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Lecture

Sustaining Living Systems: Challenge for the Twenty-first Century

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Abstract

For millennia, nature—specifically living systems—provided food, fiber, and materials to nourish, clothe, and house us. Living systems conditioned the air we breathe, regulated the global water cycle, and created the soil that sustained our developing agriculture. They decomposed and absorbed our wastes. Beyond practicality, nature fed the human spirit. But the cumulative impacts of more than 6 billion humans are taking a toll on those living systems. The toll is manifest in the decline of living water resources worldwide. Yet society has remained largely unaware of this decline because it perceives water only as a nonliving fluid—a commodity to be consumed or used as a raw material in agriculture or industry. Because water resource monitoring has focused on chemical rather than biological indicators, degradation has persisted despite powerful laws calling for broader thinking and a broader regulatory framework. The problem of poor or misleading indicators is not limited to aquatic systems: the choice of indicators to track economic vitality and social well-being is also flawed. To reverse the erosion of living systems, society needs a new generation of indicators that fully reveal the state of economic, social, or ecological systems. Without such measures, we will not fully perceive the erosion of Earth's life-support systems—human or nonhuman—and policymakers will lack the crucial foundation for informed decision making. If we watch such new-generation indicators as closely as we watch the Dow Jones industrial average, perhaps we will again value all of Earth's living and nonliving systems and thereby improve the state of the biosphere as well as our own lives.

Barely over a century old, ecology, the science, finds itself in the middle of some of the most important challenges facing human society in the twenty-first century. Just a few decades ago, the words *ecology* and *environment,* and their many contemporary connotations, were not on the public radar. In 1955, for example, the *New York Times Index* did not include the word environment, and neither *environmentalist* nor *environmentalism* made it into the 1971 *American Heritage Dictionary* (Thiele 1999). Today, in contrast, diverse segments of society call for business and government to incorporate ecological imperatives into the marketplace, for science and engineering to provide the tools to address environmental challenges, for governments to use those tools more effectively, for educational institutions to teach future generations to respect the great harmonies in their living surroundings, and for religious communities to reverse long-standing patterns of neglect and exploitation of the nonhuman world (see the appendix in Karr 2002 for specific details and complete citations). The unprecedented scale and speed of environmental disruption, many conclude, are serious threats to our children's future.

Ecology has gone from a word designating a relatively narrow scientific discipline known to a limited number of scientists to a life philosophy, a source of guidance or link to morality (Karr 2002). The status quo—unwitting or deliberate neglect of the human-environment relationship and its effect on ecological health—is no longer acceptable to people around the world.

1. What Humans Have Wrought

The 2,000-fold increase in Earth's human population during the last 15,000 years—from a few million to 6.3 billion and growing—is the result of human ingenuity and a rich biosphere. Ingenuity gave humans an edge, allowing them to efficiently exploit the second factor, the rich variety of environments and their associated living systems. During this period, human natural history changed from that of a social, patch-disturbing, hunter-gatherer (Rees 2000) dependent on materials produced by nature to that of a techno-creature with an ability to extract living and nonliving resources to support the agricultural and industrial metabolism that enabled modern society. In effect, humanity has prospered thanks to what it has taken from Earth's ecosystems. That taking permitted the 2000-fold increase—a huge number considering humans' body size—making humans the most influential species in history. Humans now occupy an extraordinary geographic area and influence an even larger area because of proliferating technology and increasing rates of resource consumption and waste generation.

Although society still views these trends with pride, overharvest of natural resources, the spread of society's waste, and humanity's ability to exploit energy—especially, over the past 1,000 years, energy in fossil fuels—have distorted the biosphere in ways that threaten human well being (Figure 1). Among the disparate challenges associated with these distortions are rising asthma rates, food insecurity, depleted fisheries, changing climate, stress syndromes from overcrowding or the pace of modern life, and mounting numbers of environmental refugees (e.g., 250,000 displaced from New Orleans by Hurricane Katrina). Because a healthy biosphere is a prerequisite for healthy humans and for societal well-being, humanity can ill afford to ignore the consequences of actions that degrade Earth's living systems.

