5 Reporting on the Transition

If a transition toward sustainability does emerge over the next two generations, it will likely be guided by the mosaic of information outlined in previous chapters. Its accomplishment will be determined by societies' ability to shape the trends toward the transitions described in Chapter 2, foresight of the future using tools presented in Chapter 3, and skill in navigating successfully the threats and challenges identified in Chapter 4, in order to meet the normative goals laid out in Chapter 1. In this chapter we explore the contributions that appropriate monitoring and indicator systems might make to our navigational abilities toward the goals of sustainability in a turbulent world of surprise and inevitable policy failure. These indicators assess the trends that signal a transition. More important, these indicators can stimulate social learning—going beyond research, and beyond science and policy debate—to attain the actual policy and behavioral changes needed for a successful course. Learning of this kind, though difficult to achieve, can be influenced by a set of indicators that shape the awareness and actions of individuals, organizations, and societies in much the way that weather forecasts and economic indicators already influence short-term behavior.

INDICATORS

Indicators are repeated observations of natural and social phenomena that represent systematic feedback. They generally provide quantitative measures of the economy, human well-being, and impacts of human activities on the natural world. The signals they produce sound alarms, define challenges, and measure progress. For example, measurements of carbon dioxide levels in the atmosphere warn of possible climate change, population statistics show trends in the rate of growth of the human species, and Gross Domestic Product statistics attest to a nation's prosperity. Generally, indicators are most useful when obtained over many intervals of observation so that they illustrate trends and changes. Their calculation requires concerted efforts and financial investments by governments, firms, nongovernmental organizations, and the scientific community.

Indicators are essential to inform society over the coming decades how, and to what extent, progress is being made in navigating a transition toward sustainability. Numerous efforts are under way to collect, analyze, and aggregate the information needed to form sets of indicators of environmental, societal, and technological change. These efforts range on an ecological scale from watersheds to the whole planet, and on a political scale from municipal to international institutions and activities. **For reporting on a sustainability transition, however, it is clear that multiple indicators are needed to chart progress toward the goals for meeting human needs and preserving life support systems, and to evaluate the efficacy of actions taken to attain these goals.** Indicators will be needed to monitor and report on human welfare and planetary life support at global, regional, and local scales to catch the appropriate signals. These signals will tell us if societies are on track or if they are headed toward unsustainability. If such indicators focus on different levels of human-environment interactions, it should be possible to measure the directions in which humanity is headed. Another set of indicators will be needed to aid navigation, and thus, help humanity steer a course toward sustainability.

We begin with an overview of the current use of indicators, and then outline an approach formulated on the basis of the Board's normative objectives; finally, we address the role of indicators in navigating the uncharted waters of a transition toward sustainability.

THE USE OF INDICATORS

Humans have made repeated, precise measurements of some phenomena since ancient times. As archeologists have deciphered the use of astronomical observations in agrarian societies, it has become clear that environmental indicators have long been used to guide human behavior. The use of indicators has expanded with efforts of industrial societies to measure and manage a widening variety of environmental and societal parameters.

In an information age, the abundance of quantitative data along with digital imagery (from satellites and ground-based observation systems) and broadband communications helps us to perceive multiple parameters in our complex and dynamic world. Yet much of the data available was understandably shaped by the conventions and precedents of scientific research, and was not specifically collected to assess progress toward selected goals for humanity and to manage future developments. Indicators are evolving to fill this gap by condensing complex trends into convenient index numbers, giving researchers, policy makers and the public concise assessments of trends and guidance for how to shape future policies and actions. Whether indicators signal the ability to understand, predict, or control important environmental or social parameters depends on the relevance and accuracy of the selected goals and measurements. How the understanding that such indicators provide is used to guide human behavior is a matter for society and its governance.

Efforts to Formulate Indicators

In day-to-day life societies use prices, news and weather reports, and other routine methods of monitoring to guide behavior and expectations. Indicators perform parallel functions for long-term changes and large-scale actions. As the members of the European Community prepared to institute a common currency, they agreed to meet numerical guidelines for their budget deficits as a fraction of gross domestic product, and this indicator was closely watched. This is a striking instance of the influence of indicators that are widely accepted in defining valued social conditions. For complex conditions such as sustainable development (or a transition toward sustainability), no single indicator can adequately track their state or changes; sets of indicators are commonly used to gauge various parameters that together indicate multi-dimensional trends in social and environmental change.

The development of sets of indicators for sustainability has aimed at combining assessments of three aspects of nature and society: economy, environmental quality, and human well-being. One major effort to achieve such a combination is the Pressure-State-Response (PSR) framework presented, for generic environmental variables, in Figure 5.1.[1] This framework is a guideline to formulate sets of indicators that assess aspects of environmental and societal trends influencing sustainability.

Illuminating the interactive nature of sustainability, the Pressure-State-Response framework posits links between human actions and environmental consequences. Human activities exert *pressures*, such as burning gasoline in cars, that alter the *state* of environmental variables, such as the quality of city air. Those impaired states, in turn, elicit *responses*, such

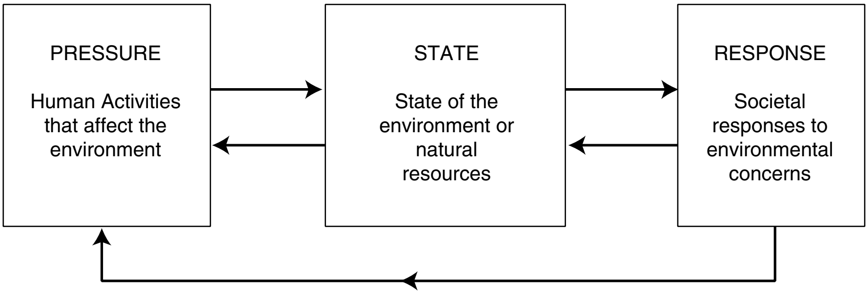

FIGURE 5.1 Pressure-State-Response framework for indicators of sustainable development.
Source: U.S. Interagency Working Group on Sustainable Development Indicators (1999).

as regulations governing pollution control technology in new vehicles. These three classes of variables identified by PSR can be measured using data that often are already collected for administrative purposes. Combining these data with a simple but flexible scenario captures a fundamental idea of sustainable development: that humans can impair the life support systems of the natural world, calling forth responses intended to protect environmental quality. Feedbacks are also possible. As the arrows in Figure 5.1 indicate, some responses can directly change the state of environmental variables, which in turn can affect the pressures exerted on people in some instances. For instance, the creation of a national park alters expectations of future uses of that land, affecting a spectrum of pressures of human origin. Some indicators, such as the value of adjacent private property, may rise, while others, such as mining permits, may decline. Also, it is straightforward to expand PSR to include the impact of economic development on equity, hunger, and other aspects of human welfare; the scenarios analyzed in Chapter 3 provide examples.

Using the PSR framework, governments and nongovernmental organizations have compiled numerous sets of indicators for sustainable development using various measurement regimes. Table 5.1 shows one set of indicators advanced recently by a working group in the U.S. government.[2] Figure 5.2 elaborates one of these indicators, high poverty census tracts, and describes how it is measured. The simplicity of this indicator set highlights the need for each of these major indicators to be backed by sound scientific understanding to evaluate their limitations for detailed interpretations.

TABLE 5.1 An Illustrative Set of Indicators for Sustainable Development in the U.S.

Issue	Selected Indicators
Economic Prosperity	Capital assets Labor productivity Domestic product
Fiscal Responsibility	Inflation Federal debt-to-GDP ratio
Scientific and Technological Advancement	Investment in R&D as a percentage of GDP
Employment	Unemployment
Equity	Income distribution People in census tracts with 40% or greater poverty
Housing	Homeownership rates Percentage of households in problem housing
Consumption	Energy consumption per capita and per dollar of GDP Materials consumption per capita and per dollar of GDP Consumption expenditures per capita
Status of Natural Resources	Conversion of cropland to other uses Soil erosion rates Ratio of renewable water supply to withdrawals Fisheries utilization Timber growth to removals balance
Air and Water Quality	Surface water quality Metropolitan air quality nonattainment
Contamination and Hazardous Materials	Contaminants in biota Identification and management of Superfund sites Quantity of spent nuclear fuel
Ecosystem Integrity	Acres of major terrestrial ecosystems Invasive alien species
Global Climate Change	Greenhouse gas emissions Greenhouse climate response index
Stratospheric Ozone Depletion	Status of stratospheric ozone
Population	U.S. population
Family Structure	Children living in families with one parent present Births to single mothers
Arts and Recreation	Outdoor recreation activities Participation in the arts and recreation
Community Involvement	Contributing time and money to charities
Education	Teacher training level and application of qualifications Educational attainment by level Educational achievement rates
Public Safety	Crime rate
Human Health	Life expectancy at birth

Source: Based on U.S. Interagency Working Group on Sustainable Development Indicators (1998).

