pressure on fragile land than the traditional mobile pastoralism. Economic reforms in the early 1990s granted households nominal shares in the collective land pool. Shared areas were fenced off, making herd mobility more difficult. Subsidized inputs, income transfers, and deep pumping of underground aquifers encouraged a rapid increase in farming. From an estimated 3 million indigenous pastoralists in the 1950s in the Inner Mongolian part of northwestern China, farmers and livestock producers today number 20 million, and cattle doubled from 17 million head in 1957 to 32 million today.

China's western development plan shares two characteristics with the policies followed in the Southern Plains of the United States: intensification of agricultural production and creation of "climate-free" agriculture in the grasslands through irrigation from underground aquifers. The objective is to make the area a bread-and-meat basket to meet China's growing demands for protein-rich diets. But unlike the Southern Plains—where about 1 million farmers left between the 1930s and the 1970s, enabling reconsolidation of landholdings and conversion of vast grassland areas to protected areas—population pressures have continued to increase in China's grasslands. Poverty rates in these degraded and ecologically sensitive areas are well above the national average (25% in some provinces, compared with the national average of 6.3%). The frequency and intensity of dust storms are increasing. Estimates of areas degraded are 50–75%, compared with 10–15% in the grasslands of Mongolia.

Improving Prospects for Well-being in the Drylands

Agricultural research in China and India shows diminishing returns to investments in many high-potential areas, but investments in drylands can produce large returns in reducing poverty, even if yields are modest (Hazell 1998; Hazell and Fan 2000; Fan et al. 2000; Wood et al. 1999). Governments, researchers, and donor organizations are beginning to pay some attention to research and development on crop breeding varieties for people on marginal lands, but much more needs to be done by the public sector to replace antiquated crop varieties (UNEP 1992, 1997). In partnership with South African institutions, the International Maize and Wheat Improvement Center (a research center of the Consultative Group on International Agricultural Research) has developed two maize varieties for small farmers in South Africa's drought-prone, acidic, nutrient-depleted soils. Both varieties are drought-resistant, and one matures early, when farm food supplies are at their lowest. Trials from Ethiopia to South Africa have shown yields that are 34–50% higher than currently grown varieties (Ter-Minassian 1997; Rodden et al. 2002; Bardham and Mookherjee 2000). There are opportunities to achieve sustainable livelihoods in quite a few areas. But development decision-makers must recognize that the drylands are not homogeneous and cannot be made to function sustainably as non-drylands.

Some arid areas can take advantage of solar energy potential; others may have scenic value worthy of ecotourism development. The Mozambique Transfrontier Conservation Area Program and Burkina Faso's wildlife reserve development are two attempts in the direction of ecotourism that combine local and international cooperation. Research and innovations for appropriate service delivery—combined with policies that link human activities (farming, herding, and settlements) with natural processes (vegetation distribution, seasonal growing cycles, and watersheds)—can help sustain vulnerable dryland ecosystems while enhancing productivity to support growing populations.

Table 5.5. Ratio of Infant Mortality Rate in Drylands to Rate in Forests, by Region

Region	IMR in Drylands / IMR in Forests
	(ratio)
Asia	1.6
Former Soviet Union	2.6
Latin America	1.0
Northern Africa	1.2
OECD	1.4
Sub-Saharan Africa	1.1

human well-being that has been most thoroughly investigated, and there are numerous well-documented examples demonstrating that declining ecosystem services are capable of having serious negative consequences on incomes, food security, and water availability. Some studies have also suggested that the decline and in some cases even the collapses of several ancient civilizations—including the Mesopotamians, the ancient Greeks, the Mayans, the Maori, and the Rapanui of Easter Island—were associated with the overexploitation of biological resources (Deevey et al. 1979; Flenley and King 1984; van Andel et al. 1990; Ponting 1991; Flannery 1994; Diamond 1997; Redman 1999).

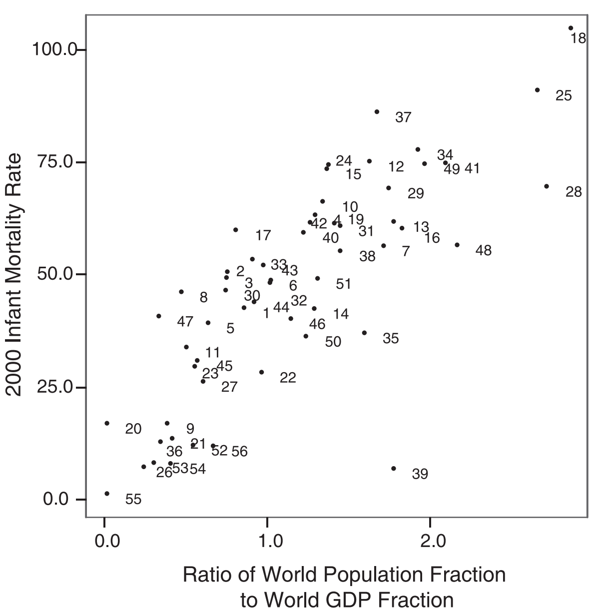
Economic theory shows clearly how continued improvements in income depend on growing levels of assets to be sustainable. If assets, or wealth, do not grow, incomes will eventually fall (Sachs et al. 2004). Some economists have attempted to quantify the natural resource components to assets, including such resource stocks as forests and minerals (Repetto et al. 1989; Vincent et al. 1997; Lange et al. 2003), and have sought to estimate the net social benefits of habitat conversion, taking into account both the narrow economic gains associated with conversion and the decline of broader social benefits. These studies support the generalization that private gains achieved by conversion are typically outweighed by the loss of public benefits, so that in overall societal terms, conversion of remaining intact habitat rarely makes net economic sense (Balmford 2002; Turner et al. 2003). For example, the early 1990s collapse of the Newfoundland cod fishery has cost tens of thousands of jobs, as well as at least $2 billion in income support and retraining (Beaudin 2001).

Recent reviews of such dynamics have concluded that many countries appear to be experiencing declines in net per capita assets when such resource components are taken into account (Dasgupta and Mäler 2004; Hamilton and Clements 1999). (See Box 5.2.) These findings suggest that some of the declines in well-being in sub-Saharan Africa may be in part attributable to declines in natural resource assets, and that other regions currently experiencing increases in well-being may be doing so at the expense of a declining resource base, which will create problems in the future.

5.4.2 Freedom and Choice

There are some direct connections between ecosystem services and the freedom and choice dimensions of well-being that are partly understood. The declining provision of fuelwood and drinking water as the result of deteriorating ecosystems, for example, has been shown to increase the amount of time needed to collect such basic necessities, which in turn reduces the amount of time available for education, employment, and care of family members. Such impacts are typically thought to be disproportionately experienced by women. However, the empirical foundation for this understanding is limited to a handful of isolated studies (e.g., Awumbila and Momsen 1995); little work based on comparative, cross-national data has been done.

The findings in the literature on common pool or common property resources is that when a resource is abundant relative to demand, there tend to be few rules about its use. If a resource is valuable and limited, however, then common property institutions develop (Ostrom 1990). Such institutions evolve according to the importance of the resource in question, the technology used to exploit it, and various social or political changes in that society. For many kinds of commons, such as forests, water, and grazing lands, resources may be controlled under government



Key:

ID	System	Subsystem
1	Coast	Coast
2	Cultivated	Agriculture/2 other land cover types
3	Cultivated	Agriculture/Forest mosaic
4	Cultivated	Agriculture/Other mosaic
5	Cultivated	Agriculture with forest
6	Cultivated	Agriculture with other vegetation
7	Cultivated	Cropland
8	Cultivated	Cropland/Pasture
9	Cultivated	Forest with agriculture
10	Cultivated	Other vegetation with agriculture
11	Cultivated	Pasture
12	Drylands	Arid
13	Drylands	Dry subhumid
14	Drylands	Hyperarid
15	Drylands	Semiarid
16	Forest	Mosaic: Tree cover/other natural vegetation
17	Forest	Tree cover, broadleaved, deciduous, closed
18	Forest	Tree cover, broadleaved, deciduous, open
19	Forest	Tree cover, broadleaved, evergreen
20	Forest	Tree cover, burnt
21	Forest	Tree cover, mixed leaf type
22	Forest	Tree cover, needle-leaved, deciduous
23	Forest	Tree cover, needle-leaved, evergreen
24	Forest	Tree cover, regularly flooded, fresh
25	Forest	Tree cover, regularly flooded, saline
26	Inland Water	50–100% wetland
27	Inland Water	Bog, fen, mire
28	Inland Water	Freshwater marsh, floodplain
29	Inland Water	Intermittent wetland/lake
30	Inland Water	Lake
31	Inland Water	Pan, brackish/saline wetland
32	Inland Water	Reservoir
33	Inland Water	River
34	Inland Water	Swamp forest, flooded forest
35	Island	Island state
36	Island	Non-state island
37	Mountain	Dry boreal/subalpine
38	Mountain	Dry cool temperate montane
39	Mountain	Dry subpolar/alpine
40	Mountain	Dry subtropical hill
41	Mountain	Dry tropical hill
42	Mountain	Dry warm temperate lower montane
43	Mountain	Humid temperate alpine/nival
44	Mountain	Humid temperate hill and lower montane
45	Mountain	Humid temperate lower/mid montane
46	Mountain	Humid temperate upper montane and pan-mixed
47	Mountain	Humid tropical alpine/nival
48	Mountain	Humid tropical hill
49	Mountain	Humid tropical lower montane
50	Mountain	Humid tropical upper montane
51	Mountain	Polar/nival
52	Polar	Barrens and prostrate dwarf shrub tundra (includes rock/lichens, and prostrate tundra)
53	Polar	Forest tundra (includes low shrub tundra)
54	Polar	Graminoid, dwarf-shrub, and moss tundra
55	Polar	Ice
56	Polar	Lakes

Figure 5.7. MA Subsystems and Relative Measures of Well-being

BOX 5.2

Economic Values Associated with Ecosystem Services

Many ecosystem services, such as the purification of water, regulation of floods, or provision of esthetic benefits, do not pass through markets. The benefits they provide to society, therefore, are largely unrecorded: only a portion of the total benefits provided by an ecosystem make their way into statistics, and many of these are misattributed (the water regulation benefits of wetlands, for example, do not appear as benefits of wetlands but as higher profits in water-using sectors). Moreover, for ecosystem services that do not pass through markets there is often insufficient incentive for individuals to invest in their maintenance (although in some cases common property management systems provide such incentives). Typically, even if individuals are aware of the services provided by an ecosystem, they are neither compensated for providing these services nor penalized for reducing them.

Nonmarketed ecosystem services do have economic value, and a number of techniques can be used to measure the economic benefits of the services and the costs of their degradation. (See Chapter 2.) A growing literature exists concerning measurements of the value of the nonmarketed ecosystem services, in order to provide better estimates of the total economic value of ecosystems (Pearce and Warford 1993). Some of the methods used to value nonmarketed services are still controversial, and in some cases estimates of the same services may differ by as much as several orders of magnitude. Moreover, even in the cases where the economic valuation methods are well established, the physical and ecological information necessary to value marginal changes in ecosystems may not be available. (For example, the calculation of the marginal cost of deforestation in terms of reduced water services requires accurate information on the relationship between forest cover loss and change in the timing and magnitude of river flows, and that biophysical information may not be available.)

Despite these challenges, even imperfect estimates of the economic costs and benefits of changes in ecosystem services can be useful for decision-making. Well-designed valuation studies tell us not only how much ecosystem services are worth, but inform resource management decisions with information about the economic benefits of alternative management options. Moreover, valuation studies help to identify who benefits from different ecosystem services and how various factors, including institutional ones, influence values. Information on beneficiaries and their willingness-to-pay under different institutional arrangements can help in the design of payment mechanisms or of mechanisms to turn economic values into actual financial flows.

The marketed portion of ecosystem services is often only a small portion of the total economic value of an ecosystem. In the case of forest ecosystems, for example, marketed services can include some provisioning services, such as timber production, and some cultural services, such as recreation. Even these services are only partially marketed: informal collections of fuelwood and non-timber products such as fruit and mushrooms, for example, are often not marketed (although local systems of rights or management may serve to maintain sustainable harvests). Regulating and supporting services have rarely been marketed, although some markets—such as for carbon sequestration—have recently been established to ameliorate the rate of change in climate services.

Figure A in Appendix A shows the results of one of the few comprehensive efforts to estimate the TEV of ecosystems on a significant scale, in this case forests in selected Mediterranean and nearby countries. Timber and fuelwood generally account for less than a third of estimated TEV, on average, and even this share is likely overestimated as it is easier to measure such provisioning services than other services. Recreation and hunting benefits were imperfectly measured, but in European countries these benefits rival and sometimes exceed timber values. Watershed protection is an important benefit in Italy, Syria, Tunisia, Algeria, and Morocco and would likely have played an important role in several other countries as well had it been possible to better estimate its value. If forests were to be considered only for their timber, as is all too often the case, they would appear much less valuable than they actually are and would tend to be managed only for their extractive uses, such as timber harvest.

The estimated values of individual non-marketed ecosystem services are often substantial but are rarely included in resource management decisions, although incorporation of these values is now beginning to become somewhat more common. For example:

- *Recreational benefits of protected areas:* The annual recreational value of the coral reefs of each of six marine protected areas in the Hawaiian Islands in 2003 ranged from $300,000 to $35 million (van Beukering and Cesar 2004).
- *Water quality:* The net present value in 1998 of protecting water quality in the 360-kilometer Catawba River in the United States for a five-year period was estimated to be $346 million (Kramer and Eisen-Hecht 1999).
- *Nursery habitat for fisheries:* Deforestation of an 860-square-kilometer mangrove habitat in the state of Campeche, Mexico, at an average rate of 2 square kilometers a year in 1980–90 resulted in a loss in shrimp harvest each year of about 28.8 tons, amounting to a loss of approximately $279,000 in revenue (Barbier and Strand 1998). In contrast, a 1981 study of the marginal value of wetlands on the Gulf Coast of Florida for production of blue crab estimated the present value of only $7.40 per hectare (Lynne et al. 1981).
- *Water purification service of wetlands:* Approximately half of the total economic value of the Danube River floodplain in 1992—which included values associated with timber, cattle, fisheries, recreation, hunting, and the filtering of nutrients—could be accounted for in its role as a nutrient sink (Gren et al. 1995).
- *Native pollinators:* A study in Costa Rica found that forest-based pollinators increased coffee yields by 20% within 1 kilometer of forest (as well as increasing the quality of the coffee). During 2000–03, pollination services from two forest fragments (of 46 and 111 hectares) increased the income of a 1,100-hectare farm by $60,000 per year, a value commensurate with expected revenues from competing land uses (Ricketts et al. 2004).
- *Flood control:* Muthurajawela Marsh, a 3,100-hectare coastal peat bog in Sri Lanka, provides an estimated $5 million in annual benefits ($1,750 per hectare) through its role in local flood control (Emerton and Bos 2004).
- *Open space protection:* In an ex-urban area of Maryland in the United States, the marginal economic benefits per household of preserving neighboring open space range from $994 to $3,307 per acre of farmland preserved (Irwin 2002). And in Grand Rapids, Michigan, lots for residential homes that border forest preserves were found to sell at premiums of about $5,800–8,400 during the 1990s (19–35% of lot price) (Thorsnes 2002).
- *Biochemical resources:* Estimates of the economic value of species-rich ecosystems (such as neotropical forests) for bioprospecting for new pharmaceutical products range from $20 to $9,000 per hectare, depending on assumptions used in the economic models (Simpson et al. 1996; Rausser and Small 2000).

Relatively few studies have compared the TEV of ecosystems under alternate management regimes. The results of several that attempted to do so are shown in the Table. In each case where the TEV of sustainable management practices was compared to management regimes involving conversion of the ecosystem or unsustainable practices, the benefit of managing the ecosystem more sustainably exceeded that of the converted ecosystem, although the private benefits—that is, the actual monetary benefits captured from the services entering the market—would favor conversion or unsustainable management.

These studies are consistent with the understanding that market failures associated with ecosystem services lead to greater conversion of ecosystems than is economically justified. However, this finding would not hold at all locations. For example, the value of conversion of an ecosystem in areas of prime agricultural land or in urban regions often exceeds the total economic value of the intact ecosystem (although even in dense urban areas, the TEV of maintaining some "greenspace" can be greater than development of these sites). Similarly, in a study of the economic benefits of forest protection for maintaining water flows as "drought mitigation" for farmers in Eastern Indonesia, Pattanayak and Kramer (2001) found that where increased watershed protection mitigates droughts, the economic benefits can be sizable (as much as 10% of annual agricultural profits), but they found that forest cover did not necessarily increase baseflow for all households in a watershed or in all watersheds.