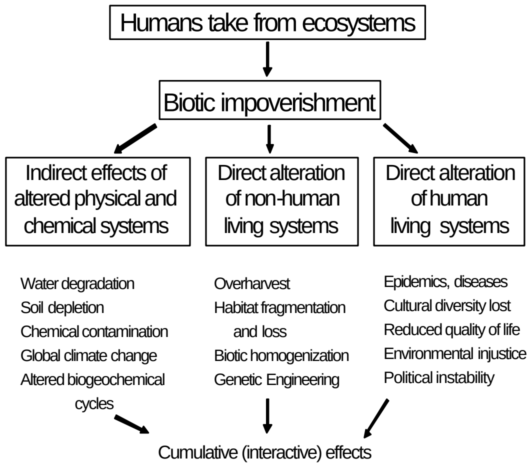

Figure 1. The many faces of biotic impoverishment that result from humans' taking from Earth's ecosystems. (Modified from Chu & Karr 2001).

2. The Lessons of History

Distortion of the biosphere is not just a twentieth-century phenomenon or a by-product of European advances in the last 500 years. Urbanization; population growth; and the accumulation of capital, or wealth, have distorted nature worldwide for at least 5,000 years (Chew 2001, Hughes 2001). The archaeological record has revealed that numerous societies did not live in harmony with nature (Redman 1999), often with serious social and health consequences for rulers as well as peasants (Fagan 1999, 2000).

These disharmonies only accelerated through the twentieth century, a period in which human consumption grew at unprecedented rates (Table 1). Energy consumption, especially, grew during the twentieth century. In ancient Rome, the wealthy used slaves, a direct subjugation of members of the current generation, as an inexpensive energy subsidy. Most twenty-first century humans recognize slavery as repugnant. Yet according to McNeill (2000), modern global citizens in 1990 consumed the per capita equivalent of 20 full-time energy slaves; for the wealthy, the number is much higher. That is, the wealthy in the new millennium practice de facto slavery through excess energy use. They indirectly subjugate today's powerless as well as future generations, who will have to contend with legacies such as global climate change and environmental contamination. I suggest that the modern energy subsidy from fossil fuels is as morally repugnant as the slavery practiced in Roman times. The twentieth-century effects of people on the planet will overshadow the importance of sociopolitical events like the world wars, the rise and fall of communism, or the spread of mass literacy (McNeill 2000). Woodbridge (2004) suggests that in our preoccupation with the war on terrorism, we have lost sight of a more dangerous enemy—ecological decline.

Table 1. Ecological changes in the twentieth century expressed as growth in consumption or the scale of human activity. (Adapted from McNeill 2000.)

Item	*Increase factor*
World population	4
Urban population	14
Global economy	14
Industrial output	40
Energy Use	16
Coal production	7
Carbon dioxide emissions	17
Marine fish catch	35
Cattle population	4
Pig population	9
Horse population	1.1
Forest area	0.8
Irrigated area	5
Cropland	2

As more historians and geographers reflect on the collapse of past societies, two lessons for our own times emerge as particularly important: (1) recent ecological history and socioeconomic history make full sense only if seen together (Diamond 1997, 2005; McNeill 2000; Hughes 2001); and (2) although humanity did not begin as a global species, it is global now (Clark 2001). Globalization has its roots in the past, and it is as much an ecological, demographic, and technological phenomenon as it is economic and political. At least five bouts of globalization can be identified (Karr 2007):

- Hunter-gatherers spread to all the major continents.
- Plants and animals were domesticated, and agriculture evolved independently in several regions.
- Packages of domesticated species spread from these centers of origin.
- Technology proliferated and spread throughout the world, eventually culminating in industrialization.
- Economic globalization and industrial capitalism arose.

Each round of globalization made humans more efficient at taking from Earth's ecosystems, to the point where we must now add a sixth round: globalization of environmental challenges.

