Human Footprints on the Global Environment

Threats to Sustainability

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Global Transformations: PaSSAGE to a New Ecological Era

Eugene A. Rosa and Thomas Dietz

The magnitude of the threat to the ecosystem is linked to human population size and resource use per person. Resource use, waste production and environmental degradation are accelerated by population growth. They are further exacerbated by consumption habits, certain technological developments and particular patterns of social organization and resource management.

—Joint Statement by Fifty-Eight of the World's Scientific Academies, New Delhi, India, October 1993

Discovery of Global Scale and Environmental Change

Scale matters. The 1980s ended with an unprecedented awakening to the global scale of environmental impacts, previously thought to be confined to the local and regional levels. The awakening, underscored in the epigram to this chapter, resulted in a conceptualization of environmental threats worldwide, expressed in the universally accepted term *global environmental change* (GEC). While GEC embeds many uncertainties, one thing is absolutely certain: the magnitude of change is doubtlessly due to the actions of the planet's dominant species, *Homo sapiens sapiens*; that is, to humans. Hence, an understanding of the causes of GEC is a function of understanding the range of choices and actions humans undertake.

This volume has two primary goals. The first is to assess our state of knowledge about the dynamics of coupled human and natural systems, with an emphasis on their human dimensions. This goal is centered on these questions: How and where has our understanding of the human dimensions of the human-nature link advanced over the past two decades? And what have been the key contributions from the social sciences in pushing the frontiers of this understanding? The second goal aims to bring into sharp relief not only the key gaps in our understanding, but

also the opportunities, challenges, and limitations for further advances in knowledge. What are the promising routes to a higher ground of knowledge about the role of human systems in the wide array of global environmental processes? And what limitations are there in producing such knowledge?

Defining Global Environmental Change (GEC)

Human societies are systems integrated with and dependent upon natural ecosystems for sustenance and survival. Known to the ecological and social sciences from their inception, this link has been brought center stage by the many ostensible threats to ecosystems due to transformations of environments around the globe. Indeed, this indispensable link has recently been given a refined conceptualization and a name: coupled human and natural systems, or CHANS (Liu et al. 2007a, 2007b). CHANS represents not only a coupling of the two systems, but also the recognition that the two systems "interact reciprocally and form complex feedback loops" (Liu et al. 2007a, 1513).

GEC is CHANS on growth hormones. In the past, and still in a few places around the world that are in the process of vanishing, CHANS were fairly isolated and, therefore, circumscribed dynamic systems. Band and tribal societies often developed sustainable CHANS in isolation from other human systems or intrusions. While lingering perhaps as a memory of a rhapsodized past, such social systems no longer exist. There is literally no place on earth that is entirely isolated.[1] Neither nuclear clouds, nor the warming of the planet, nor other ecological threats know geographic boundaries. The study of GEC is the study of CHANS in the context of dynamic global processes.

The idea of GEC is generally agreed to consist of two complementary dynamics: *cumulative* effects (that are local in domain but so widely replicated that in sum they have global consequences) and *systemic* effects (that occur on large spatial scales or alter the function of large systems; Turner et al. 1990). Cumulative effects include tropical deforestation, desertification, damaged local ecosystems, species losses, and resource exhaustion, while systemic effects include ozone depletion and global climate change. Both types of effects are traceable to human activities.

The human dimensions of GEC raise the question of whether human practices and institutions have seriously disrupted carbon, ocean, climate,

biotic, and other biogeochemical cycles. If so, what are the specific human drivers responsible for the disruptions? Which disruptions make societies most vulnerable, and where? Have human practices, old and new, led to species extinction, biodiversity loss, and overuse of nature's capital and services? What opportunities and strategies are available for preempting, mitigating, or adapting to environmental changes at the global level—large or small?

An early marker of the awakening that environmental impacts were global was the highly influential report of the World Commission on Environment and Development (WED), *Our Common Future* (WED 1987). Known as the "Brundtland Report," after the commission's chair, Gro Harlem Brundtland of Norway, the report sounded the alarm that present global trends in resource use and environmental impacts could not continue indefinitely. They would need to be reversed. And, the Brundtland Report further argued, many of the critical environmental trends could not be solved within the confines of the nation-state—instead, they must be tackled from the vantage point of global cooperation. The WED's assessment of the state of the world was hardly sanguine, but, nevertheless, the report ended on an optimistic, though cautionary, note that centered on the idea of sustainability, of taking actions to counteract the feedback from the reciprocal interaction of CHANS that could dangerously reduce nature's capital and services. The WED's creatively ambiguous definition of sustainable development read: "the ability of humankind…to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs."