Comparisons of Economic Benefits of Retaining and Converting Ecosystems. (Values in dollars, rounded to two significant digits.) Each of the examples selected includes estimates of one or more regulating or cultural services in addition to provisioning services.

Ecosystem	Alternatives Compared	Services Included in TEV Calculations	Private Benefits	Total Economic Value	Source
Comparison of benefits of sustainably managed ecosystem to converted ecosystem					
Tropical forest, Cameroon	comparison of low-impact logging to small-scale farming or conversion to oil palm and rubber plantation	benefits from agricultural or plantation output, sedimentation control, flood prevention, carbon storage, and option, bequest and existence values; 10% discount rate over 32 years	Small-scale agriculture had greatest private benefits	across five study sites, average TEV of sustainable forestry was approximately $3,400 per hectare and that of small-scale farming $2,000 per hectare; across four of the sites, average TEV of conversion to oil palm plantation was $-1000 per hectare	Yaron 2001
Mangrove, Thailand	comparison of existing uses of mangrove system to conversion to shrimp farming	benefits from shrimp farming, timber, charcoal, NTFPs, offshore fisheries, and storm protection. 10% discount rate over 20 years	conversion to aquaculture had greatest private benefits	TEV value of intact mangroves was a minimum of $1,000 and possibly as high as $36,000 per hectare; TEV of shrimp farming was about $200 per hectare	Sathirathai and Barbier 2001
Wetland, Canada	comparison of intact wetlands to conversion to intensive farming	benefits of agriculture, hunting, angling, trapping; 4% discount rate over 50 years	conversion to agriculture had highest private benefits (in part due to substantial drainage subsidies)	TEV was highest for intact wetlands (average for three wetland types of approximately $5,800 per hectare) versus TEV of converted wetlands of $2,400 per hectare	Van Vuuren and Roy 1993
Tropical forest, Cambodia	comparison of traditional forest uses to benefits associated with commercial timber extraction	examined benefits associated with swidden agriculture and extraction of non-timber forest products (including fuelwood, rattan and bamboo, wildlife, malva nuts, and medicine) and ecological and environmental functions such as watershed, biodiversity, and carbon storage; 6% discount rate over 90 years	private benefits associated with unsustainable harvest practices exceeded private benefits of NTFP collection	total benefits were greatest for traditional uses, ranging from $1,300 to $4,500 per hectare (environmental services accounted for $590 per hectare while NTFPs provided between $700 and $3,900); private benefits for timber harvest ranged from $400 to $1,700 per hectare but after accounting for lost services the total benefits were $150 to $1,100 per hectare	Bann 1997
Comparison of benefits of establishing protected area to current use					
Coastal habitat, Jamaica	comparison of current management (includes destructive fishing, loss of mangroves, pollution) to establishment of Portland Bight Protected Area	benefits of fisheries, forestry, tourism, carbon sequestration, biodiversity, costal protection; 10% discount rate over 25 years	current overfishing has resulted in a decline of profits effectively to zero	total incremental benefits of establishment of protected area estimated to be $53 million ($28 per hectare) in the optimistic tourism scenario and $41 million ($22 per hectare) in the pessimistic tourism case; cost of protected area establishment and management would total $19 million ($10 per hectare) over the next 25 years, resulting in net benefits of $11 to $18 per hectare	Cesar et al. 2000
Marine protected areas, Hawaii	comparison of net benefits of protection of six existing MPAs with the costs associated with their protection	benefits associated with tourism, contribution to fisheries in adjacent areas, biodiversity, and amenity values; discount rate of 3%, period of 25 years		benefits for individual MPAs ranged from $15 million (Diamond Head) to $84 million (Hanauma), with management costs for these two MPAs of $1.1 million and $22 million respectively; the net benefit per hectare (benefits minus management costs) ranged from $144,000 (Diamond Head) to $17 million (Kahalu'u)	van Beukering and Cesar 2004

(continues over)

BOX 5.2

continued

The economic costs associated with damage to ecosystem services can be substantial:

- The early 1990s collapse of the Newfoundland cod fishery due to overfishing resulted in the loss of tens of thousands of jobs and has cost at least $2 billion (CAN$2.66 billion) in income support and retraining (Commission for Economic Cooperation 2001).
- In 1996, the external cost of U.K. agriculture associated with damage to water (pollution, eutrophication), air (emissions of greenhouse gases), soil (off-site erosion damage, carbon dioxide loss), and biodiversity was $2.6 billion (£1.566 billion at 1996 exchange rates)—9% of average yearly gross farm receipts for the 1990s (Pretty et al. 2000). Similarly, the cost of freshwater eutrophication in England and Wales was estimated to be $105–160 million per year in the 1990s, with an additional $77 million per year being spent to address those damages (Pretty et al. 2003).
- The largely deliberate burning in 1997 of approximately 50,000 square kilometers of Indonesian vegetation (about 60% of the total area burned from 1997 to 1998) affected around 70 million people (Schweithelm and Glover 1999). Some 12 million people required health care; overall economic costs—through lost timber and nonwood forest products, lost agriculture, reduced health, increased CO_2 emissions, lost industrial production, and lost tourism revenues—have been conservatively estimated at $4.5 billion (Ruitenbeek 1999; Schweithelm et al. 1999).
- The total damages for the Indian Ocean region over a 20-year time period (with a 10% discount rate) resulting from the long-term impacts of a massive 1998 coral bleaching episode are estimated to be between $608 million (if there is only a slight decrease in tourism-generated income and employment results) and $8 billion (if tourism income and employment and fish productivity drop significantly and reefs cease to function as a protective barrier) (Cesar and Chong 2004).
- The net annual loss of economic value associated with invasive species in the fynbos vegetation of the Cape Floral region of South Africa in 1997 was estimated to be $93.5 million (R455 million), equivalent to a reduction of the potential economic value without the invasive species of more than 40%. The invasive species have caused losses of biodiversity, water, soil, and scenic beauty, although they also provide some benefits, such as provision of firewood (Turpie and Heydenrych 2000).

Significant investments are often needed to restore or maintain nonmarketed ecosystem services. Examples include:

- In South Africa, invasive tree species threaten both native species and water flows by encroaching into natural habitats, with serious impacts for economic growth and human well-being. In response, the South African government established the Working for Water Programme. Between 1995 and 2001 the program invested $131 million (R1.59 billion at 2001 exchange rates) in clearing programs to control invasive species (van Wilgen 2004).
- The state of Louisiana in the United States has put in place a $14-billion wetland restoration plan to protect 10,000 square kilometers of marsh, swamp, and barrier islands in part to reduce storm surges generated by hurricanes (Bourne 2000).
- A plan to restore semi-natural water flows in the Everglades wetlands in the United States in part through the removal of 400 kilometers of dikes and levees is expected to cost $7.8 billion over 20 years (Kloor 2000).

In addition to efforts to measure the value of nonmarketed ecosystem services, recent years have also seen increasing efforts to devise mechanisms to bring these services into the market, thus improving incentives to conserve ecosystems (Pagiola et al. 2002). Examples include:

- *Markets for carbon sequestration:* Approximately 64 million tons of carbon dioxide equivalent were exchanged through projects from January to May 2004, nearly as much as during all of 2003 (78 million tons) (World Bank 2004). (See Figure B in Appendix A.) The value of carbon trades in 2003 was approximately $300 million. Some 25 percent of the trades (by volume of CO_2 equivalents) involve investment in ecosystem services (hydropower or biomass) (World Bank 2004). The World Bank has established a fund with a capital of $33.3 million (as of January 2005) to invest in afforestation and reforestation projects that sequester or conserve carbon in forests and agroecosystems while promoting biodiversity conservation and poverty alleviation. It is speculated that the value of the global carbon emissions trading markets could reach $44 billion in 2010 and involve trades totaling 4.5 billion tons of carbon dioxide or equivalent (http://www.pointcarbon.com/).
- *Markets for forest environmental services.* In 1997, Costa Rica established a nationwide system of payments for environmental services (Pago de Servicios Ambientales). Under this program, Costa Rica pays land users who conserve forests, thus helping to maintain environmental services such as downstream water flows, biodiversity conservation, carbon sequestration, and scenic beauty. Funds for the program come partly from earmarked taxes and partly from environmental service buyers, including the Global Environment Facility (biodiversity), Costa Rica's Office of Joint Implementation (carbon), and water users such as hydroelectric producers, municipal water utilities, and bottlers (watershed services). By 2001, over 280,000 hectares of forest had been incorporated into the program at a cost of about $30 million, with pending applications covering an additional 800,000 hectares. Typical payments have ranged from $35 to $45 a hectare per year for forest conservation (MA *Policy Responses,* Box 5.3; Pagiola 2002). Payments under Costa Rica's program do not reflect the values attached to the services provided so much as the costs associated with their provision. As a result, while this market mechanism provides for the cost-effective imposition of quantitative targets, it is not a typical market in the sense of private parties undertaking voluntary transactions in environmental services. Worldwide, the number of initiatives involving payments for ecosystem services is growing rapidly.

regulations, market mechanisms, or community-based institutions that develop among the users themselves. Even with these community institutions, in some cases ecosystem services have declined, although in other cases the development of effective partnerships or of participatory management institutions—with power-sharing between governments, local communities, or corporate resource owners—has reduced the further decline and even brought about improvement of ecosystem services.

In South Africa, for instance, data gathered over decades showed that invasive forestry trees not only threaten native species by encroaching into natural habitats, but also severely reduce stream flows, with serious impacts for economic growth and human well-being (van Wilgen et al. 1998). In response to this evidence, the South African government established its Working for Water Programme. With an annual budget now over $60 million, this simultaneously increases water availability, employs 20,000 skilled and semi-skilled workers, and addresses a major driver of biodiversity change (van Wilgen et al. 2002; Working for Water 2004). Similarly, in Madagascar continued upland deforestation by an estimated 50,000 slash-and-burn farmers has led to increased siltation and reduced water flows to 250,000 downstream rice farmers (Carret and Loyer 2003), and this played an important role in the Malagasy government's 2003 decision to triple the size of Madagascar's network of protected forests (J. Carret, personal communication).

5.4.3 Health

Connections between declining ecosystem services and human health are well documented and may be the best understood of the well-being impacts. As shown in Chapter 14, infectious disease impacts are rising as a consequence of land use change such as deforestation, dam construction, road building, agricultural conversion, and urbanization. Such effects can be observed in all regions of the world. The World Health Organization has attempted to quantify the environmental burden of disease through a modeling of the percentage of disability-adjusted life years lost as a consequence of such environmental drivers as unsafe water, air pollution, indoor smoke, and climate change. (See also Chapter 2.) Such analysis provides strong evidence that deteriorating water and air quality account for a large percentage of poor health outcomes in many locations, especially in developing countries (WHO 2002 Chapter 4).

The environmental impact on health, according to WHO analysis, is dependent on levels of poverty. Such impacts are highest in poor countries with high mortality rates, where unsafe water and indoor smoke from solid fuel use account for 9–10% of DALYs (WHO 2002:86).

5.4.4 Good Social Relations

There are clear examples of declining ecosystem services disrupting social relations. Indigenous societies whose cultural identities are tied closely to particular habitats or wildlife suffer if habitats are destroyed or wildlife populations decline. Such impacts have been observed in coastal fishing communities (see Chapter 19), in Arctic populations (see Chapter 25), in traditional forest societies, and among pastoral nomads (e.g., Mather 1999; Parkinson 1999). The 95% decline in the *Gyps* vulture populations of the Indian subcontinent since the mid-1990s (Cunningham et al. 2003) has led to divisions in the Parsi religion about how to dispose of their dead now that the traditional laying out of corpses in Towers of Silence is no longer practicable (Triveldi 2001).

Deterioration in ecosystems can also provide an opportunity for social relations when communities join together to form community-based institutions in response to degraded ecosystem services (Ostrom et al. 2002).

5.4.5 Security

The impact of declining ecosystem services on natural disasters is well understood and well documented, and this is further explored in Chapter 16. Although there has been much speculation about the relationship between ecosystem conditions and political violence (Myers 1994; Homer-Dixon 1999), scholars have been unable to demonstrate causal connections robustly (Gleditsch 1998).

5.5 Multiple Causal Mechanisms Link Ecosystem Change to Human Well-being

The causal connections between ecosystem change and changes in human well-being are not uniform. A variety of mechanisms link the two. This section delineates some distinct mechanisms and illustrates them with specific examples, in order to demonstrate the variety of pathways linking ecosystem change and human well-being. The presentation is not meant to imply that ecosystem changes are linked to human well-being in simple orderly mechanisms. Socioecological systems are dynamic and nonlinear, and their response to stress may not be predictable. They typically combine in complicated ways; yet drivers of behavior may be identified, and behavior may be bounded by political, social, technological, or economic limitations. Decision-making behavior about the use of different ecosystem services needs to consider trade-offs in human well-being.

The benefits and costs of declining ecosystem services are seldom evenly distributed. There are typically winners and losers, and this can lead to an improvement in well-being for one group at the expense of another. If mountain communities convert forests to agricultural lands, for example, that may reduce downstream ecosystem services to low-lying areas in the form of increased siltation and declining water quality. (See Chapter 24.) If wetlands are converted to human settlements in one area of a watershed, other communities in the watershed may experience diminished flood buffering capacities. (See Chapters 16 and 20.) When ecosystem change is linked to well-being change through this mechanism, some groups of people improve and other groups decline.

Another example is the growth of shrimp farming and the consequent damage of such aquaculture on mangroves. (See Chapter 19.) Stonich et al. (1997) have shown how, in Honduras, social conflict has increased between shrimp farm concession holders and those who are not concession holders but believe that shrimp farms are intruding on government-reserved natural resources.

The often-cited example of the Aral Sea provides a vivid illustration of how a government policy aimed at improving the national economy can generate large negative impacts on human well-being by focusing on the benefits of a single ecosystem service. Under Soviet rule, the small-scale independent irrigation systems were transformed into unsustainable large-scale collective irrigation systems for cotton production. With the Soviet Union's attention focused on cotton self-sufficiency, the long-term adverse effects of a rapid, large-scale expansion of inefficient irrigation systems, sole reliance on high-water demanding production systems, poor water distribution and drainage, and non-dose-related uses of fertilizers and pesticides around the Aral Sea were not considered high priority.

During the second half of the 1900s, these inefficient systems decreased water inflow into the sea to a mere trickle, shrunk the size of the sea by half, reduced the water level by 16 meters, and tripled its salinity (Micklin 1993). The government and the cotton producers were the initial winners. The Soviet Union met its need to be self-sufficient in cotton. However, there were many losers who suffered. Thirty-five million people have lost access to the lake for its water, fish, reed beds, and transport functions. The fishing industry around the Aral Sea has collapsed, with fishing ceasing in the 1980s.

More far-reaching environmental and ecological problems, such as dust storms, erosion, and poor water quality for drinking and other purposes have contributed to decreased human health in the area around the Aral Sea. Rates of anemia, tuberculosis, kidney and liver diseases, respiratory infections, allergies, and cancer have increased, and now far exceed the rest of the former Soviet Union and present-day Russia (Ataniyazova et al. 2001). High levels of reproductive pathologies (infertility, miscarriages, and complications during pregnancy and childbirth) have been observed in this region for more than 20 years. The rate of birth abnormalities, another serious consequence of pollution, is also increasing. One in every 20 babies is born with abnormalities, a figure approximately five times the rate in European countries (Ataniyazova et al. 2001; Ataniyazova 2003). (For more information about the Aral Sea and ecosystems, see Chapters 20 and 24.)

China has also witnessed the effects of ecosystem trade-offs, especially in connection with economic development and land use change in the north and west. Excessive collection of fuelwood, blind mining, harvesting of medicinal herbs, construction projects, rising populations, and farming have all contributed to China's desertification through deforestation, water mismanagement, and overgrazing. Excessive cutting of fuelwood has reduced the sand fixing vegetation in Qaidam Basin by one third. Illegal cultivation, harvesting, and exploitation have degraded 12 million hectares of rangeland, steppe, and grasslands from 1993 to 1996. The large-scale diversion of water from the upper reach of some rivers has caused the reduction and even the drying off of the water flow in lower reaches. Desertification has silted up rivers, raised riverbeds, and retreated lake surfaces (Asian Regional Network for Desertification Monitoring and Assessment, n.d.).