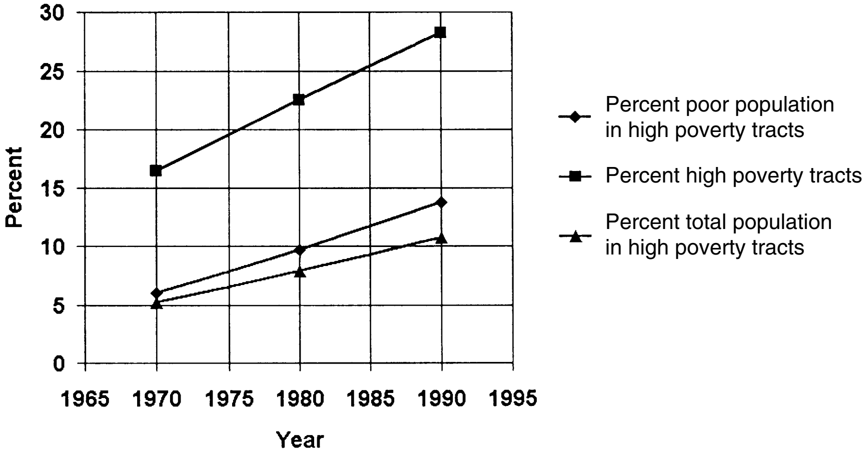

FIGURE 5.2 An illustrative indicator: high poverty census tracts. Census tracts have been defined for metropolitan areas, covering 75 percent of the total population. The poverty line is defined as the income level at which the estimated cost of a low-cost food plan for a family of three or more would consume 33 percent of the family's total income. A high poverty census tract is defined as one in which 40 percent or more of the population is below the poverty line. The percentage of poor people living in high poverty census tracts is a measure of the concentration of poverty in cities. It is widely believed that poor people are worse off living in areas of concentrated poverty than they would be in other areas, and that society as a whole suffers when these areas of concentrated poverty exist. The graph shows three measures of the concentration of poverty in urban areas: (1) the percentage of the population below the poverty line living in high poverty census tracts (from 16.5 percent in 1970 to 28.2 percent in 1990); (2) the percentage of census tracts defined as high poverty tracts, with 40 percent or more of the population below the poverty line (from 6 percent in 1970 to 13.7 percent in 1990); and (3) the percentage of total population living in high poverty census tracts (from 5.2 percent in 1970 to 10.7 percent in 1990).

Source: U.S. Department of Housing and Urban Development as published in U.S. Interagency Working Group on Sustainable Development Indicators (1999).

Indicators of Sustainable Development

Despite widespread agreement on the relevance of the Pressure-State-Response framework in formulating sets of indicators for sustainable development, diverse interests in the progress and definition of sustainable development have led to controversy over an acceptable set of indicators for its measurement.[3] Quantitative indicators are often scrutinized more for their moral, economic, and political implications than for their scientific substance. This is in part because there is no widely accepted operational definition of the term "sustainable development"[4] from which to guide the selection of the indicators (see Chapter 1). A result is that no single set of available indicators satisfies criteria for evaluation acceptable to all sides of the debate. This controversy often hinders the further collection of data, even when new studies are needed to appraise the reliability and accuracy of the measurements being taken.

Despite these difficulties, there are numerous efforts underway to assemble indicators of sustainable development. These efforts range on a political scale from municipal to international and on an ecological scale from watersheds to the planet as a whole.[5] Hundreds of indicators and numerous schemes to collect, analyze, and aggregate the information needed to form indicator sets have been proposed and various attempts have been made to rationalize them. For example, a recent effort vigorously attempts a "whole system" framework from existing schemes to provide a base for both information systems and dynamic modeling.[6] Five separate projects are discussed here with the intent of outlining what is being done rather than providing an exhaustive survey. These include two global (United Nations, World Bank), two national (Netherlands, United States), and one local (Seattle, Washington) projects.[7] A schematic overview of these studies is contained in Table 5.2, where they are sorted by the concepts of sustaining and developing set out in Chapter 1.

As Table 5.2 illustrates, sets of indicators for sustainability tend to focus on maintaining the life support systems important to humans and on monitoring development and economic activity. Many indicators, particularly in the environmental sector, do not have long time series, so their ability to discern environmental trends is weak compared to the determinations possible with economic and social data series. In addition, coverage is uneven; although environmental indicators outnumber the rest, there is greater depth of coverage in economic and some social indicators (e.g., education and health), especially in the large UN indicator set. Numerous indicators are available at the level of the nation-state, but apart from information collected on urban settlements and land cover, few indicators are available at smaller spatial scales.

The two American efforts included in Table 5.2, one by a federal interagency task force (see Table 5.1) and the other by an ad hoc citizen

Table 5.2 Indicators of Sustainable Development Proposed in Various Projects

	Sustain		
	Nature	Life Support	Community
	UN Commission on Sustainable Development (1997)		
Indicator group			
environmental	7	50	2
social	1	7	
economic		13	
institutional			6
totals	8*	70*	8*
	World Bank, *Expanding the Measure of Wealth* (1997)		
		1	
	Netherlands Environmental Policy Performance Indicators Adriaanse (1993)		
Indicator group			
environmental themes		7	
economic			
totals	0	7	0
	U.S. Interagency Working Group (1998)		
Indicator group			
environmental	8	12	1
social			7
economic		2	6
totals	8*	14*	14*
Indicator group	**Sustainable Seattle (1995)**		
environment, population	2	8	3
economy			2
health, community, education			8
totals	2	8	13

* Column totals are greater than total number of indicators because some are counted in more than one category.
† Numbers marked with a dagger indicate the number of indicators that are potentially available in spatial (geo-referenced) form, at a level of resolution finer than national boundaries.

Source: Based on US Interagency Working Group for Sustainable Development Indicators (1998).

Develop			Availability of Indicators			
People	Economy	Society	yes	no	unknown	number of indicators
	5	5	8	27	20	55
17	7	13	37	3	1	41
	16	1	12	2	9	23
	4	9	6	3	6	15
17	32*	28*	63	35	36	134
1	1		1	2		3
			7			7
	6	1	7			7
0	6	1	14			14
	4		16/13†			16
7	4	5	11/11†			11
3	14	4	13/8†			13
10*	22*	9*	40			40
	2		15			15
4	2	1	9			9
4		4	16			16
8	4	5	40			40

panel in the city of Seattle, each chose about 40 variables, sifting from a larger number but converging on sets of indicators considerably more numerous than those typically used, for example, to assess sports leagues, financial markets, or local weather. Both the national and Seattle indicator sets include variables probing the sustaining of community, the aspect of sustainable development that has been least studied. The national set includes participation in arts and recreation, while the Seattle set includes a measure of gardening activity. The federal task force made a deliberate attempt to emphasize large-scale, long-range phenomena, similar to the Board's interest in a long-term transition toward sustainability.

The efforts by the UN Commission on Sustainable Development (CSD) and the World Bank complement one another. The CSD indicators were assembled using a Driving Force–State–Response framework similar to that seen in Figure 5.1. Selected through a consensus process without an agreed-upon operational definition of sustainable development, the CSD indicators are numerous, diverse in the methods used to measure development or sustainability, and include a large number of indicators for which reliable measurements do not exist.