Since living organisms first emerged from the primordial soup, success—defined as becoming an ancestor—was determined by an ability to mobilize a continuous flow of resources. Those most effective at this activity often change the environments in which they live and have been labeled "ecosystem engineers." The first photosynthetic prokaryotes changed the Earth's atmosphere by releasing oxygen, for example; land plants and animals formed soils; beavers built dams and altered the flow of rivers, creating countless wetlands. Today, humans are the dominant ecosystem engineers, monopolizing 40 percent of annual terrestrial plant growth, 35 percent of the ocean's continental shelf production, and 60 percent of accessible freshwater (Pimm 2001).

One attribute makes humans unique among all ecosystem engineers: Humans alone are capable of recognizing the threat posed by their own natural propensities. Will we be able to move beyond our past to protect the interest of future generations?

An important step in making that transition will be recognition that the search for solutions is not a product of "progressive Western Enlightenment philosophies and their associated rationalization processes" (Chew 2001, p. 157). A sense of caring for the environment and recognizing the role of human agency in threatening that environment can be traced back at least to Mesopotamia and South Asia 4,500 years ago. Writings from those times reveal an awareness of biodiversity and of the relationships among living things. They reveal knowledge of natural order in the biosphere and of the consequences of disrupting it. In short, before ecology, the science, emerged in the modern world, humans observed and understood many of the core lessons of that science. Contemporary debate by modern philosophers, ethicists, scientists, and citizens concerned about the future simply extend these discussions (Leopold 1949; Orr 1992, 1994; Rolston 1994; Westra 1998; Pimentel et al. 2000). The need for an ethical compass—such as the Earth Charter (www.earthcharter.org)—to constrain the behavior of human society has never been more critical. Environmental laws offer secular evidence that we recognize some limits and responsibilities; implementing those laws is a test of our will (Karr 2001).

3. Water Resources and Biological Indicators

Water and associated resources illustrate the pervasive and devastating nature of human distortion of living systems. In 1995, for example, 80 countries containing 40 percent of the world's population had water shortages that crippled their agriculture and industries. In 2006, hot weather and a severe drought left 18 million people in 15 of China's provinces short of drinking water and 2.5 million hectares of cropland damaged (*Shanghai Daily* 2006). Detailed studies of two midwestern US rivers show that 67 percent of fish species from the Illinois River and 44 percent of species from the Maumee River have become less abundant or have disappeared since 1850 (Karr et al. 1985). Centuries to decades ago, harvestable populations of many freshwater fishes disappeared in many regions, and fish in rivers of the Amazon basin and Southeast Asia are rapidly following them into oblivion. Some of the world's most productive marine fisheries (for Atlantic cod, large whales, and other mammals) and freshwater environments (the Laurentian Great Lakes and African Rift lakes) are so depleted that harvest has been prohibited for many of them.

From the tsunami's devastation of Indonesia's Banda Aceh in 2004 to hurricane Katrina's destruction of Mississippi Delta wetlands and New Orleans in the United States in 2005, the effects of natural events are made infinitely worse by histories of damage and destruction to coastal wetlands and forests. Since 1925, for example, Louisiana has lost 770,000 hectares of barrier islands and coastal marshes, and the coastline in some regions has receded by up to 24 kilometers. With compaction and lack of sediment deposition without new flooding, 73 square kilometers per year of delta sinks beneath the waves. Both Banda Aceh and New Orleans have contributed to the global flow of environmental refugees caused by the collision of human abuse of natural systems and nature's own extreme events.

The recurring lesson: water bodies continue to be degraded by the activities of humans. An obvious corollary is that the patchwork of programs (legal, scientific, engineering, and political) designed to protect water resources have not been successful at preventing continuing damage.

In the mid-1970s, my own research expanded from a focus on tropical forest birds to include stream fish. My goal was to improve understanding of basic ecology, but I quickly came to see the need to view water resource problems as a biological challenge, not a plumbing problem that could be resolved by simple engineering or political solutions. For more than 30 years, I have advocated the use of biological monitoring to sample the biota of a place and biological assessment to evaluate the biological condition, or "health," of places on the basis of those samples.