The spread of desertification in northern China is threatening villages and towns, thousands of kilometers of railway, highway, and irrigation canal, and a large number of reservoirs, dams, and hydraulic power stations due to sandstorms and dune movement. Since the early 1950s, there have been more than 70 heavy sandstorms and dust devils that have caused huge losses. In the sandstorm of May 1993 in northwest China, more than 12 million people were directly affected, 116 people were killed or missing, and more than 120,000 heads of livestock were lost. The direct economic loss was approximately $66 million (Asian Regional Network for Desertification Monitoring and Assessment, n.d.).

Finally, the Chesapeake Bay in the United States provides an example of major deterioration of an ecosystem through urbanization. Land use has changed considerably in the area. The population in the bay's watershed increased 34% between 1970 and 2000 (Chesapeake Bay Program 2003b), while the number of households grew by 67% (Chesapeake Bay Foundation Report, 2004). The low-density, single-use development pattern was accompanied by infrastructure such as roads, parking lots, and shopping malls, which had a negative impact on water quality. Agriculture also expanded, and nitrogen runoff from agricultural land has been the largest contributor to pollution to the bay (Horton 2003). Chemical runoff from urban centers has also gone up (Chesapeake Bay Program 2003a, 2003b). Increased levels of air pollution have contributed to increased toxic pollution in the Chesapeake Bay.

Nitrogen pollution has depleted the oxygen levels of the waters (Cestti et al. 2003), which has resulted in increased dead zones, leading to a decline in the numbers of fish, crabs, and other aquatic life. The Chesapeake Bay has seen significant reductions in the water quality during the last decade. Declines in species like oysters and underwater grass have also accentuated the bay's capacity to naturally purify the water. Sustained high levels of pollution may result in groundwater contamination, which is the source of potable water for most people in the region.

The high pollution levels affect both income and health. The Chesapeake has been a major source of seafood, but declines in biodiversity in the bay have led to loss of income for the fishing communities who depended on it for their livelihoods (Horton 2003). The Water Quality Improvement Act requires all farms with sales of at least $2,500 to develop nutrient management plans (Joint Legislative Audit and Review Commission of the Virginia General Assembly 2003). Traditionally, farmers would rely on animal manure generated in poultry and dairy farms in the area. Since manure contains more phosphorus than nitrogen, the government advises farmers to add commercial nitrogen fertilizer. This has increased costs for farms. The animal farms, on the other hand, must now dispose of their manure as required by the Maryland Water Quality Improvement Act.

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Chapter 6

Vulnerable Peoples and Places

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BOXES

FIGURES

TABLES

*This appears in Appendix A at the end of this volume.

Main Messages

Some of the people and places affected by changes in ecosystems and ecosystem services are highly vulnerable to the effects and are particularly likely to experience much of the damage to well-being and loss of life that such changes will entail. Indeed, many of these people and places are already under severe stress from environmental, health, and socioeconomic pressures, as well as new forces involved in globalization. Further threats arising from changes in ecosystems and ecosystem services will interact with these other on-going stresses to threaten the well-being of these groups while many others throughout the world benefit and prosper from human interactions with ecosystems.

The patterns and dynamics of vulnerability in coupled socioenvironmental systems are shaped by drivers operating at scales from the international to the local, all interacting with the specifics of places. The dominant drivers and patterns of vulnerability differ, depending on the threat or perturbation addressed, the scale of analysis selected, and not least the conceptual framework employed. While our existing knowledge of the sources and patterns of vulnerability is still incomplete, substantial progress is being made in this relatively new area of analysis, and vulnerability assessment is proving useful in addressing environmental management and sustainable development.

At a global level, various efforts over the past several decades have defined vulnerability indictors and indexes and have mapped relevant global patterns. Because they use different conceptual frameworks and consider vulnerability to different types of threats, these efforts largely identify different national-scale patterns of vulnerability. Examples in the chapter introduce major efforts to address vulnerability to environmental change broadly defined, as a dimension of environmental sustainability, in respect to climate change and natural hazards. Improvements in the state of knowledge and methodology development are needed generally to deepen understanding of these global patterns and their causes, although the topics of natural hazards, desertification, and food security have received more attention than others, due to the level of societal concern on these issues.

Trends in natural hazards reveal several patterns that are known with high confidence at the national level. The world is experiencing a worsening trend of human suffering and economic losses from natural disasters over the past several decades. In the last 40 years, the number of "great" disasters has increased by a factor of 4 while economic losses have increased by a factor of 10. The significance of these events to the social vulnerability of exposed human populations is of special concern. Even before the December 2004 tsunami, Asia was disproportionately affected, with more than 43% of all natural disasters and 70% of deaths occurring there over the last decade of the twentieth century. The greatest loss of life continues to be highly concentrated in developing countries as a group.

Desertification is another phenomenon that has received extensive attention. Vulnerability to desertification has multiple causes that are highly intermingled; like all vulnerability, it is the product of the interaction between environmental change and social and political systems. The driving forces of environmental change generally have a high patchiness, and effects vary widely with differences in social and geographic scales.

Food insecurity is a third primary area of concern in changes in ecosystem services. Multiple domains of vulnerability exist in food security regimes and livelihood systems. Production, economic exchanges, and nutrition are key elements, along with more-structural issues associated with the political economy. At this point in time, the more generalized, major contributions to knowledge are emerging in the realms of better understanding of driving forces, interactions across biophysical scales and social levels, connections between ecosystems services and human well-being, and differential vulnerability at local levels. While many challenges remain in aggregating diverse case study findings, consistency is emerging around a number of themes:

- Socioeconomic and institutional differences are major factors shaping differential vulnerability. The linkages among environmental change, development, and livelihoods are receiving increasing attention in efforts to identify sources of resilience and increase adaptive capacity, but knowledge in this area is uneven in its coverage of environmental threats and perturbations as they act in relation to different ecosystems and livelihoods.

- Poverty and hazard vulnerability are often closely related, as the poor often lack assets and entitlements that allow them some buffer from environmental degradation and variability.

- The interactions of multiple forms of stress—economic, social, political, and physical—with environmental change can amplify and attenuate vulnerability abruptly or gradually, creating dynamic situations for assessment that have still to be fully captured in research methodologies. Major worldwide trends of population growth, urbanization, the spread of HIV/AIDS, economic development, and globalization are acting to shape patterns of vulnerability at national and local scales. The implications of these processes for climate change are still poorly understood.

The limitations of existing understanding point to the need for a variety of efforts to improve assessment and identify measures to reduce vulnerability. These include the need for a robust and consensual conceptual framework for vulnerability analysis, improved analysis of the human driving forces of vulnerability as well as stresses, clarification of the overlaps and interactions between poverty and vulnerability, the tracking of sequences of stresses and perturbations that produce cumulative vulnerability, the role of institutions in creating and mitigating vulnerability, the need to fill gaps in the knowledge base of global patterns of vulnerability, improved assessment methods and tools, and the need for interventions aimed at reducing vulnerability.

6.1 Introduction

The Third Assessment of the Intergovernmental Panel on Climate Change noted that over the past century average surface temperatures across the globe have increased by 0.6° Celsius and evidence is growing that human activities are responsible for most of this warming (IPCC 2001b). Human activities are also altering ecosystems and ecosystem services in myriad ways, as assessed in other chapters. While both positive and negative effects on human societies are involved, it is unrealistic to expect that they will balance out.

Many of the regions and peoples who will be affected are highly vulnerable and poorly equipped to cope with the major changes in ecosystems that may occur. Further, many people and places are already under severe stress arising from a panoply of environmental and socioeconomic forces, including those emanating from globalization processes. Involved are such diverse drivers of change as population growth, increasing concentrations of populations in megacities, poverty and poor nutrition, accumulating contamination of the atmosphere as well as of land and water, a growing dependence on distant global markets, growing gender and class inequalities, the ravages of wars, the AIDS epidemic, and politically corrupt governments. (See Chapter 3 for further discussion on drivers of change.) Environmental change will produce varied effects that will interact with these other stresses and multiple vulnerabilities, and they will take their toll particularly among the most exposed and poorest people of the world.

The most vulnerable human and ecological systems are not difficult to find. One third to one half of the world's population already lacks adequate clean water, and climate change—involving increased temperature and droughts in many areas—will add to the severity of these issues. As other chapters in this volume establish, environmental degradation affects all ecosystems and ecosystem services to varying degrees. Many developing countries (especially in Africa) are already suffering declines in agricultural production and food security, particularly among small farmers and isolated rural populations. Mountain locations are often fragile or marginal environments for human uses such as agriculture (Jodha 1997, 2002). Increased flooding from sea level rise threatens low-lying coastal areas in many parts of the globe, in both rich and poor countries, with a loss of life and infrastructure damages from more severe storms as well as a loss of wetlands and mangroves. (See Chapters 19 and 23.)

The poor, elderly, and sick in the burgeoning megacities of the world face increased risk of death and illness from growing contamination from toxic materials. Dense populations in developing countries face increased threats from riverine flooding and its associated impacts on nutrition and disease. These threats are only suggestive, of course, of the panoply of pressures that confront the most vulnerable regions of the world. It is the rates and patterns of environmental change and their interaction with place-specific vulnerabilities that are driving local realities in terms of the eventual severities of effects and the potential effectiveness of human coping mitigation and adaptation.

Research on global environmental change and on-going assessments in many locales throughout the world have greatly enriched our understanding of the structure and processes of the biosphere and human interactions with it. At the same time, our knowledge is growing of the effects that changes in ecosystems and ecosystem services have upon human communities. Nonetheless, the knowledge base concerning the vulnerabilities of coupled socioecological systems is uneven and not yet sufficient for systematic quantitative appraisal or validated models of cause-and-effect relationships of emerging vulnerability. Yet what we need to understand is apparent in the questions that researchers are addressing (Turner et al. 2003a): Who and what are vulnerable to the multiple environmental and human changes under way, and where? How are these changes and their consequences attenuated or amplified by interactions with different human and environmental conditions? What can be done to reduce vulnerability to change? How may more resilient and adaptive communities and societies be built?

In this chapter key definitions and concepts used in vulnerability analysis are first considered. Included in this is a clarification of what is meant by the terms "vulnerability" and "resilience." Several of the principal methods and tools used in identifying and assessing vulnerability to environmental change are then examined (but see also Chapter 2). Efforts to identify and map vulnerable places at the global scale are described, followed by three arenas—natural disasters, desertification, and food security—that have received substantial past analyses in vulnerability research and assessment. Several specific case studies that illustrate different key issues that pervade vulnerability assessments are presented and, finally, implications of our current knowledge for efforts to assess and reduce vulnerability and to build greater resilience in coupled socioecological systems are assessed.

6.2 Definitions and Conceptual Framework

The term vulnerability derives from the Latin root *vulnerare,* meaning to wound. Accordingly, vulnerability in simple terms means the capacity to be wounded (Kates 1985). Chambers (1989) elaborated this notion by describing vulnerability as "exposure to contingencies and stress, and the difficulty in coping with them." It is apparent from relating the notion of vulnerability to the broader framework of risk that three major dimensions are involved:

- exposure to stresses, perturbations, and shocks;
- the sensitivity of people, places, and ecosystems to stress or perturbation, including their capacity to anticipate and cope with the stress; and
- the resilience of exposed people, places, and ecosystems in terms of their capacity to absorb shocks and perturbations while maintaining function.

6.2.1 Conceptual Framework for Analyzing Vulnerability

A wide variety of conceptual frameworks have arisen to address the vulnerability of human and ecological systems to perturbations, shocks, and stresses. Here we draw on a recent effort of the Sustainability Science Program to frame vulnerability within the context of coupled socioecological systems (Turner et al. 2003a, 2003b). The framework seeks to capture as much as possible of the totality of the different elements that have been demonstrated in risk, hazards, and vulnerability studies and to frame them in regard to their complex linkages. (See Figure 6.1.)

The framework recognizes that the components and linkages in question vary by the scale of analysis undertaken and that the scale of the assessment may change the specific components but not the overall structure. It identifies two basic parts to the vulnerability problem and assessment: perturbation-stresses and the coupled socioecological system.

Perturbations and stresses can be both human and environmental and are affected by processes often operating at scales larger than the event in question (such as local drought). For example, globally induced climate change triggers increased variation in precipitation in a tropical forest frontier, while political strife elsewhere drives large numbers of immigrants to the frontier. The coupled socioecological system maintains some level of vulnerability to these perturbations and stresses, related to the manner in which they are experienced. This experience is registered first in terms of the nature of the exposure—its intensity, frequency, and duration, for instance—and involves measures that the human and environment subsystems may take to reduce the exposure. The coupled system experiences a degree of harm to exposure (risk and impacts), determined by its sensitivity. The linkage between exposure and impact is not necessarily direct, however, because the coupled system maintains coping mechanisms that permit immediate or near-term adjustments that reduce the harm experienced and, in some cases, changes the sensitivity of the system itself.

If perturbations and stresses persist over time, the types and quality of system resilience change. These changes are potentially irreversible, as the case of ozone depletion illustrates. Change may lead to adaptation (fundamental change) in the coupled system. The role of perception and the social and cultural evaluation of stresses and perturbations is important to both the recognition of stresses and the decisions regarding coping, adaptation, and adjustment. These decisions reflect local and regional differences in perceptions and evaluations. The social subsystem must be altered, or

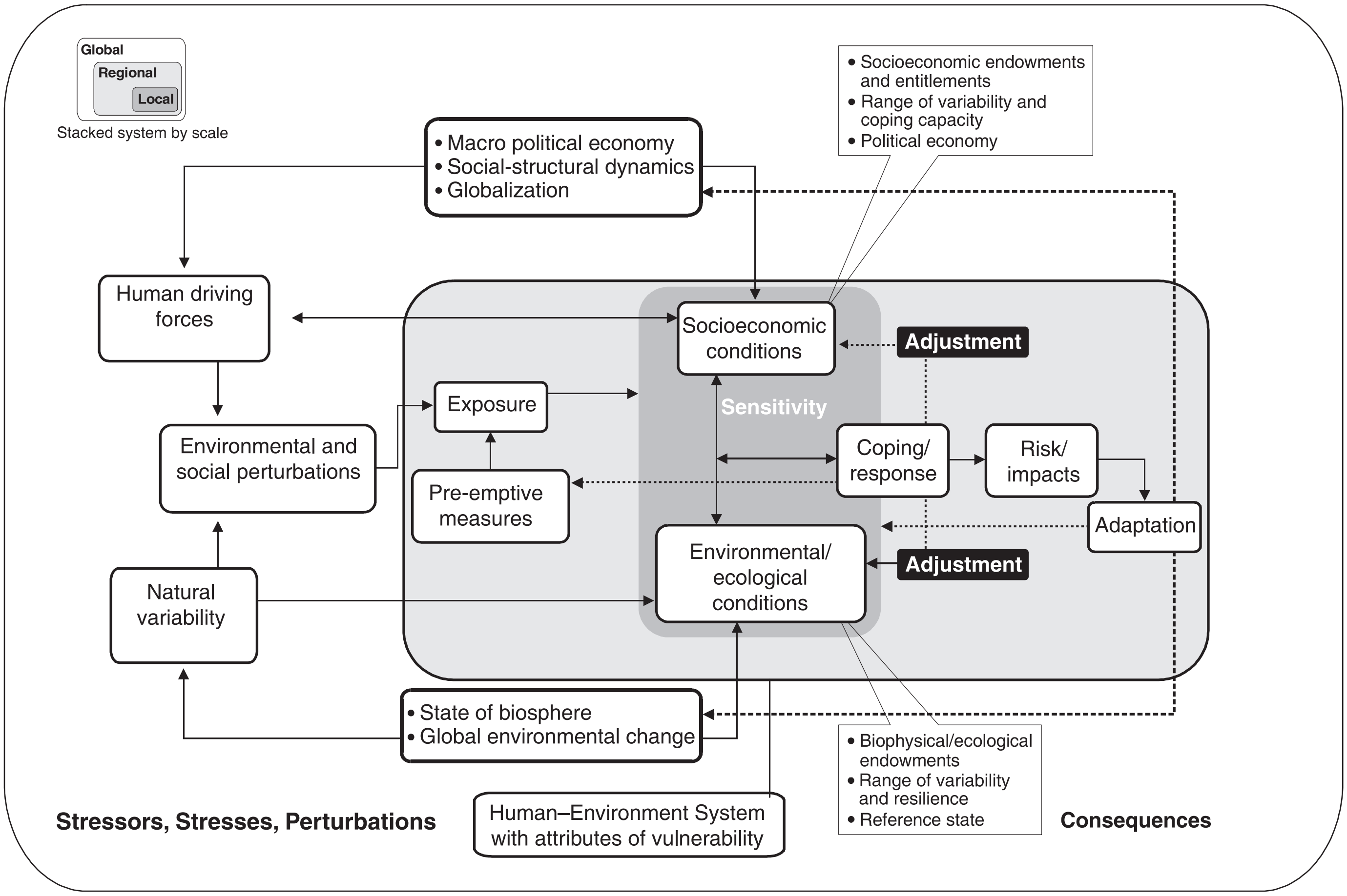

Figure 6.1. A Framework for Analyzing Vulnerability

it ceases to function (a place or region is abandoned, for example); the ecological subsystem changes in climate and vegetation. This process of more fundamental change, sometimes also referred to as ''reorganization,'' may move the coupled socioecological system in a direction of greater sustainability, but perhaps at a cost to those depending on current patterns of ecosystem services. The MA *Policy Responses* volume addresses adjustments and adaptation in ecosystems and with respect to human well-being in greater detail. By definition, no part of a system in this vulnerability framework is unimportant.