The World Bank, in contrast, has estimated three capital accounts. Each attempts to capture the value to national economies of a vital aspect of the world. The most familiar account, of "produced" capital, is what is normally called national wealth—physical capital and financial claims—and is marked in the "economy" column in Table 5.2. A second account measures natural capital—the resources and capitalized value of services provided by the natural world—and is marked in the "life support" column in Table 5.2. In principle, this would include standing timber, soil fertility, fish stocks, potable water, and the value of flood control by wetlands. Natural capital estimates are as yet primitive in comparison to those for produced capital. The most recent World Bank study takes into account only the use values of natural resources,[8] an approach that ignores unpriced damage to ecosystems, as well as ecosystem services like the flood control capabilities of wetlands and aesthetic or moral dimensions of resource value. The third component of wealth, quantitatively the largest, is human resources—the economic value of labor, knowledge, and social institutions—and is marked in the "people" column in Table 5.2. The Bank estimates this dimension of wealth as a residual, by inferring the value of human resources needed to explain the generation of the actual flows observed in national income accounts. All three accounts, including the one measuring "produced" capital, are subject to errors of estimation. Already, the World Bank study has launched debates, but has succeeded in broadening the key issue about how to capture different measures of value in a transition toward sustainability.

Although the Bank's indicators are highly aggregated and estimated using drastic assumptions, they are conceptually clear. The wealth of nations should be considered in three parts. At least at the margins wealth can be transferred from one account to another in ways advantageous to people. By contrast, the United Nations CSD indicators do not warn unambiguously of imminent hazards in any ecosystem or society, nor do they provide guidance on how to pursue sustainable development.

Only the United Nations CSD indicator set includes variables that are not now being measured. This is a notable strength of the CSD process, the realization that much of what needs to be assessed about sustainable development remains unclear. Another strength of the CSD process is its recognition of the need to transfer reliable measurement methods to developing countries. The UN also has sponsored a wide-ranging, if still diffuse, research effort under the aegis of the Scientific Committee on Problems of the Environment (SCOPE) of the International Council for Science.[9] In evaluating measurements being taken in various categories, the SCOPE effort outlines a broad research agenda for indicators (based on filling methodological gaps, resolving inadequate existing efforts, making better use of existing designs), but does not provide a framework for monitoring indictors.

In sum, the Board finds that there is no consensus on the appropriateness of the current sets of indicators or the scientific basis for choosing among them. Their effectiveness is limited by the lack of agreement on what to develop, what to sustain, and for how long—that is, there is a lack of agreement on the meaning of sustainable development (see Chapter 1), on the specificity or aggregation of indicators, or on the use of existing as opposed to desired data sets. The projects carried out over the decade since the Brundltand Commission popularized the idea of sustainable development have drawn on the large bodies of work done in past decades on the measurement of human welfare and the condition of the environment. These efforts bring together many sources of illumination, but have yet to produce a set of goals for social and natural conditions that can plausibly lead to prosperity for all while conserving the life support systems on which human economies rest. Consequently, they have not provided indicators set on goals for sustainability.

The fact that societies do not have a clear path to a sustainable future is hardly surprising in light of the long time scales, large spatial reach, and unexpected turns of the future described in Chapters 1, 2, and 3. Yet controversy over the definition of sustainable development and the set of indicators to monitor its evolution has hindered scientific and political progress. In an effort to overcome these barriers, the Board now turns to the task of defining a framework for indicators to measure essential environmental and human parameters, and whose monitoring might guide societies toward our normatively defined transition toward sustainability.

INDICATORS FOR A SUSTAINABILITY TRANSITION

Although a compact set of indicators cannot comprehensively measure the complex and qualitative dimensions of a transition to sustainability, indicators provide a clear and concise reading on progress which can have a powerful impact on both the public and policy makers, leading to essential changes in policies and behaviors. In addition, sets of indicators testify to varying claims on what matters in a transition. The Board's claims are implicit in our normative perspective: to meet human needs while maintaining life support systems and reducing hunger and poverty.

While indicators are not by themselves an answer to the question of what constitutes a transition toward sustainability, they are indispensable in helping to successfully answer that question. Multiple indicators will be needed to chart progress toward the goals for human welfare and planetary life support, and to evaluate the effectiveness of actions taken to attain these goals.

Charting Progress Toward the Goals

First, we describe five kinds of information that is monitored or needs to be monitored at different spatial scales that shed important light on whether human needs are being met and whether human activities are compatible with sustaining life support systems (see Tables 5.3 and 5.4):

• Human welfare is now being monitored by quantitative indicators that are appropriate in concept but implemented with inadequate coverage and frequency.

• Quantitative indicators to measure global phenomena are now monitoring planetary circulatory systems affected by human activity.

• Critical zones of human-environment vulnerability at regional scales are being identified, but there is not a single set of indicators that can monitor the combination of social and natural factors that lead to irreversible damage.

• Indicators are needed to describe the management requirements of ecosystems that support rapidly growing cities. Productive landscapes at local scales will help reconcile accelerated urbanization and the overall needs of human settlements.

• Inventories of ecosystems will assist conservation at local scales. Protected areas, managed to enable their biota to persist indefinitely, are being identified on a place-by-place basis, rather than through a consistent set of appraisals of their long-term sustainability.

For each of these settings, indicators form an indispensable but in-

TABLE 5.3 Global and Regional Indicators for Meeting Human Needs

NEEDS	INDICATOR	Agency	Frequency of estimate	IN NEED [year of estimate]
Providing Food and Nutrition				
Under-nourished	Number and percentage chronically underfed for work, health, and growth	FAO	5-year intervals [1970-]	828 million [1996]
Nurturing Children				
Under 5 Mortality	Number and rate of deaths 0-5 yrs.	UNICEF	Annual	12 million [1997]
Underweight	Number and percentage of 0-5 yrs. <2SD median weight for age.	UNICEF	Annual	183 million [1997]
Micronutrient deficiencies	*Iodine*: Number and percentage age 6-11 with palpable or visible goiter	WHO	Irregular; current status reviewed in de Onis and Blössner (1997)	18% [1991]
	Iron: Number and percentage of mothers and children anemic	WHO	See above	51% < 4 yrs. [1991]
	Vitamin A: Number and percentage of pre-school children at risk (living in areas where defieciency and its consequences occur)	WHO	See above	190 million [1991]
Finding Shelter				
Water	Number and percentage with access to safe water	WHO	Irregular; current status reviewed in WRI (1998, Table 8.7)	1,115 million [1994]
Sanitation	Number and percentage with access to adequate sanitation	WHO	See above	2,873 million [1994]
Housing	Number and percentage living in housing where lives and health are at risk	UNCHS	10 years	600 million

Sources: WHO (1996), UNCHS (1996), FAO (1998), UNICEF (1998).

complete part of the intelligence needed to discern a transition toward sustainability in the decades to come.

Meeting Human Needs, Reducing Hunger and Poverty

As discussed in Chapter 2, human societies have reduced hunger and poverty in relative terms as population has grown. Yet even these impressive improvements leave large absolute numbers of the destitute, together with a widening inequality between rich and poor across nations and within national economies. Human population growth is slowing, with the rate of absolute increase falling over the past decade. Urbanization of the human race is still accelerating, with roughly half of the world's population currently living in cities, a fraction that is projected to continue to increase over the next two generations. These changes seem likely to alter much of social life, including some of the ways we define human needs.

Meeting human needs is a near-term imperative, one that the world community has pursued with some success for at least two generations. Some quantitative data series are available in this area, often over times longer than a generation, together with proven analytical structures in demography, public health, and other applied social sciences.

Yet, as shown in Table 5.3, there is only a rudimentary system of indicators in place to assess human needs, hunger, and poverty. For example, a precise estimate of the number of poor and hungry people in the world remains elusive: hunger and poverty are difficult to define, the statistical data are weak and scattered, and efforts to improve data collection and analysis have been limited. In addition, resources devoted to the measurement and reporting of hunger and poverty are meager in comparison to the effort put into reporting population or economic growth. The reason is simple: national governments are rarely motivated to inquire into the fate of those for whom they have not provided. The existing indicators also reflect the implicit hierarchy of needs discussed in Chapter 1, favoring children and people in disasters—feeding and nurturing first, followed by education. Housing adequacy is rarely estimated globally and comprehensive employment not at all.