That effort has led to two advances. First, my colleagues and I demonstrated that human influences on living systems fall into five major classes: physical habitat alteration, modification of seasonal flows, addition of pollutants both chemical and biological, changes in energy sources, and shifts in biotic interactions (Karr 1991, Karr and Chu 1999). This observation demonstrates the futility of an approach that focuses only on the goal of making water cleaner. Given the choice of measuring all influences on water resources or of directly measuring the condition of the biota—which includes the prime witnesses, and victims, of environmental change—biological monitoring and assessment (for brevity, bioassessment) is the next logical step.

That next step was taken with the development of a multimetric index of biological integrity (IBI) to directly assess the condition of a water body in biological, as opposed to chemical pollutant, terms. Since IBI was first proposed (Karr 1981), literally hundreds of technical papers, many special issues of journals, and numerous books have been written on the importance of bioassessment. Seven foundations of bioassessment can be summarized as follows (see Karr 2006a for a detailed discussion of each of these points):

1. Water bodies throughout the world are not healthy.
2. Legislative mandates to correct the situation are clear.
3. Implementation programs that focus narrowly on clean water or some conception of optimal habitat for a few favored species have limited success.
4. Biological measures make the best primary measurement endpoints.
5. Selection of measures of biological condition that provide clear, easily interpreted signals is key to monitoring and assessment success.
6. Success also depends on rigorous sampling design and carefully formulated procedures.
7. Communication of the results with the public and policymakers completes the cycle.

Ecologists intuitively understand the importance of measuring biological parameters. Unfortunately, the richness of ecological perspectives (e.g., physiological, population, community, ecosystem, landscape, conservation, theoretical) leads to vigorous discussion (Figure 2) and little resolution of the core question, How should we measure biological condition?

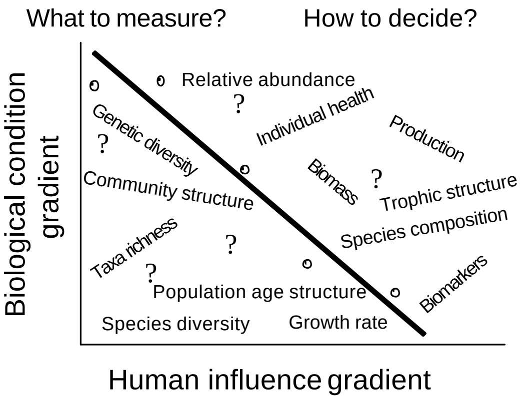

Figure 2. Dose-response curves of biological condition with respect to a gradient of human influence provide the foundation for selecting appropriate metrics for bioassessment. Almost any biological attribute can be measured, but only certain attributes provide reliable signals of biological condition and therefore merit integration into a multimetric index. Success in bioassessment is tied to choosing appropriate metrics from the profusion of attributes that could be measured. (After Karr and Chu 1999.)

The development and tuning of IBI over the last 25 years defined a formal process to select indicators (called metrics) for inclusion in the index. That development process also rigorously defined an appropriate benchmark, or standard, against which places should be assessed, just as a doctor compares the temperature of a human patient with the norm of about 37° C. Most researchers now agree that a natural system standard, now referred to as "reference condition" (Hughes et al. 1986), has biological integrity—that is, the characteristics embodied in the parts (genetic diversity, species, communities) and processes (hydrology, demography, interspecific interactions, energy flow, nutrient dynamics) of nature's legacy in a region. Protecting integrity involves protecting the living systems' capacity to regenerate, reproduce, sustain, adapt, develop, and evolve (Westra et al. 2000). Ultimately, protecting ecological health requires biological metrics to measure biological condition as a divergence from integrity.

The IBI approach to metric selection is modeled after toxicologists' use of dose-response curves to understand the effects of chemicals on individual organisms. Instead of a chemical dose in a laboratory experiment, however, the focus is on the level, or "dose," of human activity—a human disturbance gradient—in a watershed where biological attributes exhibit quantitative change in value across that gradient. In short, the goal is to identify specific biological measures that reflect how living systems change in response to human actions.

Graphically, changes in biological condition along a biological condition gradient stem from changes in human activities along a human disturbance gradient (*see* Figure 2). IBI is based on empirically defined metrics because such metrics (1) are biologically and ecologically meaningful, (2) increase or decrease as human influence increases, (3) are sensitive to a range of stresses, (4) distinguish stress-induced variation of human origin from natural and sampling variation, (5) are relevant to societal concerns, and (6) are easy to measure and interpret.