6.2.2 The Concept of Resilience

The concept of resilience as applied to integrated socioecological systems may be defined as the amount of disturbance a system can absorb and still remain within the same state or domain of attraction, the degree to which the system is capable of self-organization (versus lack of organization or organization forced by external factors), and the degree to which the system can build and increase its capacity for learning and adaptation (Carpenter et al. 2001). Socioecological systems are complex adaptive systems that are constantly changing, and the resilience of such systems represents the capacity to absorb shocks while maintaining function (Holling 1995, 2001; Gunderson and Holling 2002; Berkes et al. 2002). When a human or ecological system loses resilience, it becomes vulnerable to change that previously could be absorbed (Kasperson and Kasperson 2001).

New insights have been gained during the last 10 years about the essential role of resilience for a prosperous development of human society (Gunderson and Holling 2002). A growing number of case studies have revealed the tight connection between resilience, diversity, and the sustainability of socioecological systems (Berkes and Folke 1998; Adger et al. 2001).

Ecosystems with low resilience may still maintain function and generate resources and ecosystem services—that is, they may seem to be in good shape—but when subject to disturbances and stochastic events, they may reach a critical threshold and slide into a less desirable state. Such shifts may significantly constrain options for social and economic development, reduce options for livelihoods, and create environmental migrants as a consequence of the impact on ecosystem life-support.

In ecological systems, Lawton (2000) and Loreau et al. (2001) synthesized the evidence from many experiments and affirmed that the diversity of functionally different kinds of species affected the rates of stability and increased the reliability of ecosystem processes locally. Furthermore, a number of observations suggest that biodiversity at larger spatial scales, such as landscapes and regions, ensures that appropriate key species for ecosystem functioning are recruited to local systems after disturbance or when environmental conditions change (Peterson et al. 1998; Bengtsson et al. 2003). In this sense, biological diversity provides insurance, flexibility, and risk spreading across scales in the face of uncertainty and thereby contributes to ecosystem resilience (Folke et al. 1996). (See also Chapter 11.)

Ecological resilience typically depends on slowly changing variables such as land use, nutrient stocks, soil properties, and biomass of long-lived organisms (Gunderson and Pritchard 2002), which are in turn altered by human activities and socioeconomic driving forces (Lambin et al. 2001). The increase in social and economic vulnerability as a consequence of reduced resilience through land degradation and drought may cause losses of livelihood and trigger tension and conflict over critical resources such as fresh water or food (Homer-Dixon and Blitt 1998).

Increased vulnerability and fragility places a region on a trajectory of greater risk to the panoply of stresses and shocks that occur over time. Stressed ecosystems are often characterized by a ''distress syndrome'' that is indicated not only by reduced biodiversity and altered primary and secondary productivity but also by increased disease prevalence, reduced efficiency of nutrient cycling, increased dominance of exotic species, and increased dominance by smaller, shorter-lived opportunistic species (Rapport and Whitford 1999). The process is a cumulative one, in which sequences of shocks and stresses punctuate the trends, and the inability to replenish coping resources propels a region and its people to increasing vulnerability (Kasperson et al. 1995).

Key attributes of resilience in ecosystems, flexibility in economic systems, and adaptive capacity in institutions used in assessments include the following:

- Ecological resilience can be assessed by the amount of variability that can be absorbed without patterns changing and controls shifting to another set of keystone processes.
- Key sources of resilience lie in the requisite variety of functional groups; the accumulated financial, physical, human, and natural capital that provides sources for reorganization following disturbances; and the social networks and institutions that provide entitlements to assets as well as coping resources and social capital (Adger 2003).
- In an ecosystem, these key processes can be recognized as the processes that interact and are robust in an overlapping, redundant manner.
- When a system is disrupted, resilience is reestablished through regeneration and renewal that connect that system's present to its past.

Management can destroy or build resilience, depending on how the socioecological system organizes itself in response to management actions (Carpenter et al. 2001; Holling 2001; MA *Policy Responses*). There are many examples of management suppressing natural disturbance regimes or altering slowly changing ecological variables, leading to disastrous changes in soils, waters, landscape configurations, or biodiversity that did not appear until long after the ecosystems were first managed (Holling and Meffe 1996). Similarly, governance can disrupt social memory or remove mechanisms for creative, adaptive response by people in ways that lead to the breakdown of socioecological systems (McIntosh et al. 2000; Redman 1999). By contrast, management that builds resilience can sustain socioecological systems in the face of surprise, unpredictability, and complexity. Successful ecosystem management for human well-being requires monitoring and institutional and organizational capacity to respond to environmental feedback and surprises (Berkes and Folke 1998; Danter et al. 2000), a subject treated at the conclusion of this chapter.

6.3 Methods and Tools for Vulnerability Analysis

Many tools and methods exist for undertaking vulnerability analysis, as described in Chapter 2. This section describes several tools more specific to assessing vulnerability issues and outcomes. The vulnerability toolkit described here and in Chapter 2 is considerable, ranging from qualitative to quantitative methods, with various levels of integration among disciplines, and it is suitable for participation of stakeholders. Matching the types of analytical approaches in a toolkit to the characteristics of a specific assessment is a necessary step in scoping projects.

6.3.1 The Syndromes Approach

The syndromes approach aims to ''assess and monitor a multitude of coupled processes taking place on different (spatial and temporal) scales with different specificities'' (Petschel-Held 2002). The goal of the syndromes approach is to identify where intervention can help contribute to sustainable development pathways. In order to achieve this, similarities between regions are found by looking for functional patterns that are called ''syndromes'' (Schellnhuber et al. 1997). An assessment of these patterns of relationships is achieved by combining qualitative and quantitative approaches. Some 16 syndromes of global change are grouped according to the dominant logic: utilization of resources, economic development, and environmental sinks. The results enable critical regions to be identified for different syndromes, so that future development can set priorities for key areas necessary for establishing more-sustainable systems.

The syndromes approach recognizes the need to examine human-environment interactions, as global change is a function of how society responds to natural changes and vice versa. It is therefore important that the socioecological system is seen as a whole. Within this context, archetypal patterns are most relevant to representing the process of global change. For example, the Sahel syndrome (Lüdeke et al. 1999), characterizes a set of processes that result in the overuse of agriculturally marginal land. (Note that the names of syndromes represent an archetype rather than a specific location, event, or situation; for more detailed analysis of environmental change in the Sahel itself, see Chapter 22.)

The Sahel syndrome can be located in certain parts of the world and characterized by a number of factors. Its driving forces or core mechanisms include impoverishment, intensification of agriculture, and soil erosion, which in turn lead to productivity loss. Various factors might contribute to the disposition toward this syndrome, including socioeconomic dimensions, such as high dependence on fuelwood, and natural dimensions, such as aridity and poor soils. The core mechanisms can be quantitatively assessed to determine which areas of the world experience the syndrome most extensively and intensively. The syndromes approach is a transdisciplinary tool, drawing on both quantitative and qualitative assessments of dynamic patterns at a variety of scales, and by identifying patterns of unsustainable development, it can be used to target future development priorities aimed at enabling sustainable development.

6.3.2 Multiagent Modeling

Multiagent behavioral systems seek to model socioecological interactions as dynamic processes (Moss et al. 2001). Human actors are represented as software agents with rules for their own behavior, interactions with other social agents, and responses to the environment. Physical processes (such as soil erosion) and institutions or organizations (such as an environmental regulator) may also be represented as agents. A multiagent system could represent multiple scales of vulnerability and produce indicators of multiple dimensions of vulnerability for different populations.

Multiagent behavioral systems have an intuitive appeal in participatory integrated assessment. Stakeholders may identify with ''their'' agents and be able to validate a model in qualitative ways that is difficult to do for econometric or complex dynamic simulation models. However, such systems require significant computational resources (proportional to the number of agents), and a paucity of data for validation of individual behavior is a constraint.

6.3.3 Vulnerability and Risk Maps

The development of indicators and indices of vulnerability and the production of global maps are prominent vulnerability assessments techniques at the global level, although these approaches are still being developed to better capture the full concept of vulnerability. Global assessments using these techniques are described later in this chapter.

In order to bring conceptual understanding of vulnerability closer to their cartographic representations, vulnerability and risk mapping efforts are working to resolve several methodological challenges. Generally, risk maps are explicitly concerned with the human dimensions of vulnerability, such as the risks to human health and well-being associated with the impacts from natural hazards.

Given the common focus on human well-being at an aggregate level, vulnerability is quantified in terms of either single or multiple outcomes, such as water scarcity and hunger. Two exceptions are the hotspots of biodiversity (Myers et al. 2000) and the GLOBIO analysis (Nellemann et al. 2001), which are concerned with the vulnerability of biodiversity. For example, the hotspots of biodiversity identify areas featuring exceptional concentrations of endemic species and experiencing exceptional loss of habitat. The GLOBIO analysis relates infrastructure density and predicted expansion of infrastructure to human pressure on ecosystems in terms of the reduced abundance of wildlife. Limited progress, however, has been made as yet in integrating analyses of the vulnerability of human and ecological systems.

Many of the risk maps have been generated from remotely sensed data or information held in national data libraries. The maps are generally developed and displayed using a geographic information system. The analytical and display capabilities of GIS can draw attention to priority areas that require further analysis or urgent attention. Interactive risk mapping is presently in its infancy. The PreView project (UNEP-GRID 2003) is an interactive Internet map server presently under development that aims to illustrate the risk associated with natural disasters at the global level.

For the most part, risk maps have tended to be scale-specific snapshots at a particular time, rarely depicting cumulative and long-term risk. A challenge is linking global and local scales in order to relate indirect drivers (which operate at global, national, and other broad levels and which originate from societal, economic, demographic, technological, political, and cultural factors) to direct drivers (the physical expressions of indirect drivers that affect human and natural systems at regional or local scales). Temporally, risk maps generally depict short-term assessments of risk. The accuracy of these maps is rarely assessed, and risk maps are usually not validated empirically. Two exceptions are the fire maps and the maps of the risk of land cover change. The uncertainty that surrounds the input risk data needs to be explicit and should also be mapped.

A challenging problem for the effective mapping of risk is to move from solely identifying areas of stress or likely increased stress to mapping the resistance or sensitivity of the receptor system. This would highlight regions where the ability to resist is low or declining and the sensitivity of the receptor systems is high. The difficulty here lies in quantifying the ability to resist external pressures. Quantifying resistance, at least in ecological systems, is presently largely intractable as it requires information on the effects of different levels of severity of threats, which is usually species-specific, as well as ways of integrating this information across assemblages of species or areas of interest.

A further challenge to risk mapping is the analysis of multiple and sequential stressors. Generally, single threats or stressors are analyzed and multiple stressors are rarely treated. The ProVention Consortium (2003) aims to assess risk, exposure, and vulnerability to multiple natural hazards. Possible limitations to undertaking a multiple hazard assessment of this kind include accounting for the different ways of measuring hazards (for example, in terms of frequency, intensity, duration, spatial extent), different currencies of measurement, varied data quality, and differences in uncertainty between varying hazard assessments.

Scale and how to represent significant variation within populations of regions are common challenges for global mapping exercises, with broad implications for vulnerability assessment (German Advisory Council on Global Change 1997). Political and social marginalization, gendered relationships, and physiological differences are commonly identified variables influencing vulnerability, but incorporating this conceptual understanding in global mapping remains a challenge. Global-scale maps may consider vulnerability of the total population, or they may consider the situation of specific groups believed to be particularly vulnerable. Because many indigenous peoples are less integrated into political and social support systems and rely more directly on ecosystem services, they are likely to be more sensitive to the consequences of environmental change and have less access to support from wider social levels.

Women and children are also often reported to be more vulnerable than men to environmental changes and hazards (Cutter 1995). Because the gendered division of labor within many societies places responsibility for routine care of the household with women, degradation of ecosystem services—such as water quality or quantity, fuelwood, agricultural or rangeland productivity—often results in increased labor demands on women. These increased demands on women's time to cope with loss of ecosystem services can affect the larger household by diverting time from food preparation, child care, and other beneficial activities. While women's contributions are critical to the resilience of households, women are sometimes the focus of vulnerability studies because during pregnancy or lactation their physiology is more sensitive and their ill health bears on the well-being of children in their care. Children and elderly people are also often identified as particularly vulnerable primarily because of their physiological status.

Measures of human well-being and their relationship to ecosystems services also often incorporate data on the sensitivity and resilience dimensions of vulnerability, expressed as assets, capabilities, or security. These measures are discussed in greater detail in Chapter 5.

6.4 Assessing Vulnerability

The causes and consequences of human-induced change in ecosystems and ecosystem services are not evenly distributed throughout the world but converge in certain regions and places. For some time, for example, Russian geographers prepared "red data maps" to show the locations of what they regarded as "critical environmental situations" (Mather and Sdasyuk 1991). The National Geographical Society (1989) created a map of "environmentally endangered areas" depicting areas of natural hazards, pollution sources, and other environmental stresses. Nonetheless, it is only in recent years that concerted efforts have been made to develop indices and generate maps that depict the global distribution of people and places highly vulnerable to environmental stresses.

As noted earlier, several challenges remain in developing indicators, indices, and maps that capture all the dimensions of vulnerability, but this section reviews major notable efforts that address vulnerability in the context of human security, as an aspect of environmental sustainability, and natural disasters and that point to environmental health issues addressed further in Chapter 14.

Although modest progress has occurred in identifying and mapping vulnerable places and peoples, the state of knowledge and methodology are still significantly limited. Few of the analyses presented here integrate ecological and human systems. They rarely treat multiple stresses, interacting events, or cumulative change. Indicators continue to be chosen without an adequate underlying conceptual framework and are typically not validated against empirical cases. For the most part, they are scale-specific and snapshots in time. Disaggregated data are lacking, and much remains to be done before a robust knowledge base at the global scale will exist.

In a demonstration project, the Global Environmental Change and Human Security Project of the International Human Dimensions Programme on Global Environmental Change (Lonergan 1998) mapped regions of ecological stress and human vulnerability, using an ''index of vulnerability'' composed from 12 indicators:

- food import dependency ratio,
- water scarcity,
- energy imports as percentage of consumption,
- access to safe water,
- expenditures on defense versus health and education,
- human freedoms,
- urban population growth,
- child mortality,
- maternal mortality,
- income per capita,
- degree of democratization, and
- fertility rates.

The criteria used in selecting indicators were that data were readily available, that the resulting ''index'' consisted of a small number of indictors, and that the indicators covered six major categories—ecological and resource indicators, economic indicators, health indicators, social and demographic indicators, political/social indicators, and food security indicators. Through cluster analysis, a vulnerability ''index'' was derived and then used to map estimated vulnerability patterns, such as one for Africa. (See Figure 6.2.)

The work of the Intergovernmental Panel on Climate Change (IPCC 2001a) has made clear that ongoing and future climate changes will alter nature's life-support systems for human societies in many parts of the globe. Significant threats to human populations, as well as some potential benefits, are involved. (See Box 6.1.) As the example on the Arctic region illustrates, changes that benefit some may harm others in the same area. (See also Chapter 25.)