Nonetheless, with the exception of employment, a baseline of regional and global estimates exists against which progress in meeting human needs and reducing hunger and poverty could be measured. Examples are shown in Table 5.3. In all cases, such indicators are based on either national aggregates or on special populations within nations. Most of these data are actually nonrandom samples, but as much data is missing even when a condition is reported on; this can be seen, for example, in the data for 193 nations in the latest UNICEF report.[10] The number undernourished is inferred from the annual estimates of agricultural production and the resulting estimate of dietary energy supply for every country in the world made by the UN Food and Agricultural Organization. Many of the estimates in Table 5.3 are based on measured surveys, but even more rely on informed judgment or guesses for some countries.[11] Recognizing the difficulty of assembling comprehensive coverage, the UN estimate of 600 million inadequately housed relies heavily on a housing indicators program begun in 1990 that uses consultants in 52 cities containing 10 percent of the world's urban population to estimate 25 key indicators such as floor area per person.[12]

Broadly speaking, indicators of human need are of two types: those based on direct measurement of a condition that is symptomatic of the condition to be assessed, and indicators one step removed, measuring the number "at risk." The following examples are drawn from studies of hunger.[13] Measurements for *underweight* are mostly direct, based on measurements of children's weight carried in national demographic and health surveys in 120 countries.[14] Those data are supplemented by more recent UNICEF-sponsored multiple-cluster indicator surveys carried out in 60 countries in 1995 and 1996,[15] as well as reports from key clinical programs in developing countries. But even when weight is adequately sampled, measured, and reported, age estimates remain a problem. There is also a lively debate about the adequacy of the reference standard (based on weight for age in industrialized countries) from which underweight is calculated. Other direct measurements of human need may include observing goiters for iodine deficiency, anemia for lack of iron, and xerophthalmia incidence for vitamin A deficiency. In contrast, *undernourished* is an "at risk" estimate, an effort to calculate the numbers resident in households whose income or food production is insufficient to provide a minimal diet sufficient for work, health, and child growth. Key assumptions in such calculations, in addition to dietary energy supply, are the minimal dietary requirements and the distribution of income and food production within a national account. Other at-risk estimates have been made of numbers resident in areas with extensive iodine or Vitamin A deficiencies.

It is clear that a responsibility of the world community should be to report quantitatively on human well-being, with particular attention to hunger and poverty, on an annual or biennial basis sufficient to mark movement toward or away from the agreed-upon goals for basic human needs. Achieving regular reporting with usable accuracy could build on the efforts now put into the annual report of the UN Development Program, extending the already widespread use of targeted surveys (e.g., health, population, living standard), and incorporating reporting mechanisms with the creation of international targets and goals.

Monitoring Planetary Circulatory Systems

Indicators also play a role in monitoring global threats to a sustainable future. Earth has biophysical circulatory systems—rapid circulation in atmosphere and oceans, driven by solar energy, and slower changes in the lithosphere, as tectonic plates move, and the biosphere, as migration patterns shift and species radiate—that act as an analog to human vital signs. To these circulatory patterns, humans have added travel, technology, and trade—moving people and their companion life forms with increasing speed and momentum across spatial and biogeochemical domains (see Table 5.4).

An objective of worldwide scientific studies of planetary circulatory systems is to search for phenomena and potential surprises that may affect the stability of natural systems and the sustainability of human endeavors and well-being. Trouble in the circulatory systems is important because the scale of circulation can involve the entire planet more rapidly or persistently than governments can address through regulation. The transportation of infectious diseases by human travelers has been cited recently.[16] Less noticeable but sometimes more important surprises lurk, as global phenomena increasingly interact with other forces to cause unanticipated consequences. The interactions of nitrogen deposition and elevated CO_2, and of sulfur aerosols and climate, both discussed in Chapter 4, are such examples. Such interactions are difficult to predict and, once discovered, can be hard to manage when they involve processes important to human economic activities, as almost by definition they do. More generally, changes in planetary circulatory systems are subtle and largely invisible in the short run without scientific measurements and their theoretical interpretation.[17] Thus, long-term monitoring programs must include supportive fundamental scientific research. While indicators sometimes provide signals that are valuable and comprehensible, numerous examples, such as the failure to recognize seasonal depletion in polar stratospheric ozone,[18] underscore the value of scientific research as a social resource for recognizing surprising threats and opportunities that indicators on their own do not delineate.

Indicators of important chemical changes in the atmosphere have become well utilized in recent years. There is agreement that changes in atmospheric composition indicate changes in the radiative balance of the planet, with consequences that are likely to include long-term and large-scale modifications of climate.[19] The search for reliable indicators of human-caused climate change is well under way. Similarly, some monitoring of ozone and of the gases that deplete the stratospheric ozone layer is in place as part of an international legal regime aimed at eliminating ozone-depleting chemicals. At the regional level, long-range transport of air pollutants including ozone, sulfates, and oxides of nitrogen is being monitored in many places in an attempt to implement regulations that cross political boundaries.

Planetary circulatory systems of increasing significance are the networks of communications and trade, and migration and travel, now expanding rapidly. These evolving networks carry direct threats already identified (see Chapters 2 and 4), such as the transfer of diseases and exotic species, together with a large spectrum of opportunities (such as the expanding telecommunications and computing networks) both to develop and to sustain human welfare. To date, study of this network from a scientific perspective has been done within the framework of the social sciences. Those studies have illuminated the conflicts between the transformations driven by global trade and the goals of environmental protection and economic equity.[20] But few analyses have been done of the effect of communications and computer technology (especially the increasing use of the Internet) on work or consumptive patterns, or on productivity and efficiency, to determine how these networks might mitigate the threats associated with meeting the needs of a more crowded, more consuming human population. Indicators of trade are now reported at high levels of aggregation[21] with data organized by dollar volume and nation. Datasets with much finer resolution on the production of specific commodities are now becoming available.[22] But these more detailed data do not become useful indicators without an agreed-on framework of specific questions. The Board has not studied trade indicators at the global level, although we believe the long-term growth of trade will play a significant role in a transition to sustainability; we have listed trade as an indicator in Table 5.4 as a placeholder for this belief.

Identifying Critical Regions

While indicators of circulatory systems monitor the directions of human and environmental systems on a planetary basis, indicators are needed to catch the signals of critical change at the regional level, thereby identifying stresses on ecosystem services resulting from human mismanagement and overexploitation.[23] Although humans were modifying the natural world on local and regional scales even before the invention of agriculture, the scale and scope of human-induced change has accelerated over the past century as both population and consumption have increased. Accordingly, it is useful to consider a definition proposed recently by an international team of geographers: a critical environment is one in which the extent or rate of environmental degradation precludes the maintenance of current resource-use systems or levels of human well-being, given feasible adaptations and the community's capacity to mount a re-

TABLE 5.4 Global and Regional Indicators for Life Support Systems

System	Indicator
Circulatory Systems	
Atmospheric composition	Concentration of carbon dioxide, other greenhouse gases, and patterns of global temperature, precipitation, snow, ice, sea level, and ocean circulation
	Cross-border transport of air pollutants (Europe, N. America)*
Infectious diseases	Alerts of emergent diseases
Invasive exotic species	No regular monitoring Studies of particular sites, e.g., San Francisco Bay
Trade across ecosystems	Economic transactions across governmental boundaries (not ecosystems)
Critical Regions	
Natural setting	Region-specific; not identified
Social capacity to respond	Region-specific; not identified
Feasible steps to mitigate or restore	Region-specific; not identified
Productive Metropolitan Landscapes	None defined in terms of ecosystem damage or cost to rehabilitate
Protected places	Total area protected
	Effectiveness of preservation

Note: EMEP, Geneva Protocol on Long-term Financing of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe; EPA, U.S. Environmental Protection Agency; WHO, World Health Organization; IMF, International Monetary Fund; NRC, National Research Council.

*A North American monitoring program for transboundary air pollutant flows is being developed under the 1991 U.S.–Canada Air Quality Agreement (United States–Canada Air Quality Committee (1999)). Additional datasets may be found in Center for Air Pollution Impacts and Trends Analysis (1999). In addition, the RAINS Asia project at the International Institute for Applied Systems Analysis (IIASA 1999) has estimated emissions for East Asia.