Other indicators soon followed. Perhaps the most significant were the emergence of a variety of institutions devoted to global environmental change, such as the founding of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and the Human Dimensions Programme of GEC in 1990 (becoming in 1996 the International Human Dimensions Program); and the beginning of sustained attention by the U.S. National Research Council/National Academy of Sciences (NRC/NAS) to the human dimensions of GEC. The standing NRC/NAS Committee on the Human Dimensions of Global Change published the germinal report *Global Environmental Change: Understanding the Human Dimensions* in 1992 (Stern, Young, and Druckman), referred to as the GEC92 hereafter.[2] This report codified and highlighted human dimensions as an important and separate field of study, provided an initial state-of-the-art

assessment of social scientific knowledge about global change, and proposed an early research agenda for advancing the field.

The foundation of GEC92 is consonant with the core idea of CHANS, namely that human and environmental systems are inextricably connected in webs of mutual causation. Because of this mutuality the range of human responses to global change typically alter both kinds of systems—further underscoring the pivotal importance of proximate human drivers.[3] GEC92 also underscored the intersection of human with physical and biological processes and of the need to understand how they interact, often via complex feedback. That intersection recurs in two conceptual locations. One is where proximate human (anthropogenic) actions produce direct and relatively immediate environmental changes. The other is where changes to physical and biological systems directly and indirectly affect the natural capital and services that determine what humans value and what they can do. The GEC92, a systematic review of the literature existing then on the human driving forces, made it clear that, despite the immense contributions of individual scholars, sustained research traditions were difficult to find. Since GEC92's publication, the social science literature on GEC has grown in both volume and sophistication, and is on the verge of becoming fully interdisciplinary and well articulated.

Proximate Driving Forces

GEC92 distilled the key proximate anthropogenic drivers implicated in global environmental change from a multilayered synthesis of the social science literature. There were five social variables identified as key human forces: (1) population change, (2) economic growth, (3) technological change, (4) political-economic institutions, and (5) attitudes and beliefs (Stern, Young, and Druckman 1992, 75). This identification catalyzed the course of social science research and, accordingly, directly shaped the choice of topics we have covered in the chapters of this volume. It also provides a baseline against which to measure the cumulative social science knowledge of the past fifteen years. Hence, the majority of substantive chapters in this volume are devoted to a state-of-the art assessment of what scholars in the social sciences know about these drivers, or what they need to learn. The chapters do not cover all these topics, nor do they exhaust the subject matter relating to the included topics—indeed, they are not intended to do so. Rather, our volume has a more refined scope, to present selected, vanguard exemplars of analyses of

those topics. The chapters, in our judgment, are representative of the more mature lines of human dimensions research.

Missing from this volume—as it is more generally in analyses of global change—is detailed coverage of the third social variable from our list of five drivers: technological change. It is omitted not because it lacks importance, but because of the difficulty of harnessing the complex and proximate effects of technological change. On the one hand, this unmet challenge is reflected in the glacial growth in our understanding of technology's role in GEC. That lacuna, in turn, accounts for its absence from this volume. On the other hand, it simultaneously pinpoints one of the most serious gaps in human dimensions research and the one, perhaps, most desperately in need of concerted attention.

While the GEC92 provided a template for the topics covered in these chapters, it is important to understand the geophysical and historical context leading to that template, to understand what led us to the processes it summarizes. Hence, in the remainder of this chapter we outline key features of the linked human and natural systems of the earth that illuminate the past and present role of human impacts on the planet. We also situate the current state of anthropogenic forces on that system in a larger context: that of an accelerated Pace, Scale, and global Spread of environmental impacts driven by a process of Autocatalysis, Globalization, and the interconnectedness of Ecosystems around the globe. The acronym PaSSAGE provides a summary of these processes and an aid to remembering them.

To begin, we sketch the long history that set the stage for these processes. We then delineate the narrower context of contemporary global processes sparked by human actions or impacting them.

The Biosphere

The biosphere is the global envelope of all life. The biosphere[4] comprises not only the dynamics of large, linked physical processes such as the carbon cycle, the hydrological cycle, short- and long-term atmospheric dynamics, and geological change, but also the global ecosystem comprising the dynamics of living systems of all the species of life on the planet. It appears that earth's evolutionary history has alternated between long periods of relative balance among these dynamics followed by cataclysmic disruptions. In the modern era the biosphere is threatened with one such major disruption. But unlike previous planetary catastrophes—excursions brought about by the impact of asteroids, changes in solar

radiation, or major geological disruptions—the current one is due to an entirely new force, the actions of the biosphere's dominant species: *Homo sapiens sapiens*. Humans are changing the global environment in unprecedented ways.