But it is unrealistic to assume that positive and negative effects will balance out, particularly in certain regions and places. Many of the regions and human groups, the IPCC makes clear, will be highly vulnerable and poorly equipped to cope with the major changes in climate that may occur. Many people and places are already under severe stresses arising from other environmental degradation and human driving forces, including population growth, urbanization, poverty and poor nutrition, accumulating environmental contamination, growing class and gender inequalities, the ravages of war, AIDS/HIV, and politically corrupt governments. The IPCC points to the most vulnerable socioecological systems: one third to one half of the world's population lack adequate clean water; many developing countries are likely to suffer future declines in agricultural production and food security; sea level rise is likely to greatly affect low-lying coastal areas; small-island states face potential abandonment of island homes and relocation; and the poor and sick in growing megacities face increased risk for death and illness associated with severe heat and humidity.

In preparation for the World Summit on Sustainable Development in 2002, the Global Leaders for Tomorrow Environment Task Force (2002) of the World Economic Forum to created a global Environmental Sustainability Index. It has five major components developed from globally available national data, including one on reducing human vulnerability. (See Table 6.1.) While it would be desirable to display regional differences within countries, finer-scale information is not consistently available for many types of data.

Human vulnerability seeks to measure the interaction between humans and their environment, with a focus on how environmental change affects livelihoods. Two major issues are included in the vulnerability component (one of the five components in the overall index): basic human sustenance and environmental health. The index is based on five indicators: proportion undernourished in the total population, percentage of population with access to improved drinking water supply, child death rate from respiratory diseases, death rate from intestinal infectious diseases, and the under-five mortality rate. The standardized values for each indicator were calculated and converted to a standard percentile indicator for ease of interpretation. The indicators were unweighted. Country scores were then derived to demarcate global patterns, as shown in Table 6.2.

The United Nations Environment Programme (UNEP 2003) has also assessed definitions, concepts, and dimensions of vulnerability to environmental change in different areas of the world. In particular, it calls attention to the importance of environmental health in the vulnerability of different regions and places. It notes, for example, that every year thousands of people die from a range of disasters, but the fate of many of these people is never reported. The International Red Cross Federation (IFRC 2000) has shown that the death toll from infectious diseases (such as HIV/AIDS, malaria, respiratory diseases, and diarrhea) was 160 times the number of people killed in natural disasters in 1999. And this situation is becoming worse rapidly. It is estimated, for example, that over the next decade HIV/AIDS will kill more people in sub-Saharan Africa than died in all wars of the twentieth century.

The United Nations Development Programme, in *Reducing Disaster Risk: A Challenge for Development* (UNDP 2004), undertakes the formulation of a ''disaster risk index,'' which it then uses to assess global patterns of natural disasters and their relationship to development. The Disaster Risk Index calculates the relative vulnerability of a country to a given hazard (such as earthquakes or floods) by dividing the number of people killed by the number of people exposed to the hazard. The analysts then compared the risk of the hazard (the number of people actually killed by the hazard in a country) with 26 indicators of vulnerability, selected through expert opinion. Analyzing a series of statistical analyses, a number of findings concerning the impact of development on disaster risk emerge:

- The growth of informal settlements and inner city slums has led to the growth of unstable living environments, often located in ravines, on steep slopes, along floodplains, or adjacent to noxious industrial and transport facilities.

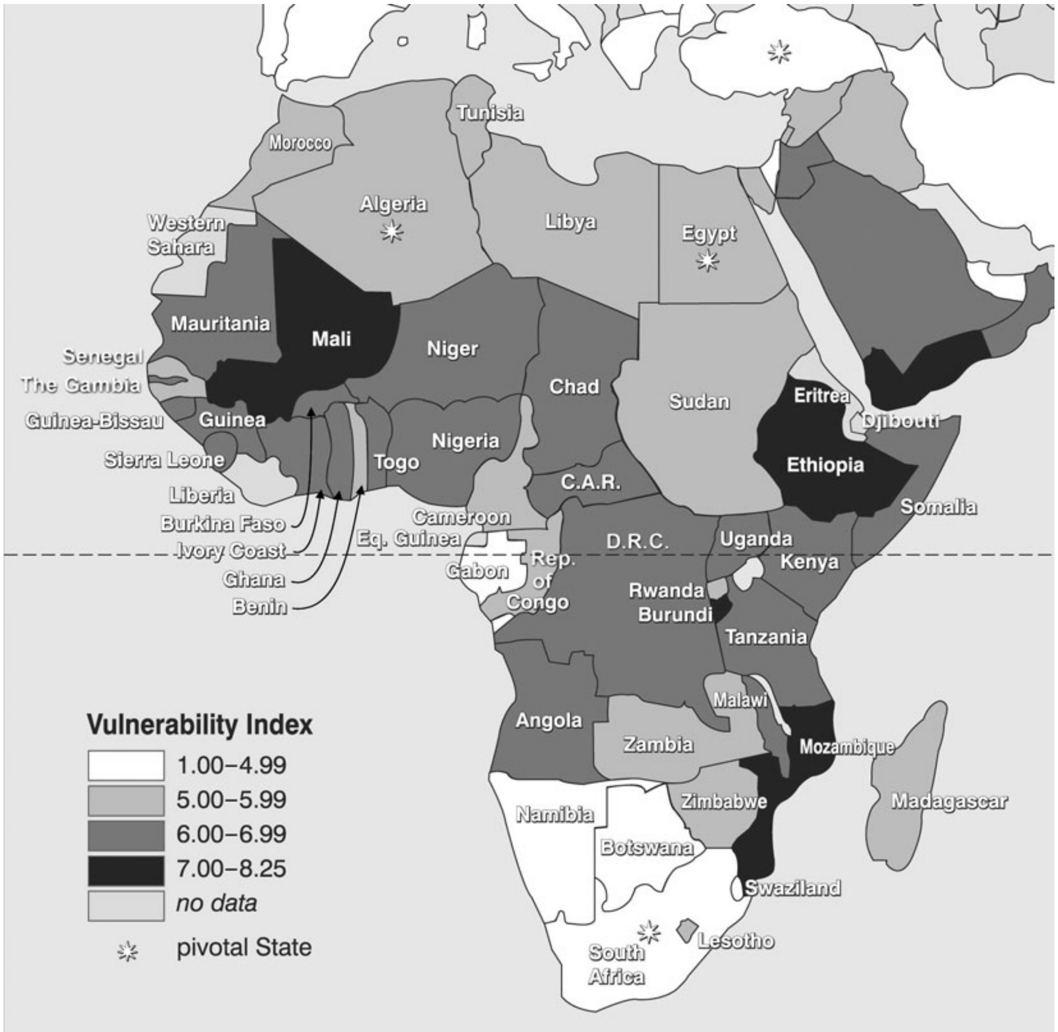

Figure 6.2. Vulnerability Index for African Countries (Lonergan 1998)

- Rural livelihoods are put at risk by the local impacts of global climate change or environmental degradation.
- Coping capacities for some people have been undermined by the need to compete in a globalizing economy, which presently rewards productive specialization and intensification over diversity and sustainability (UNDP 2004, p. 2).

6.5 Natural Hazards and Vulnerability

Natural hazards and disasters are products of both natural variability and human-environment interactions, and vulnerability to them has received substantial past attention. (See also Chapter 16.) The extremes of environmental variability are defined as hazards when they represent threats to people and what they value and defined as disasters when an event overwhelms local capacity to cope. Natural hazards offer a particularly dramatic view of the role of vulnerability in explaining patterns of losses among people and places. Indeed, research on this topic was the first realm to document the vast differences in the magnitude of losses among people and places experiencing the same types of events (White 1974). Since the 1970s, researchers have consistently reported greater loss of life among poorer populations and countries than in industrial countries, along with the inverse relationship for economic damage.

Natural hazards and disasters have always been a part of human history. Yet human relationships to hazards have evolved as the power of humans to shape natural landscapes and their biogeochemical processes has grown. Over the centuries, humans have changed from relatively powerless victims in the face of natural hazards and disasters to active participants shaping natural hazards and our vulnerability to them. Only recently has policy recognized that natural hazards are not ''Acts of God'' and begun to shift hazard management from a model of response and relief to an active engagement with mitigation, prevention, and integration of hazard management into development planning (ISDR 2002).

It is well established that the impacts of natural disasters continue to create uneven patterns of loss in populations around the world. The rising economic costs, the relative significance of those costs to the budgets of developing countries, the increasing numbers of people affected, and the decreasing loss of life demonstrate the dynamics of vulnerability across scales and experienced in local places.

6.5.1 Trends in Natural Hazards and Vulnerability

The best available data on a global scale (e.g., Swiss Re 2000; Munich Re 2003; CRED 2002) indicate that the world is witnessing a worsening trend of human suffering and economic loss

BOX 6.1

Threats and Potential Benefits of Climate Change to Human Societies (IPCC 2001a)

Threats

- Reduced potential crop yields in some tropical and sub-tropical regions and many mid-latitude regions
- Decreased water availability for populations in many water-scarce regions, particularly those with inadequate management systems
- An increase in the number of people exposed to vector-borne diseases (such as malaria) and waterborne diseases (such as cholera)
- Increases in the number of people dying from heat stress, particularly in large cities in developing countries
- A widespread increase in the risk of flooding for many human settlements throughout the world
- Severe threats to millions of people living on low-lying islands and atolls
- Threats to aboriginals living in Arctic and high mountains (for example, through the breakup of ice fields preventing people from reaching their traditional hunting and fishing grounds)

Potential Benefits

- Increased potential crop yields in some mid-latitude regions
- A potential increase in global timber supply from appropriately managed forests
- Increased water availability for populations in some water scarce regions (such as parts of South East Asia)
- Reduced winter mortality in mid- and high latitudes
- Improved marine transportation in the Arctic

Table 6.1. Components of Environmental Sustainability (Global Leaders for Tomorrow Environmental Task Force 2002)

Component	Logic
Environmental systems	A country is environmentally sustainable to the extent that its vital environmental systems are maintained at healthy levels and to the extent to which levels are improving rather than deteriorating.
Reducing environmental stresses	A country is environmentally sustainable if the levels of anthropogenic stress are low enough to engender no demonstrable harm to its environmental systems.
Reducing human vulnerability	A country is environmentally sustainable to the extent that people and social systems are not vulnerable (in the way of basic needs such as health and nutrition) to environmental disturbances; becoming less vulnerable is a sign that a society is on a track to greater sustainability.
Social and institutional capacity	A country is environmentally sustainable to the extent that it has in place institutions and underlying social patterns of skills, attitudes, and networks that foster effective responses to environmental challenges.
Global stewardship	A country is environmentally sustainable if it cooperates with other countries to manage common environmental problems, and if it reduces negative transboundary environmental impacts on other countries to levels that cause no serious harm.

to natural disasters over recent decades.(Data available at the time this chapter was written do not include losses caused by the 2004 tsunami.) While the general trend is clear, the precise estimates vary somewhat, due to improvements in reporting over time, data gathering practices, and definitional differences across organizations. (See Chapter 16 for more detailed description of the limitations and variations among data sets.)

During the past four decades, the number of ''great'' catastrophes—when the ability of a region to help itself is distinctly overtaxed, making interregional or international assistance necessary—has increased about four times, while economic losses have increased over 10 times. (Munich Re 2000) (See Table 6.3.) This trend reflects the increasing economic costs of disasters, lives lost, and the unequal ability of nations to cope with the impacts. Natural disasters affected twice as many people in the 1990s as in the 1980s (CRED 2003). The annual average losses for all disasters over the 1990s were 62,000 deaths, 200 million affected, and $69 billion in economic losses (IFRC 2001). Although comprehensive global databases do not exist for smaller-scale natural hazard events, the significance of these more common events to the social vulnerability of exposed human populations is also a major concern (ISDR 2002; Wisner et al. 2004).

Throughout the twentieth century, three general observations can be drawn from global trends: the number of disasters has increased, economic losses from disasters have increased (primarily in industrial countries), and the ratio of loss of life to total population affected has decreased, although this decline has also been heavily concentrated in industrial societies. (See Figure 6.3 in Appendix A.)

The global trends in natural disaster occurrences and impacts suggest several important patterns of vulnerability among people and places at the same time that they mask considerable geographic variation. Asia is disproportionately affected, with more than 43% of all natural disasters in the last decade of the twentieth century. During the same period, Asia accounted for almost 70% of all lives lost due to natural hazards. In China alone, floods affected more than 100 million people on average each year (IFRC 2002).

Variation among types of natural hazards is also significant. Over the decade 1991–2000, the number of hydro-meteorological disasters doubled, accounting for approximately 70% of lives lost from natural disasters (IFRC 2001). Floods and windstorms were the most common disaster events globally, but not consistently the cause of greatest losses. Disasters causing the greatest number of deaths varied among regions, with floods causing the most deaths in the Americas and Africa, drought or famine the most in Asia, earthquakes the most in Europe, and avalanches or landslides narrowly exceeded windstorms or cyclones in Oceania. Chapter 16 provides a more comprehensive description of flood and fire hazards.

While the economic loss per event is much larger in industrial countries, the greatest losses still occur in developing nations in absolute numbers of lives as well as in relative impact as measured by percentage of GDP represented by disaster losses. (See Figure 6.4.)

Considering lack of resources and capacity to prevent or cope with the impacts, it is clear that the poor are the most vulnerable to natural disasters. Among the poorest countries, 24 of 49 face a

Table 6.2. Reducing Human Vulnerability: Country Scores (Global Leaders for Tomorrow Environmental Task Force 2002)

1. Austria	85.1	49. Colombia	71.7	97. Zimbabwe	39.2
2. Netherlands	85.1	50. Trinidad and Tobago	71.4	98. Namibia	38.5
3. Sweden	85.0	51. Jordan	70.9	99. Gambia	37.3
4. Canada	85.0	52. Iran	70.7	100. Laos	35.3
5. Slovenia	85.0	53. Kazakhstan	70.6	101. Iraq	33.8
6. Australia	84.9	54. Tunisia	68.8	102. Mongolia	32.8
7. Finland	84.9	55. Syria	68.1	103. Myanmar (Burma)	32.6
8. United Kingdom	84.8	56. Mexico	67.2	104. Ghana	32.3
9. Norway	84.8	57. Turkey	66.8	105. Nepal	31.5
10. Hungary	84.3	58. Panama	66.2	106. Bhutan	31.4
11. Slovakia	84.3	59. Brazil	66.0	107. Senegal	30.6
12. Switzerland	84.3	60. Lithuania	64.8	108. Sudan	29.5
13. Ireland	83.9	61. Algeria	64.2	109. Gabon	25.6
14. Iceland	83.6	62. Bosnia and Herzegovina	63.7	110. Congo	25.1
15. Italy	82.7	63. Romania	62.7	111. Côte d'Ivoire	22.4
16. New Zealand	82.2	64. Libya	62.2	112. Tajikistan	21.6
17. France	82.2	65. Egypt	62.1	113. Benin	21.0
18. Japan	82.1	66. China	61.9	114. Togo	18.3
19. Denmark	82.0	67. Jamaica	61.4	115. Nigeria	18.2
20. Greece	81.9	68. Honduras	61.3	116. Papua New Guinea	18.0
21. South Korea	81.7	69. Ecuador	61.2	117. Uganda	15.4
22. Uruguay	81.1	70. Paraguay	60.7	118. Cameroon	15.1
23. Germany	80.9	71. Morocco	60.4	119. Burkina Faso	10.3
24. Belgium	80.8	72. Uzbekistan	60.3	120. Kenya	10.2
25. Spain	80.6	73. Albania	59.8	121. Tanzania	9.9
26. Israel	80.4	74. Thailand	58.9	122. Mauritania	9.7
27. United States	80.4	75. North Korea	57.9	123. Central African Rep.	9.4
28. Chile	79.9	76. Venezuela	57.8	124. Mali	9.3
29. Russia	79.7	77. South Africa	57.7	125. Cambodia	8.2
30. Czech Republic	79.7	78. Indonesia	57.5	126. Guinea	8.1
31. Belarus	79.3	79. Philippines	56.4	127. Madagascar	7.9
32. Bulgaria	79.1	80. Sri Lanka	56.3	128. Haiti	7.9
33. Costa Rica	79.1	81. Kyrgyzstan	52.3	129. Malawi	7.4
34. Portugal	78.9	82. Guatemala	52.3	130. Zambia	6.9
35. Poland	78.5	83. Dominican Republic	51.5	131. Burundi	6.4
36. Moldova	77.3	84. Peru	51.1	132. Rwanda	6.1
37. Croatia	76.6	85. Botswana	51.0	133. Mozambique	5.4
38. Kuwait	76.5	86. Armenia	51.0	134. Niger	5.1
39. Estonia	76.3	87. Viet Nam	50.5	135. Guinea-Bissau	5.1
40. Saudi Arabia	76.2	88. El Salvador	48.8	136. Liberia	3.9
41. Argentina	75.2	89. Azerbaijan	47.6	137. Chad	3.8
42. United Arab Emirates	75.0	90. Nicaragua	45.6	138. Somalia	3.5
43. Lebanon	74.8	91. India	43.8	139. Zaire	2.7
44. Latvia	74.8	92. Bolivia	43.5	140. Ethiopia	2.4
45. Macedonia	73.8	93. Turkmenistan	42.0	141. Sierra Leone	2.2
46. Ukraine	73.6	94. Pakistan	41.5	142. Angola	1.9
47. Malaysia	73.0	95. Oman	41.0		
48. Cuba	72.6	96. Bangladesh	40.3		

high level of disaster risk; at least 6 countries have been affected by two to eight major disasters per year in the past 15 years, with long-term consequences for human development (UNEP 2002). Ninety percent of natural disaster–related loss of life occurs in the developing world. When countries are grouped according to the UNDP Human Development Index, socioeconomic differences are strongly reflected in disaster losses (IFRC 2001). For the 1990s, countries of low human development experienced about 20% of the hazard events and reported over 50% of the deaths and just 5% of economic losses. High human development countries accounted for over 50% of the total economic losses and less than 2% of the deaths.