Agency	Frequency of Estimate	Condition
Carbon Dioxide Information Analysis Center (1999)	Annual	Climate change in progress
EMEP (1984) (Europe); US EPA (1998a,b)	Annual (Europe only)	Controls on emissions being negotiated and implemented
WHO	As found	Increasing frequency (see NRC (1992a))
None	—	High frequency in some places (see NRC (1995e,f))
IMF (1998)	Annual	Threat to life-support systems unclear
—	—	Locally severe damage
—	—	Unknown
—	—	Unknown
—	—	Unknown
World Conservation and Monitoring Centre (1999)	Every 3 years	Unknown (see Green and Paine (1997))
—	—	Unknown

sponse.[24] A comparative study of nine regions, each of which had attracted scientific notice as a potentially critical region, concluded that one of the nine, the Aral Sea in the former Soviet Union, was in a critical state. Two others were firmly in the region marked "endangered" in Figure 5.3, eastern Sundaland—Borneo and peninsular Malaysia—which has experienced severe deforestation and consequent forest fire damage, and the basin of Mexico, the scene of rapid industrialization and population increase during the 20th century.[25] Thus, regional environments move through trajectories from sustainable to critical as their ability to recover from damage diminishes and the ability of society to sustain the costs of mitigation or substitution of environmental services increases.

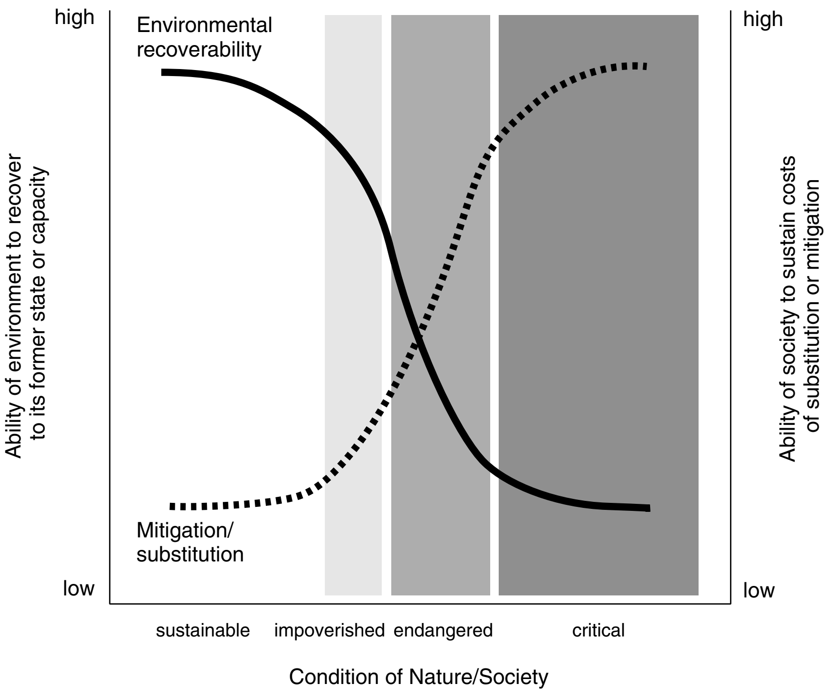

FIGURE 5.3 Regional trajectories and emerging criticality. The criticality of a region is a joint function of the ability of the environment to recover to its former state or capacity and the ability of society to sustain the costs of mitigation of damage or substitutes of environmental services.

Source: Redrawn from Kasperson et al. (1995). Courtesy of United Nations University Press.

Whether a region is on a path to criticality depends on three factors: the state and vulnerability of the natural setting, the social capacity to recognize, and choose to cure, the problems brought about by human activity, and the feasible steps available to avoid irreversible damage. Note that these factors are explicitly grounded in human interest. (Preservation of ecosystems and species is discussed separately below.)

The risks facing potentially critical regions are a function of their social systems as well as their natural settings. All three key elements of critical damage—pressure on natural systems, capacity to respond, and adaptations that would constitute an effective response—are conditioned by history. The risks to a region, accordingly, are "contingent upon unique socioeconomic structures."[26] Those structures may include international markets or other forces involving societies and actors from afar. Although the critical risk has a local impact, its cause may be distant.

The highlighting of the social variables here does not mean that natural variables are unimportant, but rather that both social and natural variables matter (see Figure 5.3). Pressure on natural systems is typically measured using variables from the natural sciences, but the pressures are exerted by human activities. Feasible adaptations are often described in engineering terms, but whether they are feasible is a social question and whether the adaptations are put in place is an institutional matter. Risks to sustainability are specific to the social and natural history of the region. In part for that reason, researchers have no satisfactory means as yet of comparing risks to sustainability across different regions.

These facts imply that useful indicators of regional unsustainability will reflect the specific conditions of each region. Researchers suggested a generic set of trajectories (Figure 5.3): as intensity of exploitation increases, the modifications made to ecosystems decrease the potential for complete recovery; correspondingly, the costs to mitigate ecosystem damage or to provide substitutes for the goods and services provided by the regional ecosystem rise.[27] In the critical zone, costs rise so much that irreversible damage to both natural and social systems is done. Of global relevance are the criteria for critical damage—irreversible losses and threats to human well-being or economic sustainability. The dynamics of criticality are local, but criticality in any region is an indicator of global significance.

Criticality is not a quantitative indicator, however, but a judgment informed by a combination of social and natural system considerations. It is a judgment likely to be contested. In the current state of understanding, the assessment of whether a region is headed for unsustainable damage and of whether its resident social system is capable of avoiding that damage cannot be reduced to a computational algorithm.

Given this constraint, researchers should search for quantitative and qualitative information that can inform different kinds of judgments:

- Identify regions at risk of critical damage. Develop region-specific indicators to assess critical risks.
- Provide information to the world community on the scope and scale of potential critical risks and on the costs of avoiding irreversible damage.
- Advance basic understanding of the social processes and natural vulnerabilities that expands knowledge of the potential risks associated with damage.
- Advance basic understanding of the social processes—including politics, markets, and culture—that both form and undermine the capacity to sense and to avoid critical damage.[28]
- Working with regional communities, develop ways to recognize critical decline before irreversible damage is done, and develop means of learning from experience so that capacity to respond will strengthen over time. As necessary, work in support of external intervention to forestall critical decline.

Although these activities make use of quantitative indicators, these analytical tasks cannot all be routinized into the standard protocols that define an indicator. Nonetheless, the social functions served by indicators would be realized if the tasks were reasonably well carried out.

Conserving Productive Landscapes

As human settlements—particularly cities—grow in the coming century, it will be important that patterns of growth take into account the dependencies of populations on local ecosystems.[29] For some resources such as food supply, it is possible to meet the needs of urban dwellers economically by importing goods over longer and longer distances. For others, such as water or air, it is costly or infeasible to build technological systems to substitute for the natural systems already in place. The conservation of productive landscapes is implicit in the Pressure-State-Response framework (Figure 5.1). One task of society is to anticipate the pressures of future populations, designing infrastructures that respond to those pressures in ways that can be sustained by an affordable fraction of the economic surplus generated by the population of a settlement or urban region. Sensing the pressures upon environmental services and resources with enough lead time and analytical vision to respond is a challenge that is being met, imperfectly, by the indicators gathered by governing authorities.[30] For example, the Sustainable Seattle project (Table 5.2) includes measures of soil erosion, air quality, and solid waste generation and recycling. Yet none of these measures is explicitly stated in a way that provides insight into the relationships among increasing pressure, declining ecosystem recoverability, and increasing costs of mitigating or providing substitute services shown in Figure 5.3.[31] Such insight is important for sensing irreversible damage, but it is difficult to provide (Table 5.4).

The spatial and temporal structure of ecosystem services is often not apparent to humans and the institutions and markets through which they organize their activities. As a result, the development of human activities and settlements frequently does not take into account the patterns and vulnerabilities of ecosystem services. Unsustainable development then results, a pattern of settlement far more costly to maintain than expected;[32] in severe cases, the region may also face a larger risk of critical environmental damage. Metropolitan sprawl has been criticized as a form of unsustainable development, although there is lively controversy about whether sprawl is wasteful in an economic sense.[33] Unsustainable development is further accelerated and reinforced by pressures to accommodate urgent human needs rapidly when investment capital is scarce.