Knowledge, Agency, and Uncertainty

All species are reliant on ecosystems. CHANS are uniquely different from nonhuman ecosystems because of the self-referential capacity of humans: the extensive ability to plan, organize, and create systematic solutions to repeatable problems—to create institutions. Contemporary societies have a unique advantage over their predecessors in that we have a repertoire of success and failures of past societies and, therefore, the opportunity to learn from them (Diamond 2005). The chapters in this volume are intended not only to summarize key developments in global human dimensions research, but also to underscore the many uncertainties that remain to be addressed. One of the most compelling themes to have emerged is the recognition that uncertainties about the human drivers of GEC trump, by a considerable margin, the uncertainties in biophysical processes. The greater uncertainties shrouding human ecosystems are a function of two key factors: complexity and reflexivity. Humans, more than all other species, elaborate their ecosystems and act reflexively within them. What might be reasonable strategies for addressing these uncertainties?

Then, of course, there is the even more intractable form of uncertainty: meta-uncertainty. There are, no doubt, key factors for which our knowledge is uncertain but we do not know how uncertain it is. In some cases we may even be unaware that our knowledge of it is uncertain. Our hope is that this volume not only will point to the direction for future research on the human dimensions of CHANS, but also will become a foundation for addressing this hierarchy of uncertainties.

The Context of Time: Its Arrow, Its Cycles[5]

Cataclysmic disruptions to the entire planet are recorded in geologic time. In contrast, human impacts are recorded in historical time. The idea of historical time, the concept for interpreting human experience through the fourth dimension favored for centuries in the West, captures the unique "irreversible sequence of unrepeatable events" (Gould 1987,

194) experienced by the human species. *Time's arrow* is the widely adopted metaphor to capture the concept of this lens of retrospection. But more than metaphor, time's arrow also reflects one of the universe's most basic processes and most basic markers of time—the law of entropy, the relentless process toward disorder. The second law of thermodynamics, the most ostensible manifestation of entropy, bears directly on the sustainability of the principal sources of fuel available to humans around the globe.[6]

But the physical world does not follow unique and unidirectional time sequences alone. It is also punctuated with repeatable and, to some degree, predictable processes over time: *time's cycles*. The cycles of time are presumed to have no clear direction, no vector of progress. Ecosystems, for example, are understood to reflect the reasonable predictability of dynamic cycles. Global environmental change can be understood as the total collection of these evolutionary processes and cycles. Perhaps more importantly, it can also be understood as the linking together of countless CHANS around the globe into what might be called a mega-CHANS. Similarly, GEC can be viewed as the extension of human systems into an ever-widening natural system—nature in a global sense. In perhaps the broadest way to frame it, GEC is borne of the interaction and interpenetration of these two sequences—as the trajectory of time's arrow interacting with time's cycles—and the consequences of this coupling for ecological sustainability.

The principal driving forces of GEC, as noted, are the proximate anthropogenic drivers reflecting practices and institutions emerging from time's historical trajectory. A key challenge—indeed, *the* challenge for GEC—is whether these anthropogenic arrows have markedly disrupted time's cycles, and whether the entropic forces of human history have disrupted—perhaps irreversibly—global cycles.

As we will see, most work on CHANS has focused on the last half century. It is during this period, sometimes called "the Great Acceleration," that many forms of environmental change became manifest and trade—the flow of information, politics, and human migration—became truly global. Of course, as the term *acceleration* implies, these processes were under way well before the mid-twentieth century. But their pace clearly intensified after World War II. This manifest global transformation in human and natural systems has prompted the research reviewed in this volume. But while the majority of scholarship has focused on the Great Acceleration, there is widespread acknowledgment that longer

time scales can provide essential insights into the large dynamics of coupled human and natural systems at the global, regional, and local levels. For example, the Integrated History and Future of People on Earth project (Costanza, Graumlich, and Steffen 2007; http://www.aimes.ucar.edu/activities/ihope.shtml) considers CHANS at scales of ten thousand, one thousand, and one hundred years. Data are often much more sparse at such longer scales than for inquiries focused on the more recent path. But long time scales also may reveal dynamics that cannot be observed with less diachronically extensive data. In the long run, better integration of long-term extensive and short-term intensive analysis is bound to yield powerful insights. For the moment, however, most research focuses on the Great Acceleration and that is reflected in this volume.

Scientific Worldview: Tipping the Balance of Nature

Examining CHANS on a global level, the focus of GEC, represents a remarkable reinterpretation of one of science's most deeply embedded presuppositions, the firm belief in the balance of nature. For well over a century one of the most pervasive and persistent scientific worldviews presupposed nature to be in near-perfect balance, a balance virtually impervious to internal and external disturbances—and certainly impervious to the actions of members of the puny hominid species we call *humans*. For example, the gases that envelop the planet, warm its surface, and protect it from harmful radiation were generally in balance in between occasional excursions from one equilibrium to another—thereby exercising a moderating influence that makes life possible on Earth (but not on Earth's closest neighbors, Mars and Venus).