In assessing the distribution of vulnerability, several limitations to existing research need to be considered. First, economic valuations do not reflect the difference in relative value of losses among wealthier and poorer populations or the reversibility of environmental damages incurred. Similarly, land degradation due to landslides, flooding, or saline inundation from coastal events can diminish the natural capital resources of livelihoods, further compounding recovery challenges. The meaning of the economic value of these losses of ecosystem services is also difficult to capture and is seldom included in conventional economic assessments.

Second, because of the definitions of disaster used, local-scale disasters of significance to the affected community are often not reflected in these disaster statistics. If those losses were included, the figures on damages could easily be much higher.

Finally, there is the tendency to treat natural hazards in separate categories and to treat disasters as discrete, individual events.

Table 6.3. Great Natural Catastrophes and Economic Losses: Comparison of Decades, 1950–99 (Munich Re 2000)

Catastrophes and Losses	1950–59	1960–69	1970–79	1980–89	1990–99
Number	20	27	47	63	82
Economic losses (bill. 1998 dollars)	38.5	69.0	124.2	192.9	535.8
Insured losses (bill. 1998 dollars)	unknown	6.6	11.3	23.9	98.9

Note: Natural catastrophes are classified as "great" if the ability of the region to help itself is distinctly overtaxed, making interregional or international assistance necessary.

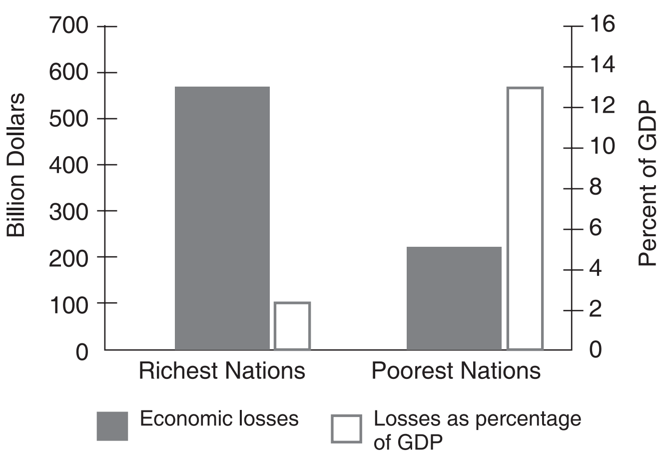

Figure 6.4. Disaster Losses, Total and as Share of GDP, in 10 Richest and Poorest Nations, 1985–99 (Abramovitz 2002)

This accounting practice limits insights into the consequences of threats from multiple hazards in one place and of sequences of disasters following upon one another. Over time, multiple and recurring hazards exacerbate vulnerability, and across scales, vulnerability is generally greater during the recovery period, when systems are already damaged. These patterns of differential impact affect efforts to cope with the impacts of environmental variability and degradation, as described earlier.

6.5.2 Explaining Vulnerability to Natural Hazards

Human-driven transformation of hydrological systems, population growth (especially in developing countries), and movements of people and capital into harm's way are major driving forces underlying the increasing numbers of disasters (Mitchell 2003). Conflict among people contributes further to vulnerability (Hewitt 1997). The causal reasons relate to basic characteristics of economy and political system but also to the perceptions, knowledge, and behavior of local managers and institutions (Hewitt 1997).

In some regions, significant environmental changes have resulted in the degradation of ecological services that mediated the effects of hydro-climatological events. Two common forms of ecological change—desertification and deforestation—can exacerbate the impacts of drought in some areas by reducing the moisture-holding capacity of the soil and contribute to increased flooding through reducing infiltration. (See Chapter 16.) In Honduras, deforestation contributed losses through increasing flooding as well as landslides following Hurricane Mitch in 1998. In other areas, efforts at river or flood control have reduced vulnerability to smaller hazard events, but increased losses when larger events overwhelmed dams, dykes, or levees and damaged the usually protected area.

The growth in numbers of people affected is a particularly important measure, as it provides an indication of the potential increase of exposure and sensitivity of people to environmental variability. The global annual average number of people affected has increased over the last decade, although the number of deaths due to disasters has declined. This shift highlights the potential for changes in pattern of vulnerability though adaptations. (See also MA *Policy Responses,* Chapter 11.) The greatest proportion of people affected resides in countries of medium human development, which include the large-population countries of Brazil, China, India, and Indonesia (IFRC 2001).

In addition to changing exposure, socioeconomic changes are shaping the overall patterns of vulnerability. First, while poverty is not synonymous with vulnerability, it is a strong indicator of sensitivity, indicating a lack of capability to reduce threats and recover from harm. The number of people living in poverty is increasing (UNDP 2002a). The greater number of people affected in medium human development countries may also reflect their experience with the additional challenges of transition, a situation somewhat akin to recovery, in which infrastructure and support systems, both physical and social, may be disrupted by the processes of change and be unable to contribute to reducing vulnerability.

Urbanization creates particular problems in disaster vulnerability. Due to the concentrations of people and complex infrastructure systems involved, the repercussions of an event in cities can spread quickly and widely, and the scale of resources needed for effective response is often challenging for national or international coordination. In many cases, these cities also draw in vast numbers of people seeking better lives, but they are often unable to keep up with the demand for planning, housing, infrastructure, and jobs. The informal housing that immigrants create is often located in marginal areas, such as hill slopes and floodplains, and accessible construction options cannot address the site limitations (Wisner et al. 2004). In 1950, just under 30% of the world's population (of 2.5 billion) lived in cities; by 2025 it is projected to be over 60% (of an estimated 8.3 billion) (UNDP 2002b). This rapid urbanization trend is particularly pronounced in countries with low per capita income. (See also Chapter 27.)

Globalization is contributing to natural hazard vulnerability as it is changing the sensitivity and coping options available (Adger and Brooks 1003; Pelling 2003). On an international scale, increasing connectedness is causing societies to become more dependent on services and infrastructure ''lifelines.'' In such a connected world, the consequences of natural disaster reach far beyond the area physically damaged. It has been estimated that the possible extent of damage caused by a extreme natural catastrophe in one of the megacities or industrial centers of the world has already attained a level that could result in the collapse of the economic system of entire countries and may even be capable of affecting financial markets worldwide (Munich Re 2000, 2002). Globalization has also increased the risks faced by marginalized indigenous peoples; many of these are developmental effects that will become apparent over only the long term. Traditional coping mechanisms have come under severe pressure, and adaptation strategies, at one time effective, can no longer cope (Pelling 2003).

Data on global trends do not report on the social differentiation among victims, but case study evidence and other synthesis efforts indicate some social groups are continually disproportionately represented among those harmed the most (Wisner et al. 2004). These are often people who are marginalized within society, due to combinations of prejudice, lack of or ignored rights, and lack of access to social supports or personal resources or due to distance from concentrations of services and power. Indigenous peoples, such as the Inuit, Sami, and others from northern regions, represent the vulnerability of this type of situation well. (See Chapter 25 for further details). These circumstances often apply to poor people, women, children, elderly individuals, and ethnic minorities in affected areas. In addition, the elderly, children, women, and handicapped people are more likely to have physical limitations or special needs that reduce their ability to cope with disaster.

6.6 Desertification: Lessons for Vulnerability Assessment

Desertification—land degradation in drylands—has been a subject of interest for over 30 years, with numerous technical assessments and policy analyses, and it is a good example of changes in a coupled socioecological system that threaten livelihoods across large swaths of Earth. It is also a good example of understanding vulnerability. (See Downing and Lüdeke (2002) and Chapter 22 for more on drylands and desertification and a useful set of maps.)

Local to global studies of social vulnerability to desertification suggest at least three lessons for vulnerability from past experience:

- *Vulnerability is dynamic.* Desertification arises from the interactions of the environment and social, political, and economic systems—through the actions of stakeholders and the vulnerable themselves (Downing and Lüdeke 2002).
- *Vulnerability takes different forms at different scales.* Similar constellations of institutions have diverse effects at different social or geographic scales. The patchiness of driving forces, often represented in global scenarios, precludes developing a simple hierarchy from local vulnerability to global maps of desertification risks.
- *Vulnerability cannot be differentiated into different causes.* At the level of human livelihoods and systems, exposure to desertification is entangled with poverty, drought, water, food and other threats and stresses.

One example of the close coupling of social and environmental systems related to desertification is apparent in the syndromes approach developed by the Potsdam Institute for Climate Impact Research, which depicts the close linkages and components involved in the coupling. The basic idea behind syndromes is "not to describe Global Change by regions or sectors, but by archetypical, dynamic, co-evolutionary patterns of civilization–nature interactions" (Petschel-Held et al. 1999, p. 296). Syndromes are charted in dynamic process models that link state variables that change over time and between states. The scale is intermediate, reflecting processes that occur between household and national/macro scales. The typology of syndromes reflects expert opinion, modified over time based on modeling. Local case examples are used to generalize to mechanisms in the modeling and also to validate the syndrome results. Desertification is a case of several syndromes operating independently, reflecting the internal dynamics of places, resources, economies, and populations.

The syndrome approach illustrates how concepts of dynamic vulnerability might be implemented to understand multiple stresses arising from the human use of ecosystem services. It takes the analysis one stage beyond purely biophysical explanations to examine linkages with human systems. The next steps might be integrated analysis at the level of different users of ecosystem services, and how they interact with each other in markets and in governance.

6.7 Food Insecurity

The arena of food security has been a third primary focus of vulnerability analysis. The severe famines in the 1980s in Africa saw the launch of dozens of famine early warning schemes. These implemented various designs, but all expanded beyond the simple monitoring of agricultural production. By the mid-1980s, Amartya Sen's entitlement theory (Sen 1981), which emphasized factors influencing the distribution of food as well as the absolute levels of available food, was widely circulated and implemented in food security monitoring. Attention to the socioeconomic failures that limit access to global food supplies became a substantial component of these efforts. More recently, more holistic approaches have sought to focus on livelihood security, to include food security, thereby widening the conceptual framing of vulnerability still further.

Much of the literature on food security focuses on human vulnerability; ecosystem services are limited to crop production, grazing for livestock, and to a lesser extent wild foods. While vulnerability assessment is maturing as an analytical tool, the need exists for assessments that are more dynamic and actor-oriented. An essential way forward in vulnerability analysis is to adopt a more precise terminology and nomenclature (see, e.g., the papers in Smith et al., 2003).

6.7.1 Methodology

Methodological lessons learned in vulnerability assessment over the past several decades reinforce the general messages of this chapter: food security is a relative measure that can be captured in various quantitative and semi-quantitative ways, but it is not an absolute condition that can be measured objectively. Food security is multidimensional and it integrates exposure to stresses beyond more narrow treatment of the production or availability of food. (See Chapters 8 and 18 for a further description of food provisioning services.) It is also clear that indicators of food security need to represent an explicit conceptual framework, such as that offered earlier in this chapter. The collation of indicators into profiles and aggregated indexes needs also to reflect the causal structure of food insecurity, going beyond the indiscriminate adding up of available indicators into a single index (see Downing et al. 2001).

A common feature of almost all food security (and livelihood) analyses is the recognition of multiple domains of vulnerability. Operational assessments commonly treat production, economic exchanges, and nutrition, while longer-term and more structural analyses include some measure of the political economy that underlies the more immediate dimensions of food security. Examples of operational assessments include India (MSSRF 2001) and Kenya (Haan et al. 2001). Figure 6.5 charts three domains of rural food insecurity for states in India.

A more heuristic illustration of the multiple dimensions of food security, related to climate change, is shown in Figure 6.6 (in Appendix A). The Figure is speculative, based on a subjective assessment of food security and climatic risks. Nevertheless, it clearly shows that global food production is of less concern than

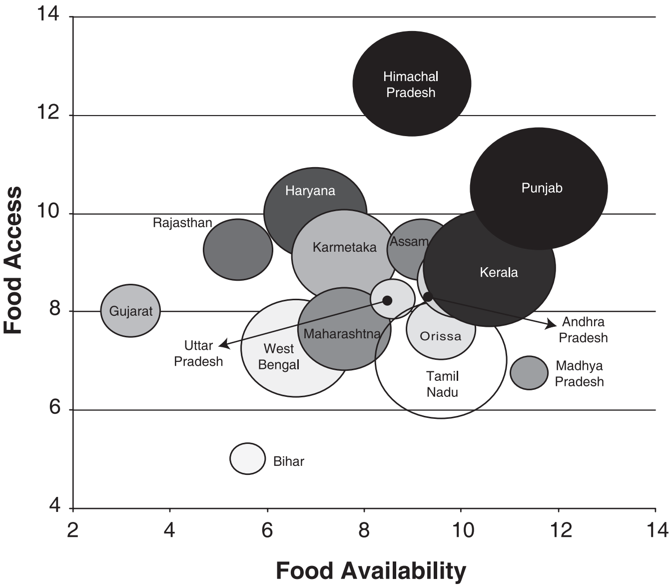

Figure 6.5. Food Insecurity Indicators of Rural India. Compiled at the state level, the MS Swaminathan Research Foundation aggregated food insecurity into three dimensions—food availability and production (x-axis), economic access (y-axis), and nutritional utilization (size of the circles, where larger is better-off). (MS Swaminathan Research Foundation 2001)

the impacts of droughts, which are already economically and socially significant for some livelihoods.

6.7.2 Wild Foods at the Local Scale

While a myriad of propositions regarding food security are possible, relating to different elements of causal structure, from the nature of the hungry themselves to the global political economy of food trade, here the case of wild foods and their role in food security is examined. (See also Chapters 5, 8, and 18 for food production and hunger issues.)

The most common approaches to food security are designed to balance consumption and production at the household level—including such indicators as expected yields of major foods (related to rainfall, soil quality, and pests, for instance), economic exchanges (such as terms of trade for agricultural sales or access to off-farm employment), hunting of wild foods, and some measures of entitlement through remittances from kin, official food relief, and relief work schemes. Set against the total of available food is the expected consumption, from meeting the FAO calorie standards to various levels of deprivation and starvation resulting in measurable effects on health. Aggregating to a regional or national level, such food balances guide policies for imports and exports, for targeted relief, and for declaration of a food crisis.

Notably absent from such food balances is the role of off-farm food collection—the gathering of wild foods either for consumption or sales. (See Chapter 8 for a more detailed description of the role of wild foods, including game, fish, and plants, in diets and for the underestimation in accounting in food balances.) In forest regions, these are called non-wood forest products and can be a major livelihood activity. Equally, few monitoring schemes include direct measures of ecosystem services such as charcoal sales, increased burdens of water shortages, or even effects of vegetation and land cover on livestock and pests. Nevertheless, for some marginal communities, such ecosystem services are essential and particularly important for surviving food shortages (Ericksen 2003).