For centuries, physical infrastructure—sewers, aqueducts, roads—have been used to overcome the imperfect match between human needs and the supply of ecosystem services. In the great urbanization underway, however, it makes sense in many places to anticipate greatly increased human demands and to design infrastructure so that those demands may be met efficiently by resources nearby. Ecosystems are valuable to people, frequently in ways that are literally irreplaceable in practical terms.[34] The design of urban infrastructure should reflect the value of ecosystems, especially freshwater ecosystems in their value for future water resource needs, wetlands, flood plain habitat, commercial fisheries and other services.

Such an approach requires, however, understanding and nurturing the ecosystems surrounding urbanizing sites—an understanding that comes in part from long-term studies of those ecosystems. Improved understanding would also illuminate the nonmarket value of species and ecosystems, permitting better-informed choices when utilitarian values and conservation biology come into unavoidable conflict.[35] The required long-term ecosystem monitoring and supporting field science is just beginning with the creation of the first two long-term ecological research stations in Baltimore and Phoenix.[36]

Preserving Ecosystems

We described in Chapter 4 how the preservation of species, habitats, and ecosystems has become a significant part of the effort to conserve and maintain biodiversity and to effect a sustainable biosphere.* In spite of its importance, preservation remains controversial for social and scientific reasons. Improved understanding of which conservation methods are biologically effective would assist in implementing preservation strategies. As noted in Chapter 2, there is no question that many ecosystems are at critical risk and that irreversible losses of species are under way at a pace and scale seen only five times before in the history of life.[37] But translating that grim reality into indicators at the scale of ecosystems managed by humans for purposes of preservation remains one of the significant challenges of a transition toward sustainability.

The realization that human activities are causing a wave of species extinctions that have only been met or exceeded a few times in the entire geological record is itself a recent discovery.[38] The massive endangerment of species and ecosystems has stimulated two responses over the past several decades—worldwide effort to preserve species and areas, and the field of conservation biology. Land or waters that contain species harvested by humans are not protected easily. Various approaches have emerged for overcoming resistance to preservation. International environmental activism has played a significant role in influencing national governments to preserve habitats. Transnational arrangements for bioprospecting and debt-for-nature swaps have provided financial support for changes in the use of terrestrial and aquatic ecosystems.[39] But conflict persists, as illustrated by the legal and political struggle over private property rights brought about by passage of the Endangered Species Act in the United States.[40]

As described in Chapter 4, preservation efforts are moving away from an emphasis on single species to an emphasis on management of multiple species and their interactions with one other and their physical environments.[41] This expansion of the scope of preservation also greatly increases the complexity of the choices to be made, both scientifically (especially in selecting indicators for monitoring change) and in the way that human activities are considered and reshaped to ensure the maintenance of critical interactions.

The flowering of conservation biology has made clear that the pressure on the world's biological wealth cannot be gauged simply by counting land area being converted or fishing grounds being overharvested. Biodiversity is a complex geographic phenomenon, requiring new tools to assay its richness. An initial attempt to identify a set of large ecosys-

*In this discussion the word "preservation" means setting aside land (or water) for the maintenance or recovery of species, habitats, or ecosystems that are judged to be vulnerable to extinction, failing an explicit decision to preserve them.

tems that would in aggregate provide complete representation of all types of ecosystems and habitats is the Global 200 nominated by the World Wildlife Fund,[42] shown in Figure 5.4. Large-scale conservation is slow work that must contend with the urgent demands of poor people and the powerful forces of governments, trade, and greed.

Innovative methods are now being developed—including rapid assessment methods to assess habitats quickly; population and genetic models that combine information from museum collections and field studies to inform judgments about how species and ecosystems may respond to anthropogenic changes; and fundamental studies of the relationships between the diversity of ecological communities and their stability when subjected to disturbance.[43]

In parallel with conservation science, there has emerged a social capacity to elicit and focus the concern of citizens, governments, and philanthropists. The ideas of conservation biology are now being applied in a wide variety of situations. In addition to the seed banks and zoos that have long provided living collections of biota, captive breeding of animals has enabled a small number of species to be preserved outside the wild.[44] Biotechnology has also been applied to extract desirable traits from the

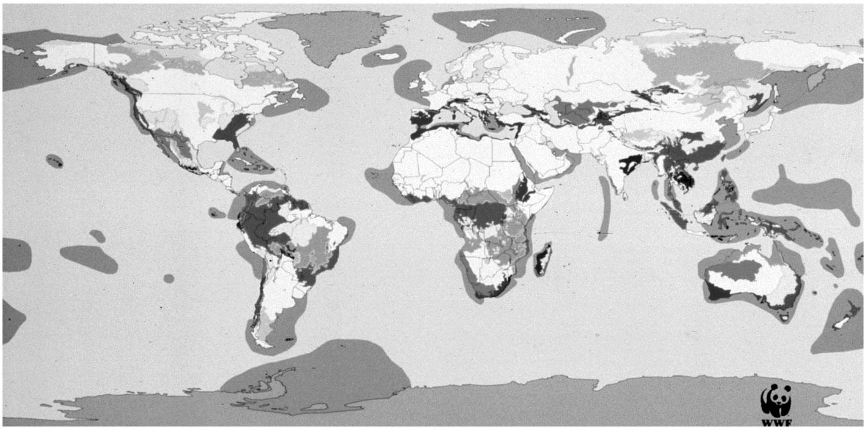

FIGURE 5.4 Global 200 ecoregions proposed by the World Wildlife Fund. The shaded areas would, if successfully conserved, provide representation for all ecosystem and habitat types. Because of the large size of the ecoregions, nearly all will be permanently inhabited by humans. The human economies in these ecoregions would need to join in a sustainability transition accordingly.

Source: Olson and Dinerstein (1998). Courtesy of the World Wildlife Fund.

genomes of some wild species, such as the capacity to make medicinal compounds like taxol, originally discovered in the Pacific yew.[45]

The most visible and controversial efforts in preservation may be protected areas, terrestrial and aquatic habitats in which human use is excluded or altered so as to be compatible with the continued survival of these habitats' biotic communities and wild species.[46] Protected areas have now been declared in many nations around the world, with a quarter of the land base of Costa Rica now in national parks and biological reserves.[47] Often, the social choice to preserve a habitat is organized around a biological indicator—an appealing "flagship" species, such as the salmon of the Pacific Northwest, which may or may not be an effective indicator of the conservation of the habitat as an ecosystem.[48] Without the protected area, there would usually be little chance to sustain or restore valued species and habitats, but without monitoring and assessment there will be no chance of learning what works and, just as important, what does not work, to preserve ecosystems.

A focus of worldwide research should be on sharing and improving methodologies for monitoring and assessment, to evaluate strategies for meeting management objectives (e.g., spatial boundaries, legal status, funding, and personnel), for protecting targeted species (e.g., population parameters such as size, fecundity, and some dimensions of genetic variability), for furthering understanding of how species interact with their environments, and for taking into account the human populations that inhabit regions of high biological diversity (e.g., measuring use, restricting access, maximizing opportunities for traditional land use practices).[49] The indicators collected in each area should be selected to maximize the effectiveness of the protected area in meeting the identified goals of preservation.

Evaluating the Efficacy of Actions

Indicators of human welfare and life support systems identify urgent needs. Indicators selected to evaluate different levels of human-environment interactions can help to steer a course toward sustainability, because in each of these levels of interactions there are hazards that we must strive to avoid. Success in responding to the hazards has been uneven and is likely to continue to be so. There is also the question of navigation, of the long-term directions in which humanity should aim, in light of the possibilities hinted at by the scenarios of Chapter 3 and the goals we laid out in Chapter 1. In this task, quantitative information complements the narratives provided by scenarios. We comment briefly on four different approaches for evaluating the efficacy of actions taken to achieve the goals for sustainablity (see Table 5.5) below, with the aim of provoking debate on navigational aids for a sustainability transition.

National Capital Accounts

Most of the planet will continue to lie outside critical regions and protected areas for the immediately foreseeable future. How should we monitor the evolution of this part of the world for signs of trouble or improvement in a transition toward sustainability? Large fractions of freshwater and solar energy are already appropriated by humans, in the sense that we make use of them directly and indirectly in our economies.[50] Yet what is occurring is hard to see, in part because its human driving forces are decentralized.