After a number of such metrics are defined by their empirical relationship with the human influence gradient, they can be integrated into an IBI. The resulting IBI will be highly correlated with the human influence gradient. Implicit in this relationship is the reality that the condition of living systems varies continuously with human influence (*see* Figure 2).

Such a conception of biological evaluation is more appropriate than the common tendency of regulatory agencies to simplify the designation of water bodies as "impaired" or "unimpaired." As a result, scientists and managers can express biological condition (or ecological health) with greater precision along a continuous scale of biological condition.

In the US Pacific Northwest, for example, benthic IBIs (B-IBI; uses benthic invertebrates as the monitored organisms) show the healthiest streams supporting an ecologically rich assemblage of invertebrates (high native taxa richness, abundance of predators, and many long-lived and intolerant taxa, among others). As human influence increases, anadromous salmon and most stoneflies disappear, and B-IBI drops below 35 out of 50. When IBI drops below 20 out of 50, cutthroat trout largely disappear, and only the most tolerant mayflies and caddisflies are present. These and other shifts in the biota, and the progressively declining IBIs that quantitatively summarize those shifts, are associated with a variety of human land uses, from protected parks through suburban and urban development, that also vary continuously in their effects.

The development and testing of IBI in the United States stimulated action from a number of state and federal agencies, actions designed to strengthen implementation of the US Clean Water Act (Ohio EPA 1987, 1989a,b; USEPA 2002, 2005, 2006; Davies and Jackson 2006). As noted by one official from the US Environmental Protection Agency (USEPA), "Few events can transform the nature of a discipline as has the development and application of the original IBI. IBI is a fundamentally sound and critical approach to measuring the health of our waters" (Davis 1999). USEPA's *Draft Report on the Environment 2003* (USEPA 2003) states that IBI "is a useful approach" that "combines multiple variables" and "reflects the ecological condition of a place." Successful application of IBI in Europe (Pont et al. 2006) and other regions throughout the world demonstrates the value of bioassessment to informed decision making in aquatic and terrestrial environments (see the appendix in Karr 2006a for a listing of nearly 75 key references on multimetric indexes and bioassessment).

4. Beyond Biological Indicators

The development of IBI was an explicit response to the need for improved protocols to track the health or condition of the biota of rivers. The approach has now been used to examine the effects of human activities in a broad range of aquatic and terrestrial environments (Karr 2006a). Realizing that a lack of appropriate indicators of biological condition contributes to the continuing decline of water resources, I began to ask broader questions such as, What other indicators does society use to track well-being? How successful are these indicators at protecting human society over the long term? Humans use a rich variety of indicators (Table 2). Some are important to understanding individual health (e.g., cholesterol level) while others emphasize other dimensions of well-being for individuals (annual income, ratio of expenditures to income) and nations (gross domestic product [GDP], index of leading economic indicators).

Table 2. Examples of classes of indicators used by human society with selected indicators used for each class.

Indicator class	*Indicator examples*
Individual health	Temperature, cholesterol level, blood chemistry, weight
Economic	
Individual	Income, stock profile, ratio of expenditures to income
Business	Number of items manufactured or sold, profit per item
National	Index of leading economic indicators, GDP, inflation rate
Social	Crime, literacy, suicide, and poverty rates; education
Technology	Automobile gas mileage, recycled raw materials
Planetary alignments	Horoscope
Biological	Largely ignored historically, IBI and other indexes today