Investigations of two dryland sites in Kenya and Tanzania found that indigenous plants were an important source of raw material in the majority of coping mechanisms when alternative sources of food or income were required, such as when the harvest failed or sudden expenses had to be met. Such coping mechanisms included making use of trees for making and hanging beehives (flowering trees are also a source of nectar); of fuelwood for sale, burning bricks, or producing charcoal; of reeds, fibers, and wood for handicrafts such as mats or tools; and of fruit, vegetables, and tubers for food and sale. Indigenous plant-based coping mechanisms are particularly important for the most vulnerable, who have little access to formal employment or market opportunities, thus providing a crucial safety net in times of hardship. Wild fruits provide important nutrients to children during times when meals are reduced at home in many parts of Africa and South Asia (Brown et al. 1999), for example.

Such raw materials can often be acquired from communal land or from neighbors without cash transactions, and they are available at critical times of the year due to the climatic resilience of indigenous plants. In addition, the sale of livestock and poultry and engaging in casual labor, which are critical sources of cash during crises, often depend on ecosystem services, such as grazing land and fodder or forest products for fencing, construction, and other typical casual labor tasks. Table 6.4 shows the high percentage of households that depended on indigenous plant-based coping mechanisms in the Kenya and Tanzania site (Eriksen 2000), and Figure 6.7 illustrates the relative importance of indigenous foods. While the findings refer to a particular point in time (the 1996 drought), the widespread use of forest products as a source of food and income figures is consistent with findings from numerous other studies (Arnold 1995; Brown et al. 1999).

6.7.3 Global Influence on Local Food Balance

The literature on food security has a long tradition recognizing that local food balances are embedded in national economies and global flows of food trade and aid (for one representation, see Kates et al. 1988). A fictitious illustration captures the notion of global exposure:

> *During a drought, a farm household suffers a loss of yields in one of its fields of maize and beans. The field is primarily used for domestic consumption, cultivated by the women. Rainfall shortages are apparent with the delay in the onset of the rains—although the field is planted and later weeded by the women, the family does not apply expensive pesticides and fertilizers, expecting low returns during a poor season. Another field has a different problem. The head of the household acquired it as part of a community-based irrigation scheme*

Table 6.4. Households That Depended on Indigenous Plant-based Coping Mechanisms in Kenya and Tanzania (Eriksen 2000)

Activities that Involve Use of Indigenous Plants	Share of Households, Kenya site	Share of Households, Tanzania site
	(percent)	
All use	94	94
Food use	69	54
Non-food use	40	42

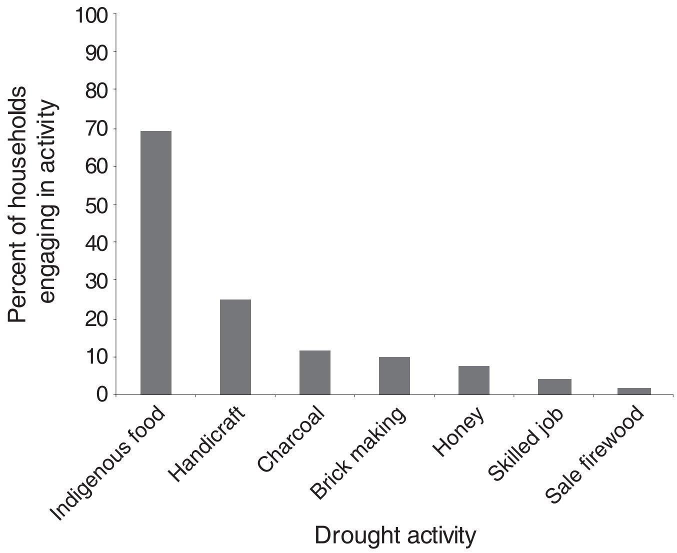

Figure 6.7. Use of Indigenous Plants in Mbitini, Kenya, by Activity during the 1996 Drought. "Skilled job" entailed tailoring, stone masonry/construction of houses, and woodcarving. Total number of households is 52. (Eriksen 2000)

that he joined a few years ago. He plants it this year with a cash crop of tomatoes and invests in fertilizer and pesticide. Halfway through the season, however, the drought restricts the availability of irrigation water. As a "junior" member of the scheme, his supply is reduced earlier than expected and his yields and quality are poor. When he tries to sell his crop to the local factory for processing into tomato juice, he discovers that there is a glut in the market due to a relaxation of import controls. Good conditions in a nearby country and export subsidies have produced a surplus, and the factory cannot afford to purchase local produce.

The fictitious example is not unrealistic—farmers have to contend with local conditions, with social, economic, and environmental relations in their community, and with the global and national food system. This global nature of vulnerability makes it impossible to clearly "bound" exposure, and it is often misleading to adopt a single spatial scale, as is often attempted in mapping vulnerability (as noted earlier regarding tools and methods).

6.7.4 Reporting Vulnerability

An essential way forward in food security analysis is to use at least a more precise terminology and nomenclature. A fairly simple scheme is proposed here, which makes clear four fundamental considerations that are not consistently reported: who is exposed, what the stresses are, what time frame is considered, and what consequences evaluated (see Downing et al. 2004). The notation below calls for reporting vulnerability (V) as specific to time frame (t); the sector, such as agriculture (s); the group, such as small-scale farmers, women farmers, or residents of peri-urban areas (g); and the consequences evaluated, such as food production, change in food purchasing power, nutritional levels or hunger (c).

$${}^{t}V_{s,g}{}^{c}$$

(where s = sector, g = group, c = consequence, t = time frame and V = vulnerability)

For instance, an examination of climate change vulnerability in agriculture could offer greater utility to future comparisons and policy by specifying differences as follows:

- Climate change vulnerability (T = climate change, no other terms specified)
- Drought (T) vulnerability for food systems (s)
- Drought (T) vulnerability for smallholder (g) agriculturalists (s)
- Drought (T) vulnerability for smallholder (g) agriculturalists (s) at risk of starvation (c = health effects of reduced food consumption)

These four different statements about climate change vulnerability suggest the range of potential differences in assessment findings. The process of conducting a vulnerability assessment can be labeled VA. If the indicators are mapped, this is extended to a vulnerability assessment map, a VAM. A database of vulnerability indictors used in a VA (or VAM) can be labeled VI. Greater precision and analytical comparability could be gained by assigning a nomenclature to individual indicators (VI_x), such as:

t = time period (historical, present or specific projection)
g = group of people if specific to a vulnerable population
r = region (or geographic pixel)
$*$ = transformed indictors, as in standard scores

This basic set of relationships can be extended into a variety of assessment tools and facilitate comparison of case studies.

6.8 Exploring Vulnerability Concepts: Three Case Studies

The broad patterns of vulnerability apparent in the patterns and trends of natural disasters, the assessment of desertification, and the lessons from food security studies all demarcate important aspects of the sources and outcomes of stresses and perturbations on coupled socioecological systems. But it is well known that these interactions are highly place-specific. Thus it is useful to turn to particular cases to explore these issues in greater depth.

This section considers three specific examples. First, the situation of two types of resource-poor farmers in northeastern Argentina is examined, illustrating how vulnerability can take different forms with different types of farming systems. Second, we look at how shifting the scale of analysis or vulnerability and resilience yields quite different insights on the sources of vulnerability and the potential effectiveness of resilience-building strategies, using a case study from Southern Africa. Finally, efforts to reduce vulnerability and the challenges involved in assessing the benefits of different types of interventions are examined through a case study from the one of the poorest areas of India.

6.8.1 Resource-poor Farmers in Northeastern Argentina

The Misiones region, in a hilly area of northeastern Argentina, has a sub-tropical wet climate where about 60% of the original vegetation (sub-tropical forest) has now been replaced by agriculture, despite the fact that soils are fragile, ill-suited for continuous cropping, and subject to nutrient depletion and erosion (Rosenfeld 1998).

Subsistence farming is common in the region, and two major types of farmers can be distinguished. Both have a similar farm structure in terms of land, capital, and labor; both are very poor; and both types often cannot meet their basic needs (Cáceres 2003). But they have designed very different farming systems and developed contrasting strategies to interact with the wider context within which they operate. On the one hand, agroecological farmers have developed farming systems of very high diversity, use few external inputs, rely mostly on local markets, and are part of representative peasant farmer organizations. Tobacco growers, by contrast, manage less diverse agroecosystems, rely on external inputs provided by the tobacco industry, have a weak participation in local organizations, and are closely linked to external markets. (See Table 6.5.)

6.8.1.1 Agrobiodiversity

The number of domesticated animals and cultivated plants (agrobiodiversity) maintained by the two types of farmers is strikingly different. On average, agroecological farmers grow or raise three times as many species within a single farm as tobacco growers do. The total number of species in all surveyed farms is also very different: 97 species in the case of agroecological farmers and 41 species for tobacco growers. This indicates that agrecological farmers maintain a higher degree of heterogeneity among farms and a higher agrobiodiversity at the landscape-to-region level. Horticultural, aromatic, and medicinal crops and fruit trees are the most diverse categories both within and among farms.

Agrobiodiversity has a direct impact on food security (Altieri 1995). The more diverse farms are, the more likely they are to meet subsistence food needs. The opposite occurs in the case of farmers specialized in the production of commodities (such as tobacco), since most of the farm resources are allocated to a goal that does not strengthen local food security (Dewey 1979; Fleuret and Fleuret 1980). This situation is clearly observed in this case, where agroecological farmers grow more than three times as many species for food as tobacco growers do.

6.8.1.2 Technology

Agroecological farmers and tobacco growers also differ strongly in terms of farm technology. Although both draw on the same technological matrix (draft power and the use of fire to clear up land), the ''final'' technologies used in their farms are very different (Cáceres 2003). In order to produce their cash crop, tobacco growers rely on modern technology and a conventional approach to farming. This involves the use of high external input technology (chemical pesticides and fertilizers and high-yield seeds) and monocropping. Nearly all the inputs needed for tobacco production come from the market. Because tobacco growers have an extremely limited financial capacity, they rely on the credit provided by tobacco companies, which in turn buy the tobacco leaves from them, in a typical contract-farming relationship.

In contrast, the technology used by agroecological farmers rests mostly on the understanding and management of natural processes and cycles. Rather than relying on external inputs, they maximize the use of both local and agroecological knowledge and resources that are locally available. As a consequence of both their traditions and the extension work of development agencies, the use of raised beds, composting practices, intercropping, biological pest control, and crop rotation is common among the agroecological farmers (Rosenfeld 1998). In order to gain access to this technology, these farmers do not need to develop a heavy reliance on the market, nor do they require the financial support of the agroindustry.

6.8.1.3 Scale Interactions

The socioeconomic and institutional context, in particular of markets and organization, is another key element shaping the vulnerability of rural societies. Tobacco growers in the Misiones have a less diversified relationship with the markets, since the tobacco companies are the main social actor with whom they interact. This is the highly asymmetrical relationship that typically develops in contract farming (Watts 1990). Tobacco growers are unable to make the most important farming decisions (such as how many tobacco plants to have, or which varieties), negotiate the quality and price of their tobacco with the agroindustry, or even decide which company to sell their product to.

The contacts of agroecological farmers with the agroindustry, on the other hand, are weak, and they are mostly linked to NGOs and governmental programs fostering rural sustainable development. Agroecological farmers have substantial control over the productive decisions concerning their farms and have developed a more diversified relationship with the market. They sell their production through different channels, of which the organic farmers' markets is the main one. In these markets, farmers and consumers meet once a week, when they set the price and other aspects of the commercial transactions. The wider range of products that agroecological farmers bring to the market also allows more spreading of commercial risks and thereby has a favorable impact on the stability of their cash flow.

The differences among these two types of farmers are even more noteworthy in terms of their participation in local organizations. Agroecological farmers not only relate with a higher number of organizations, they are also part of a larger number of grassroots representative organizations committed to peasant interests and civil rights. In contrast, tobacco growers are almost exclusively related to the Tobacco Growers' Association of Misiones, a highly bureaucratized organization that primarily represents tobacco company-interests (Schiavoni 2001). Yet the participation of tobacco growers in this organization is compulsory in order to be able to sell their tobacco to the agroindustry.

6.8.1.4 Synthesis: Differential Vulnerability

Agroecological farmers and tobacco growers share many key social and productive features. Both types of farmers and the envi-

Table 6.5. Differences between Agroecological Farmers and Tobacco Growers in Terms of Agrobiodiversity, Food Safety, Links with Markets, and Representative Organizations (P< 0.001, Mann-Witney U test for independent samples) (Cáceres 2003)

	Agroecological Farmers			Tobacco Growers		
Variable	Median	Minimum	Maximum	Median	Minimum	222
Total number of plant and animal species grown or raised on the farm	40	21	54	14	7	82
Number of species grown or raised for family consumption	28	18	42	10	4	11
Number of species sold in the market	5	3	10	2	1	1
Participation in organizations (number)	2	1	5	1	1	1

ronment in which they develop their farming strategies may be regarded as "vulnerable." However, as this case illustrates, factors shaping vulnerability can come together in a variety of ways that result in substantial variations in the magnitude and types of vulnerability, even among a group such as small-scale farmers, who are often assumed to be homogeneous.

Given these differences in vulnerability, the agroecological farmers appear less vulnerable overall than tobacco growers. Differences in agrobiodiversity, technology, and articulation to the wider context are the main factors underpinning this contrast. On the one hand, agroecological farmers appear to have developed more autonomous and resilient livelihood strategies. They manage more diverse and stable agroecosystems, produce more food, and show a stronger negotiating capacity within the political process. The strategy of tobacco growers, in contrast, depends far more on the agroindustry. They produce less food, have very limited negotiation power, and are more exposed to the control of tobacco companies and the fluctuations of tobacco prices and industry.

All this suggests that livelihood strategies used by different groups can dramatically increase or decrease their level of vulnerability. Since the articulation to the wider context is a key aspect in determining the vulnerability of poor farmers, the latter can change drastically due to external factors, no matter how "sensible" the within-farm decisions. This suggests that vulnerability involves the amplification and attenuation of a variety of conditions that depend on both internal and external circumstances, and that vulnerability changes over time with changing stresses or needs in households or with wider socioeconomic and political changes that increase or decrease access to various assets and opportunities.

6.8.2 Vulnerability and Resilience in Southern Africa: Perspectives from Three Spatial Scales

The southern African region is currently facing a suite of complex emergencies driven by a mix of factors, including HIV/AIDS, conflict, land tenure, governance, and lack of access to resources, coupled with climate risks—not least of which is the emergence of floods as a serious hazard (Mano et al. 2003; Vogel and Smith 2002; IPCC 2001a). Existing adaptive capacity is also, arguably, being increasingly eroded and undermined by such factors. The World Food Programme has recently estimated that around 14 million people in the region are in a heightened food insecurity situation (Morris 2002). Contributing factors emerging from this situation include, among others, low opening stocks of cereals from previous years, low grain reserves in some countries, low levels of preparedness for such food insecurity, and inappropriate and constraining policies that contributed to market failures (Mano et al. 2003).

This case examines the multiple roles of global environmental change as part of a complex suite of stressors (such as climate, governance, and health) and adaptation to such stressors in South Africa, using the 2002/03 famine situation in the Southern African Development Community as a backdrop. The theme of resilience and adaptation in the face of global change (Adger 2000) is analyzed at three spatial scales, moving from the regional (SADC) level to the district and community levels, focusing particularly on the role of information as a potential input into building sustainability. The greatest priority in such an investigation is less one of describing the problem than it is interactively crafting appropriate sustainable interventions. (No suitable "sustainable" interventions can be designed in isolation of the institutions and stakeholders involved.)

6.8.2.1 The SADC Region 2002/03 Season: Coping with Complex Environmental Stress

The contributions of various socioeconomic and political factors, often generated outside the region, have long been acknowledged to contribute to the complexities associated with climate stress and food insecurity facing Southern Africa (Benson and Clay 1998). Several of these myriad of factors usually become particularly important during a severe dry spell, flood, or other climate-driven event.

In response to the droughts of the 1970s, 1980s, and 1990s, international organizations, bilateral donors, African governments and NGOs established numerous early warning systems and enlarged institutional capacity to manage food security and risks (Moseley and Logan 2001). These entities have been actively undertaking efforts to reduce vulnerability to a number of risk factors in the region. A clear activity has been to examine current risks and threats primarily relating to drought-induced production deficits and to provide improved climate information to serve the agricultural sector (see, e.g., Archer 2003).