It is in this context that the World Bank's studies of the wealth of nations provide a usefully provocative approach: to estimate the state of the world through three national accounts, described earlier in this chapter—accounts of natural, human, and produced capital.[51] In this economic formulation, each of these categories of capital might be transformed by human activity, but so long as a nation's total capital increases over time, its trajectory is in roughly the right direction to contribute to a transition toward sustainability.

The word "roughly" is important. An economic accounting is inadequate to assess sustainability, even without the many major assumptions made in the Bank's current estimates. These studies also demonstrate anew the difficulty of valuing human resources, social institutions, and environmental stewardship using only a utilitarian metric. But the capital accounts make two important contributions. First, the framework draws attention to transformations among forms of wealth—transformations that will continue through, and beyond, any long-term search for sustainability. Monitoring those transformations is useful to highlight them and to acknowledge the importance of undervalued natural capital. Second, the accounting framework is one that can be disseminated via the United Nations' System of National Accounts, an intellectual infrastructure that encourages the finance ministries and governments of the world to use common accounting standards. This is one means for transferring technical assistance, particularly to developing countries, so that the rudimentary reporting of today can be improved over time and made comparable and reliable.[52]

There is a larger question here, though, of whether some sort of "weak" sustainability[53] might be appropriate in the long run—an approach in which many natural assets might not be preserved in perpetuity, but in which the stock of natural assets would vary in response to the needs of humans. The Board believes that we are too early in the pursuit

TABLE 5.5 Navigational Aids for a Sustainability Transition

Navigational Aid	Indicator	Agency	Frequency of estimate	Comments
Economic	National capital accounts: — Natural assets — Human resources — Produced assets	World Bank	Under development; needed at 5-year intervals	Utilitarian framework incomplete in principle; approximations in practice add further errors; simplicity valuable
Policy	PSR indicators used in adaptive management	Needed at local to regional scales	—	Difficult to implement but yields reliable knowledge when successful
Ongoing Transitions				
	Energy intensity (joules/GDP)* carbon intensity (tonnes C/GDP)	WRI, UN, World Bank	Climate convention assessments	"De-carbonization" of energy supply†
	Material flows and recycling	Not implemented	Tied to economic reporting	"De-materialization," closing of material flow cycles
	Population	UN	Annually	Demographic transition
Surprises	None, by definition	—	—	Warning of factors not taken into account; opportunity to improve management—and run larger risks.

Note: PSR, Pressure-State-Response model; GDP, Gross Domestic Product.

*This data series is not regularly reported but is readily calculated from standard sources. Estimates for 1993 are in WRI (1996, Table 12.2, pp. 286-287).

†Nakicenovic (1997).

of sustainable development even to frame this question tractably. What we emphasize here instead is that the World Bank accounts constitute a useful starting point for discussion and learning.

Assessing Policies

The Pressure-State-Response framework envisions indicators as policy assessment tools. It is important that indicators become the basis for learning, an approach called adaptive management. Adaptive management treats policies as experiments, designing them so that lessons may be learned reliably from the implementation of policies, even those that fail. In the PSR framework, this means assembling pressure and state indicators to test the effectiveness of responses. Then, as the responses are carried out, the indicators provide two kinds of learning. First, they should inform those who manage the responses of how to do their work better. Second, the indicators should permit better appraisals of whether the responses are effective at all, so that better responses may be designed as necessary. These simple goals have turned out to be remarkably difficult to achieve.[54] Yet, over the generational time scale of a transition toward sustainability, there is reason to think that a deliberately adaptive approach to policies will yield benefits.[55]

Adaptive management borrows the idea of experiments from laboratory science, where three concepts could be said to underpin the process of learning. First, if an experiment is to produce reliable understanding, the effect must be repeatable. Cold fusion was discarded as a promising energy source because other laboratories could not reproduce the results claimed by the original discoverers. In policy assessment, this means that an effectively designed policy should work in different contexts to some reasonable degree of generalization.

Second, to pin down what makes the experiment work, there must be controls—ways to turn off the causal agent to see if the result also declines or ceases. If a medicine works to moderate pain, then the pain will remain intense if the medicine is withheld and the patient receives a placebo. In policy, in theory this means that there should be circumstances in which *only* the policy is omitted, while all else is the same, to be sure that it is the policy that is making the difference, though obviously this is extremely difficult to do.

Third, it is hard to detect weak effects, so in many cases it is important to provide a large enough experimental manipulation to see the effect. Efforts to restore the ecosystems of Western rivers need large releases of water, so that a rough approximation of the spring flood can recreate the ecological effects that have been eliminated by upstream dams.[56] The technical name for this idea is assuring adequate power of test. In a policy context, it means designing responses that are large enough to have observable impacts on the state or the pressure indicators under study.

None of these three conditions is readily achieved. Policies adopted by governments are usually implemented with little attention to gathering data on the policies' effectiveness. Moreover, neither those who originally advocated a policy (often against stiff opposition) nor those implementing it welcome news that the policy is failing. Finally, many policies are assessed by their cost or other inputs, rather than by their results. It is accordingly easy when resources are scarce to cut back spending so that no observable result can be obtained.

Because the conditions for adaptive management are often difficult to achieve, policies that fall within the framework of a set of indicators can provide important opportunities for learning. The indicators will usually be in place already, in support of a commitment to sustainable development or for other reasons, so that it may be easier to tackle the issues of repeatability, controls, and power of test without securing the cooperation of the agencies and people implementing the policy. A by-product of a well-functioning set of indicators should thus be social learning through adaptive management.

Monitoring Ongoing Transitions

A transition to sustainability is a dynamic process. It will be essential to monitor the trends identified in Chapter 2 to determine whether the specific transitions involved (for example, the globalization of the economy and changes in demographics, consumption patterns, health, energy-intensity, pollution per unit value produced by the economy, and the role of the state in global governance) actually occur on a global basis. In particular, if economies are to continue to grow as populations level off, it will be essential to improve technology and energy efficiency so that humans can accomplish more, economically, with less impact on the natural world.

There is no assurance, however, that the trends described in Chapter 2 will unfold in the direction of greater material efficiency. So it is important to update and to argue over the questions raised by those and other data. In particular, it is important to see if the long-term trend of "decarbonization"* (Figure 5.5) can be accelerated, so that energy for growing economies can be supplied in ways that cause less disturbance to the climate. Ideas on this and other fronts are described more fully in

*The term "decarbonization" is used to refer to the decrease in tons of carbon emitted per unit of energy consumed.

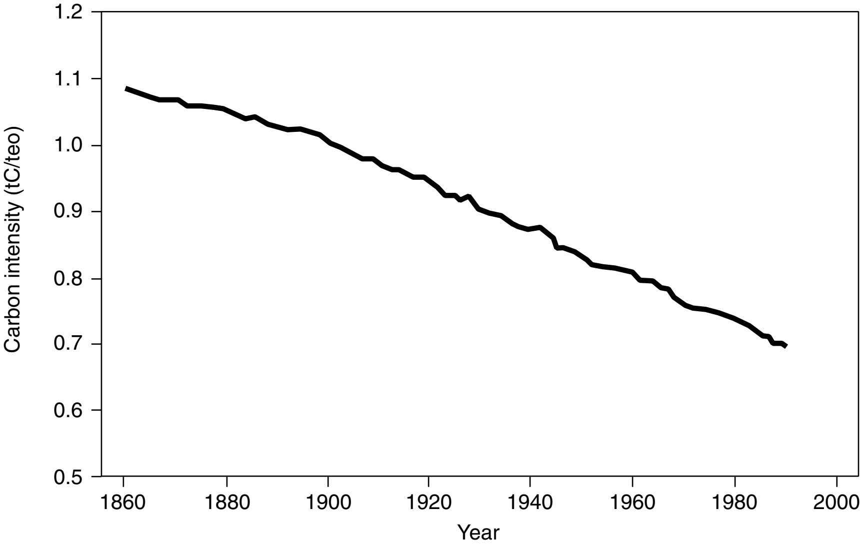

FIGURE 5.5 Carbon intensity of global energy consumption (tC/toe—tons of carbon per tons of oil equivalent).