In theory, nations should be compiling information to reflect the status of and trends in economic, social, and ecological well-being; such indicators should drive policymaking. But, alas, some indicators are more mythology than fact (personal horoscopes based on planetary alignment); others leave out so much that they mislead by distortion. Weaknesses in GDP, for example, are widely recognized (Cobb et al. 1995, Davidson 2000), even if certain politicians do not seem to recognize them. In his 1999 State of the Union address, US President Bill Clinton proclaimed that the nation was in the "longest peacetime expansion in history" (Rowe and Silverstein 1999). But no one asked what was expanding, and the president didn't tell; this wonderful news went without challenge. As Rowe and Silverstein note, many things are expanding—from waistlines to medical bills, from debt to traffic. The monetary and health costs of obesity illustrate the problem. Each year the food industry in America spends $700 billion on advertising to compel Americans to eat more industry products. And each year Americans spend $32 billion on diet and weight-loss programs; they undergo 110,000 liposuctions at a cost of about $2,000 each. The health consequences of this behavior include rising incidences of childhood obesity and type II diabetes. Yet the costs of all this consumption and health care go into the GDP, along with the assumption that they increase the nation's wealth. In fact, the health care costs should be subtracted.

GDP measures the economy's throughput—the amount of money changing hands—but it fails on several counts as a measure of societal well-being. First, it ignores important aspects of the economy such as income distribution, unpaid work, and the black-market economy. Second, it does not valuate nonmonetary contributions to human fulfillment such as health, education, freedom, security, and peace. Third, it omits social and environmental costs such as pollution, resource depletion, cancer, and crime. GDP simply does not measure the state of Earth's ecosystems. Perhaps most perversely, GDP counts social and environmental costs—like those associated with excessive food consumption—as benefits. Other economic indexes like the Dow Jones industrial average, index of leading economic indicators, or consumer price index are similarly limited as measures of societal well-being.

GDP, like so many of the other indicators used by modern industrialized society, implicitly gives permission to escape responsibility for actions. It implicitly endorses unsustainable values and lifestyles that distort social systems and disrupt ecological health. Two hundred years of using such indicators has produced a society that values what it measures rather than measuring what is valuable. Biotic impoverishment is an alarming by-product of our indicator choices.

Although social indicators have not been a high priority, efforts to produce social indicators measuring the condition of living human systems are gaining ground. Beginning in the 1970s, at least eight European nations formalized "national social health reports." Other nations (e.g., Canada, Hungary, Turkey, and Australia) joined these countries in the 1980s and 1990s. In 2002 the ruler of Bhutan mandated production of a "gross national happiness" report.

The United States still does not participate with nearly 20 other countries explicitly mandating systematic evaluation of social well-being. Concern about the inability to monitor public human services the way the United States monitors financial markets stimulated development of a social index of leading indicators (Miringoff and Miringoff 1999, Stille 2002). This social index combines 16 measures of social health, including child poverty, teenage suicide rates, average weekly wages, homicide rates, health insurance coverage, and alcohol-related traffic deaths. When aggregated at state levels, such indexes reveal variation among US states, with Iowans suffering the least (73 out of a maximum 100) and New Mexicans the most (scoring 21). Three indicators in particular—child poverty, high school completion, and health insurance—were bellwethers of overall social health (Stille 2002). The Miringoffs' study showed that although gross domestic product increased by 92 percent over the preceding 30 years, Americans' social health declined

29 percent, because problems such as child poverty, lower average wages, youth suicide rates, and health insurance coverage had all worsened.

In his book titled *The Wellbeing of Nations*, Robert Prescott-Allen (2001) developed and applied an index to track human well-being for 184 nations. His "human wellbeing index" includes measures of health, population, household wealth, national wealth, knowledge, culture, freedom and governance, peace and order, household equity, and gender equity. The patterns observed by Prescott-Allen are not encouraging. Only three countries—Norway, Denmark, and Finland—are rated as good. The distribution of other countries is disappointing but not surprising: fair (34), medium (52), poor (51), and bad (40). These social indicators reinforce the view that conventional economic indicators may yield substantial risk to noneconomic dimensions of human society.

Both social and nonhuman biological indexes yield a very different picture from the one based on GDP. Our planet develops over time without growing, and our economy must adopt a similar pattern of development, without growth in throughput (Daly 1991). Econometric indicators should reflect that reality. One effort to improve such econometrics is the index of sustainable economic welfare, which adjusts for negative impacts on natural capital, wealth disparities across classes, the effects of pollution, and other long-term social and environmental damage (Costanza et al. 1997). The world needs more such comprehensive indicators.