Another priority has been not only to increase the understanding of food provision and production but also to improve assessments of food procurement and access to food by households in the region (e.g., see Devereux 2000; Vogel and Smith 2002) and the factors (such as institutions, governance, and policy issues) that enhance or constrain access to food. The contributions of adverse synergies, including natural triggers (such as drought) and politics (such as civil stress) that have precipitated famines (Devereux 2000), have in some cases become more prevalent and endemic in sub-Saharan Africa.

A number of interesting adaptive measures have emerged from assessments undertaken of the 2002/03 famine in the region (see www.fews.net). Vulnerability assessments show, for example, that cereal production is sometimes not a key activity in procuring food in risk-prone households. Rather, it is food purchases and other inputs (remittances, gifts, and so on) that enable households to obtain food. Such insight on adaptation practices has only emerged from detailed food economy investigations. Such studies reveal and question the role of "food relief" as an intervention strategy in reducing the impacts of the crisis. Furthermore, the role of HIV/AIDS in aggravating the situation in several households is also emerging as a strong and negative factor (SADC FANR Vulnerability Assessment Committee 2003).

With the background of this regional scale, vulnerabilities to a similar suite of risks (including climate, management, and other factors) can be understood at the scale of South Africa and Limpopo Province. These case studies clearly show that, similar to the regional examples described earlier, a well-intentioned focus on early warning can do little to enhance resilience to risks if it is not coupled with a careful examination of the wider socioeconomic environment in which such activities operate (such as the policy environment, or institutional strengths and weaknesses), consistent with the northern Argentina case.

6.8.2.2 South Africa, 2002/03 Season—The National Scale

An unusually dry 2002/03 summer rainfall season caused widespread livestock mortality and water scarcity for growing crops in Limpopo, Mpumalanga, and North West Provinces in South Africa. In Limpopo, the provincial government requested 40 million rand in drought relief from the National Department of Agriculture, in addition to 6 million rand of provincial emergency funding that was made available (largely for subsidized fodder). Official estimates were that drought-related cattle mortalities exceeded 18,000.

A range of potentially valuable mechanisms to promote drought mitigation and risk reduction was, however, in place. Institutions and mechanisms included the Agricultural Risk Management Directorate, whose Early Warning Subdirectorate was substantively involved in improving awareness of early warning in the agricultural sector. The Early Warning Subdirectorate was established to improve forecast dissemination to smallholder farmers after forecasters and decision-makers realized that the information did not reach any further than provincial departments of agriculture (Archer and Easterling 2004). In addition, the National Agrometeorological Committee was established as a forum for reviewing updated seasonal outlook and provincial reports regularly throughout the season.

Essentially, the seasonal warning advisory was developed and disseminated at least to the provincial level in South Africa for the 2002/03 season. In spite of this, the adverse effects of climatic risk were substantial. Accepting that further investigation is required (and is planned), some preliminary observations on the 2002/03 season at the national scale in South Africa are possible.

As is well documented in a variety of case studies, forecasts, warnings, and information were in themselves insufficient to ensure action to improve resilience to environmental stress. In this case study, failures may have occurred in dissemination (for example, forecast information may not have been disseminated to extension officers or farmers). There may also have been failures in response capacity—even had farmers heard the seasonal warning, they may, for a variety of reasons, have been constrained in their ability to take anticipatory action (such as destocking). Last, there may have been weaknesses in institutional capability as well as weaknesses of ''fit'' and ''interplay'' between what institutions are providing and what is required (see, e.g., Folke et al. 1998; Berkes and Folke 1998; Orlove and Tosteson 1999; Raskin et al. 2002). Even with effective information dissemination, provincial, municipal, and local institutions may themselves be constrained in their ability to either recommend or support appropriate actions to improve resilience.

6.8.2.3 Vhembe District, Limpopo Province, 2002/03 Season

Results from research at the district and local level in Vhembe district of Limpopo Province show where gaps and weaknesses existed with regard to improved resilience to climatic risk in the 2002/03 season. It appears that this was the first season that the surveyed community (first surveyed in 2000/01) had exposure to seasonal forecast information. The Vhembe District Department of Agriculture and the District Department of Water Affairs and Forestry also received the forecast. Yet both at the community level and at the district institutional level, little response was apparent. Identifying the reasons for the lack of action is key to understanding the adverse drought effects at the national and provincial level described earlier.

First, it is clear that the forecast alone was insufficient, both for the needs of farmers and for district institutions. Both farmers and institutions explicitly asked for more guidance in terms of what actions might be appropriate in the light of the forecast or warning information. Farmers requested, for example, that when the seasonal forecast (or severe weather warning) was broadcast over the radio, the announcement needed to be coupled with an advisory. Such an advisory could include a wide range of general advice at various scales—at the district level, for instance, information on planting dates; at the farm level, very specific information on cultivars and planting. The District Department of Agriculture asked that the existing agricultural advisory be further developed and refined for local district conditions. The District Department of Water Affairs and Forestry requested that the agricultural advisory be adapted for the water sector (and for other climate-sensitive sectors as well, such as health).

Second, farmers themselves may have been constrained in their ability to respond to information about climatic stress. The most commonly documented constraint on response capacity was resource limitation, including lack of access to credit, supplemental irrigation, land, and markets as well as lack of decision-making power (particularly in the case of women farmers) (Archer 2003). Further research in the area is seeking to understand the precise role of resource limitations and misdirected inputs (such as inappropriate irrigation infrastructure) in constraining both the ability to respond to forecasts and warnings and, more important, the ability to increase resilience and adaptive capacity.

There are also, however, encouraging signs in Vhembe district and at the national scale in South Africa of building adaptive capacity under conditions of climatic (and environmental) stress. Progress has been made in the dissemination of the forecast to district institutions and to the community level. And intermediary mechanisms described at the national scale (such as the programs under the Directorate of Agricultural Risk Management) show promise. There are signs that research on ways to improve adaptive capacity in South Africa is becoming increasingly well positioned to produce generalized recommendations that may inform policy.

6.8.2.4 Synthesis: Cross-scale Interactions and Multiple Stressors

The results from this case suggest that although gaps and weaknesses were evident in the ability of entities at different scales to decrease vulnerability to the emergence of multiple stressors, success stories were also apparent. In this example it is clear that the spatial scale is a valuable unit of analysis. The level of interplay, however, between scales of ''intervention'' is equally important (e.g., Orlove and Tosteson 1999).

This example illustrates the ''misfit'' between scales of research and intervention, between what is investigated and what is required. This example points to a greater understanding of these complex issues, particularly in a region undergoing complex shocks and stressors, and the deeper interrogation that is required of the range of institutional responses that may be needed to manage these systems effectively. The South African Weather Service, as the official national forecast producer, works with other forecast producers at the international and national levels to derive a multiple-sourced seasonal outlook, containing three-month rainfall and temperature forecasts. The forecast, looking specifically at the agricultural sector, is disseminated to the National Department of Agriculture and from there to provincial, district, ward extension, and finally farm level.

The process of sub-provincial dissemination of the forecast is still in progress. There are three areas of on-going activity to improve the system: the process of combining multiple source forecasts, the role of the National Disaster Management Centre in receiving forecasts and coordinating response in appropriate areas and sectors, and the sub-provincial receipt of, and response to, the forecasts.

At present, however, there remains a misfit between what is currently being provided by the forecast producers and the suggested requirements from the agricultural sector within the provincial levels. From the province down to ward level extension, suggested forecast information differs from the three-month temperature and rainfall forecasts provided from the national and international levels. Finer levels suggest information be provided on seasonal quality (such as information on intra-seasonal variability), advisories coupled to forecasts, retroactive forecast applications, and impact-specific interpretation of forecasts (Orlove and Tosteson 1999). To reiterate, the system is highly dynamic and should be seen as evolving. The key question remains how to best intervene to aid a system in building resilience to sustain socioecological systems under conditions of environmental stress and surprise.

6.8.3 The Benefits of Reducing Vulnerability in Bundelkhand, India

The Bundelkhand region in the central highlands of India consists of semiarid plateau land. Rising population, subsequent agricultural expansion, and increased demand for wood has led to rapid deforestation in the region, which together with poor land management practices and government-approved commercial logging has aggravated soil erosion and ecological degradation. Erratic rainfall coupled with soil erosion has further reduced soil productivity and contributed to crop failure, and the area is now highly degraded (EcoTech Services 1997). (This paper draws on EcoTech Services 1999; the study was carried out to support the Uttar Pradesh state government initiatives in the area, under a grant from the Government of the Netherlands.)

The region has some of the lowest levels of per capita income and human development in India. Illiteracy and infant mortality rates were high, and local inhabitants depended on rain-fed single-crop agriculture and small-scale livestock production. The forests that were the traditional source of livelihood have largely disappeared.

Lalitpur district lies at the heart of the Bundelkhand region. The main monsoon crops grown in the district are maize, gram, and groundnut, while the main winter crops are wheat, peas, and gram. Most people collect green fodder from their own land during kharif and feed harvest remains to the animals in rabi and summer. Harvest is sold as dry fodder. Most households use the same well through the year, and it takes approximately two hours per household to collect water each day. Nonavailability of potable water is a major problem across the district (EcoTech Services 1997).

6.8.3.1 Watershed Management

A technical plan for the Donda Nala watershed in Lalitpur district was drawn up, aimed at land treatment and drainage line treatment measures (EcoTech Services 1997). Land treatment measures sought to reduce the loss of topsoil and to augment rainwater retention and biomass production. Measures such as embankments, earthen gully (channel) plugs, and agroforestry were deemed applicable to cultivated land, while silvipasture was deemed applicable to uncultivated lands. Drainage treatments suggested by the plan included mechanical measures such as the construction of dams and surface water storage tanks. Long-term benefits envisioned from these measures were retention of topsoil and an increase in the moisture-retaining capacity of soil. The technical plan estimated that the high-grade lands in the watershed would show increased crop yields by about 50% in the first five years as a result of such improvements.

6.8.3.2 Quantifying Benefits

Benefits projected from the watershed management activities included increased productivity of land, improvement in the health of animals due to increased fodder availability, better access to drinking water, increased employment, lower rates of soil erosion, and stabilizing environmental degradation. For the economic analysis in the plan, the benefits were summarized as irrigation benefits, benefits from vegetative treatments, drinking water benefits, and employment benefits. (The assessment did not attempt to evaluate environmental and health benefits, which are more complex to quantify.)

Farmers realized benefits from cultivation in the form of increased profits. The incremental net profit was computed as the difference between current profits and potential future profits from cultivation. Assuming that prices would remain constant, profits in the future were estimated on the present value of future cultivation. It was estimated that the average annual incremental profit would be 3,910,700 rupees (or 1,450 rupees per acre) as a result of additional water on existing farmlands. It was estimated that there would be additional benefits due to cultivation on marginal lands due to a further 257 hectares coming under cultivation during monsoon and 90 hectares in winter. This value was estimated as 1,681,000 rupees.

Vegetative treatments led to increased biomass in the form of fodder, firewood, and timber. Locally accepted species were identified for long-term community-managed common land. The estimates from increased fodder availability were based on fodder collection amounts. The incremental production of dry fodder or crop residues was valued at the existing market rate and estimated at 777,800 rupees for the watershed as a whole. A detailed cost-benefit estimation of silvipastural treatments planned in the wastelands for a period of 30 years was also assessed to compute the net present value of the future stream of benefits. Some 420 hectares of land were to be covered under the afforestation plan.

The potential benefits from better access to drinking water were valued by using the opportunity cost of time saved in water collection for women. Three open wells were proposed in the villages of Agar, Dhurwara, and Ghisoli. These sought to enhance women's participation in the project and to benefit families who lacked easy access to drinking water. The new wells were typically located near a cluster so that these families would not have to go more than a quarter of a kilometer. The estimated cost of digging wells in the watershed was 304,065 rupees, and the total value of time savings was 45,090 rupees for the year. The value of this is projected to rise over time as daily wages increase.

Given the labor requirements for each type of project activity, the market and opportunity costs for labor were determined. The benefits were calculated from activity-specific labor components of the technical work plan. Total incremental benefits from employment were valued at the prevailing wage rate. The employment benefits disbursed in the first two years of project activities were estimated at 5,480,000 rupees.

The projected present value of the future stream of the total annual benefits from each of the estimated components provides the overall value for the stream of benefits accruing from the project. The average projected present value of benefits per hectare was 47,461 rupees as opposed to an average project activity cost of 7,500 rupees per hectare. (See Table 6.6.) Assuming a 30-year horizon, the present projected value of the estimated benefits were computed using a 12% discount rate. The net present value of total benefits worked out to be over 100 million rupees for the entire watershed.

6.8.3.3 Synthesis: Distributional Issues

Most of the village community of Lalitpur district consists of small farmers and landless people. While the benefits from additional employment and access to drinking water are projected to directly enhance their quality of life, benefits from irrigation and green fodder production (which are the major source of benefits) are

Table 6.6. Total Benefits for Donda Nala Watershed (EcoTech Services 1997)

Project Activity	Total Undiscounted Benefits	Total Discounted Benefits
	(Rs crores)	
Irrigation	16.5620	3.5799
Digging wells	0.1300	0.0281
Employment	0.5476	0.4132
Silvipasture	24.4177	6.0871
Forestry	5.5876	0.3949
Total benefits	**47.2449**	**10.5320**

likely to accrue to those with land or cattle. The benefits will reach poorer households only if the access to treated wastelands and to harvest can be assured.

6.9 Implications for Assessment and Policy

The discussion and cases in this chapter emphasize that the patterns and dynamics that shape the vulnerability of coupled socio-ecological systems are composed of a multitude of linkages and processes. As such, assessments of vulnerability need to be comprehensive, sensitive to driving forces at different scales, but also appreciative of the differences among places.

A number of observations relevant to attempts to assess and reduce vulnerability and to build resilience may be offered. First, conceptual frameworks of vulnerability have improved, representing human and biophysical vulnerabilities as a coupled socio-ecological system. However, the relationships across scales and the role of specific actors (as drivers of systems) are poorly represented in most frameworks, and the existing state of knowledge is still weak. Different components of the coupled socioecological system may have quite different vulnerabilities and may experience exposure to stresses and perturbations quite differently. Diverse impacts are likely as a result; broad frameworks should not be taken as reliable guides to local conditions. The term vulnerability is still used in disparate ways in many assessments; a clear nomenclature is required to make assessments more consistent and coherent.

Second, the driving conditions of vulnerability have been well characterized at least at a general level. Human alterations of ecosystems and ecosystem services shape both the threats to which people and places are exposed and their vulnerabilities to the threats. The same alterations of environment can have very different consequences, depending on the differential vulnerability of the receptor systems.

Third, poverty and hazard vulnerability are linked and often mutually reinforcing by creating circumstances in which the poor and those with limited assets have few options but to exploit environmental resources for survival. At the same time, poverty and vulnerability are overlapping but distinct conditions, and they require analysis to determine overlaps and interactions.

Fourth, vulnerability can also be increased by the interaction of stresses over time. In particular, sequences of stresses that erode coping capacity or lengthen recovery periods can have long-term impacts that still often are not adequately treated in many assessments. Capturing these dynamics of vulnerability in assessment is an ongoing challenge.

Fifth, socioeconomic and institutional differences are major contributors to patterns of differential vulnerability. The linkages among environmental change, development, and livelihood are attracting increasing attention as a nexus in building resilient communities and strengthening adaptive capacity, but existing knowledge is still uneven and not well developed.

Sixth, despite this general level of explanation, it is still difficult to document adequately the effects of different changes upon different human groups with precision. While environmental changes and natural disasters are affecting increasing numbers of people, the existing knowledge base of vulnerability and resilience is highly uneven, with much known about some situations and very little about others. Some of the most vulnerable peoples and places are those about which the least is known. New vulnerabilities may be realized in the future, as in the dramatic increase of flooding damages in Africa or the effects of HIV/AIDS as a compounding factor in livelihood security. Filling the major gaps is a high priority in improving current assessments.

Seventh, assessment methods are improving. Entering vulnerability assessments at different scales of analysis, and particularly the local scales of place-based assessments, holds potential for greater depth and understanding of the complexity and dynamics of changing vulnerability.

Finally, despite the limitations of theory, data, and methods, sufficient knowledge exists in most regions to apply vulnerability analysis to contemporary problems of ecosystem management and sustainable development in order to provide useful information to decision-makers and practitioners.

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