Source: Nakicenovic (1997).

Chapter 6. The point here is that quantitative indicators are necessary to monitor ongoing transitions and trends.

As transitions do and do not take shape in these areas, people are likely also to develop a clearer idea of how a sustainable economic order is beneficial or easily obtained, and of the ways in which sustainability is costly or infeasible. Navigation is more than avoiding hazards, it is also a way of identifying desirable destinations.

Surprise Diagnosis

A transition to sustainability is an improbable development after a half-millennium of especially restless and sometimes heedless expansion of the human footprint on the planet. Many of the continuities and discontinuities of the past century were not anticipated by leading thinkers of the time. Neither the continuation of economic growth at the end of the Second World War nor the end of the Cold War in 1989-1991 was expected; both were positive surprises for the United States. There is no reason to think that the coming century will have fewer surprises.

Reflecting on environmental surprises over the past three decades, researchers concluded that events like the deadly industrial accident at Bhopal, India, or the discovery of the effect of chlorofluorocarbons on the stratospheric ozone layer shared several characteristics.[57] First, the events were surprises, confounding social expectations. Second, however, they were not incomprehensible in retrospect, but arose from causes that were known in principle, often driven, in part, by variables that were being monitored, even though the surprise itself was not anticipated. Third, these surprises have the potential to harm large numbers of people and have actually done so in instances like Bhopal.

Fourth, after the surprises occurred, the understanding of their causes provided opportunities to increase the social capacity to manage problems in the future. This is a promising finding: it says that societies can learn from surprises, so that they can better anticipate, avoid, or mitigate their consequences. But knowing how to improve management is also a temptation to operate closer to the edge.[58] Surprises could therefore become *more* frequent as humans gain better knowledge of the world. This possibility qualifies the conventional notion that science is valuable because it improves our ability to control or at least predict danger. Even when we do gain knowledge, the fact that social systems may use that understanding to venture further into the unknown may lead to more frequent surprises.

From this perspective, surprises are valuable indicators in themselves, both identifying particularly fragile or brittle endeavors and pointing to phenomena and processes that humans need to take into account. It is well accepted that surprises should produce humility. Surprises should also produce curiosity. On the time scale of the transition toward sustainability, curiosity and the learning it prompts are likely to be important, whether or not control can be extended in the short term.

INDICATORS AND SOCIAL LEARNING

The lack of an operational definition of sustainable development leads to disagreement about which indicators societies should use to measure progress toward or away from sustainability. Without that agreement, one should expect spirited debates over the value, biases, and meanings of indicators. In the related sphere of economic policy, one can observe over the past half-century sharp disputes in the United States over economic growth, the incidence of poverty, unemployment, and inflation. All these characteristics have been indicators that American politicians think will influence voter behavior.[59] Remarkably, the independence of the data gathering and analytical organizations has survived, despite their location within government agencies.[60]

This is one lesson for science: the independence of science is central to the social value of scientific information in a transition to sustainability. Preserving that independence requires prudent judgments about the use of science as a political resource.[61]

Another lesson emerges from the incomplete understanding of the nature of a transition to sustainability. Indicators are useful in the scientific quest for that understanding, but the collection and appraisal of those indicators must be part of a *research* enterprise that goes beyond what is conventionally called monitoring. Looking over the 50 year horizon for a transition toward sustainability, such an enterprise involves creative inclusion of both knowledge and know-how; it will have to go beyond the typically exclusionary lines drawn between science and technology. In Chapter 6, we call this sustainability science; indicators are an important element of study in that science.

A third lesson is that surprise is itself a valuable indicator. Governments and societies should anticipate unexpected things to happen. In a policy context, the inevitability of surprise calls for a kind of precautionary principle: because surprise is likely, action should be undertaken with thought, humility, and caution. These qualities are not quantifiable, but that does not diminish their significance.

Indicators used to report on a transition toward sustainability are likely to be biased, incorrect, inadequate, and indispensable. Getting the indicators right is likely to be impossible in the short term. But not trying to get the indicators right will surely compound the difficulty of enabling people to navigate through a transition to sustainability.

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ENDNOTES

1 See Adriaanse (1993).

2 Note that this set is relatively long, and yet still too simple for many purposes, such as sensing trends in health or work.

3 Farrell and Hart (1998); http://www.subjectmatters.com/indicators/.

4 Moldan and Billharz (1997), pp. 1-5.

5 For a compilation, see IISD (1998).

6 The Balaton Group, see Meadows (1998).

7 UN Commission on Sustainable Development (1997); World Bank (1997); Netherlands Environmental Policy Performance Indicators, see Adriaanse (1993); US Interagency Working Group (1998); Sustainable Seattle (1995).

8 World Bank (1997), p. 21.

9 Moldan et al. (1997).

10 UNICEF (1998).

11 Uvin (1994).

12 UNCHS (1996).

13 See Uvin (1994) for a discussion.

14 Uvin (1994).

15 UNICEF (1998).

16 E.g., Garrett (1994); NRC (1995c).

17 Magnuson (1990).

18 Benedick (1991).

19 Houghton et al. (1996).

20 E.g., Korten (1995).

21 E.g., IMF (1998).

22 E.g., FAOSTAT (1999).

23 Franklin (1993); Slocombe (1993); Stork et al. (1997).

24 Kasperson et al. (1995).

25 Ibid.

26 Kasperson et al. (1995), p. 14.

27 Kasperson et al. (1995).

28 Regions that appear to be at risk of critical damage have one or more important common-pool resources—natural assets that cannot be readily managed by individual owners. Common-pool resources themselves are not a defining characteristic, however, because there are numerous examples of communities that depend on such resources and that have managed them well over long periods. A useful perspective on the governance structures that have enabled management to succeed has been advanced by Ostrom (1990). Ostrom's findings underscore the importance of monitoring and enforcement, so that individuals who engage in irresponsible behavior can be detected and brought back in line with community norms. Practical application of that analysis, to strengthen the capacity of communities to manage common-pool resources, has been slow because the social dynamics of communities are both complex and resistant to intervention by outsiders. The logic of monitoring as a precursor to corrective action is implicit in the discussion of indicators generally in this report.

29 WRI (1996), Ch. 1.

30 UN (1998), WRI (1996).

31 For an example of work that seeks to build such a context, see Rothman et al. in press.

32 E.g., Egan (1996).

33 Metropolitan sprawl, Ewing (1997); economics of sprawl, e.g., Gordon and Richardson (1997).

34 Daily (1997).

35 Goulder and Kennedy (1997).

36 NSF (1997); Baltimore Ecosystem Study (1998); Central Arizona–Phoenix Long-Term Ecological Research Project (1998).

37 Wilson (1993).

38 Wilson and Peter (1988).

39 Bioprospecting, Weiss and Eisner (1998); Eisner (1994); Reid et al. (1993); debt for water swaps, Pearce and Warford (1993); Hopkins (1995).

40 Endangered Species Act and private property rights, NRC (1993a, 1995h); Tobin (1990); environmental activism and habitat preservation, Lowe and Goyer (1993); Nature Conservancy (1982); Mickelwright (1993); Hopkins (1995).

41 Lubchenco et al. (1991).

42 Olson and Dinerstein (1998); The Nature Conservancy (1996, 1997).

43 Rapid assessment, e.g., Tangley (1992); response and anthropogenic changes, Groom and Pascual (1997), Fiedler and Kareiva (1997), diversity and stability, Tilman (1997).

44 Olney et al. (1994).

45 Sasson (1996).

46 Fiedler and Kareiva (1997); NRC (1998).

47 Gamez (1996).

48 NRC (1996b).

49 See, e.g., Stork and Samways (1998) for a treatment of monitoring and assessment of biodiversity.

50 Vitousek et al. (1986); Postel et al. (1996).

51 World Bank (1997).

52 UN (1998).

53 Pearce and Atkinson (1993).

54 Lee (1993); Gunderson et al. (1995).

55 E.g., Volkman and McConnaha (1993).

56 Barinaga (1996).

57 Kates and Clark (1996).

58 Tenner (1996).

59 Tufte (1978).

60 See Duncan and Shelton (1978).

61 Lee (1993), Ch. 7; cf. Holmes (1998).