5. Altering Current Trajectories

Human society faces a paradox (Karr 2007). Despite unprecedented advances in science and technology over the last two centuries, threats to human and nonhuman living systems worsen. How can we be smarter and more knowledgeable, yet ignore so many of the lessons of that knowledge? How can we continue to ignore signs of social and ecological degradation without taking definitive action to alter downward trends?

One obvious reason for our ignorance is the tendency to use indicators, like GDP, that allow us to overlook serious long-term trends. Another obvious reason is the tendency to assume that the human economy is separate from the environment and free from biophysical constraints. This assumption is grounded in an expansionist perspective (Rees 2002) that assumes the environment is the source of an unlimited supply of resources and a sink for an unlimited quantity of wastes. Expansionists have faith that human ingenuity always has and always will provide creative solutions to all challenges faced by society. In reality, the Earth, a finite body, does not continue to grow, so neither populations nor their material consumption can continue to grow forever. As anyone familiar with the science of ecology will recognize, a steady-state (as opposed to expansionist) perspective more accurately reflects the reality of a finite Earth.

Putting the need for indicators together with understanding of the dependence of human society on Earth's living systems often leads those striving to move society toward long-term sustainability to produce a Venn diagram to demonstrate relationships and the need for an integrative understanding of ecological, social, and economic dimensions of well-being (Figure 3, left). In this conception, the goal becomes understanding of the small central area of overlap.

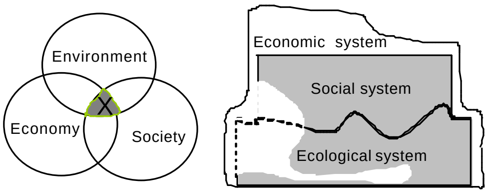

Figure 3. *Left*: Relationships among the three key components of Earth systems—natural, social, and economic—are often inappropriately depicted with a Venn diagram. *Right*: These relationships are more appropriately depicted as a layer cake. Human economies (the frosting) are shown here eroding the underlying social and ecological systems, threatening the foundation and sustainability of those systems. Indicators of economic vitality, social well-being, and human and ecological health are needed to understand the true condition of Earth's systems. (Modified from Karr 2007.)

But even this conception is as flawed as the expansionist perspective. A more realistic alternative (Karr 2007) arrays social, economic, and ecological systems in three dimensions as interdependent, like the layers of a cake (Figure 3, right). The economic system is the top layer, supported by the social system. Both are supported by the bottom layer, Earth's ecosystems. A focus on growth in the economy has allowed society to overlook social inequities and depletion of natural capital, which are in reality uncounted costs of growth and threats to the very foundations of society.

6. The Role of Ecologists

A majority of ecologists came to their profession because they were fascinated by living things. During the last half century, ecologists' research has documented the importance of relationships and interdependencies among organisms. Legumes and nitrogen-fixing bacteria, corals and algae, diseases and their hosts, predators and their prey, forested landscapes sustained by disturbances such as fire or insect outbreaks—all these phenomena and more illustrate the richness of ecological interactions. Humans, too, depend on the health of the larger living systems in which they are embedded. Ecologists recognize this interdependence and should be shouting about it from the rooftops. They should lend their technical and scientific expertise to the many others concerned about ecological decline (e.g., the thousands that participated in developing the Earth Charter). Ecologists should at minimum inform the general public about the relevance and importance of their work (Bazzaz et al. 1998). Perhaps the farthest-reaching ecological effort is the Millennium Ecosystem Assessment, a pathbreaking international assessment that hopes to meet decision makers' needs for scientific information on the consequences of ecosystem change for human well-being and on the options available to respond to undesired changes (Millennium Ecosystem Assessment 2005).

Society cannot come to grips with the global ecological challenges it faces without coordinated thinking and action among ecologists and everyone else. We cannot achieve a sustainable society without a revised worldview that, rather than dissociating humans from ecosystems, regains awareness of our dependence on the rest of life on Earth. Neither can we achieve sustainability without assessing and communicating the impacts of human actions on ecological health, social well-being, and economic vitality. Professional ecologists have a vital role to play in this task, or they risk marginalizing themselves and their profession just when they are most needed (Karr 2006b).

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