Human disturbances to that balance were axiomatically dismissed in the past as perturbations that were local in scope and transitory in time. Humans had no measurable impacts on the larger dynamics or their balance. In this worldview, time's cycles could be read in the continuous balance of nature. Time's arrow could be read as transitory and circumscribed in its disturbances, not only insignificant in the larger picture of the natural world, but also clear evidence that the natural balance always prevailed (Weart 2003). In a sense, the cycles were epicycles in the grand design and neither the cycles nor the arrow were susceptible to human influence in any consequential way.

This deeply held presupposition about the balance of nature provides an engaging backdrop for understanding GEC. With that backdrop one

can view the scientific focus on GEC as a scientific mind shift, as a fundamental change in the overarching conceptualization of nature, as a replacement of a dominant worldview with an entirely different one.

GEC, by replacing the worldview presupposing natural balance, underscores the recognition of disturbances to nature's balance on a global scale. Growing evidence shows that global physical cycles may no longer be in the balance that has characterized them for the last dozen or so millennia. The global CHANS—that is, the global hydrological, carbon, climatic, and oceanographic cycles—are no longer seen as forces in equilibrium but as systems disturbed by the overreaching of the human species. Are such disturbances simply the circumscribed and localized manifestations of time's cycles on a larger scale? Growing evidence suggests the answer to this question is "no." Interestingly, the evidence pointing toward that conclusion comes from a hybridization of the scientific method.

Hybrid Scientific Method: Residual Framing and Inferences

The textbook ideal of scientific investigation that follows iteration between theory development and experimentation to test theory is denied to GEC research. The experimental method remains the gold standard of scientific investigation; however, scientists cannot manipulate the earth in its entirety.[7] Hence, the consistent and convergent indicators showing that the global environment has been markedly altered, especially in recent centuries, provide an exemplary scientific puzzle that raises the question: What is causing these changes? While the question is endemic to science, the approach to answering it is not. It places before us an asymmetrical scientific problem to which we can apply considerable knowledge about changes to the dependent variable (environmental change), but remarkably meager knowledge about the independent variables (specific causes) producing those changes or their causal pathways. While progress has been made over the past two decades in expanding knowledge of both the dependent and independent variables, the gap remains because progress has been uneven.

Physical science research addresses this limitation with an approach that might be called *residual framing* and *inference*, which seeks to identify whether current geochemical and other cycles have deviated significantly from long-term global and geological cycles (presumed "natural patterns"), and examines disruptive physical events such as volcanic activity and changes in solar radiation. This approach then reasons that

residual or remaining differences between long-term and current patterns must, therefore, be due to anthropogenic drivers, that is, to human activities. Hence, the physical sciences have identified and are assessing the variety of natural-cycle disruptions and discontinuous environmental changes now occurring at a global level. To the extent these cycle disruptions deviate significantly from past patterns and where they cannot be explained by changes in "natural" processes the disruptions provide prima facie evidence that the chain of causal links leads back to human activities—to proximate anthropogenic drivers, to human activities as the fundamental causes of environmental change at a global level. For example, climate modelers—literally using some of the most powerful computers in the world—are determining how much of the current changes in the global climate are attributable to dynamic natural processes and how much, through a process of inference from the residual framing approach, is attributable to anthropogenic sources.

This inferential chain of reasoning has led to an epistemic agreement among scientists that proximate anthropogenic drivers now either match or surpass natural processes as the causal agents of environmental changes across the planet. Humans appear to be disrupting global ecological cycles in unprecedented ways. What are the human domains and dynamics that are disrupting the replenishing cycles of nature? How do these dynamics operate at a global level? The extensive record of human history offers one tool for addressing these questions.

Archaeological Science: Nothing New?

Humans, even our protohuman predecessors, have transformed the global environment since the beginnings of historical time.[8] Ecological transformations across the planet have occurred in the past—and many times. Hence, at first blush the current dynamic of ecological change due to human activity appears to be, literally, nothing new under the sun—or the other stars, or the planets, or the moon.

The question that naturally follows is: Are contemporary environmental dynamics merely an extension of past challenges? Or are they uniquely more challenging, and if uniquely more challenging, do the lessons of those bygone eras and the scientific tools at our disposal make us better prepared to avoid the repeated ecological disasters of the past? Does the available scientific evidence sustain the initial observation that humans have disrupted the global environment in unprecedented ways?

Human impacts on ecosystems are a clearly documented feature of prehistory.[9] For example, Central and South American rain forests show evidence of human habitation as far back as ten thousand to twelve thousand years ago (Rice 1996).[10] And evidence of disturbances to these rain forests appears in Panama as early as eleven thousand years ago and in Amazonia by eight thousand years ago (Roosevelt et al. 1996).

History provides additional supporting evidence. Ice core samples from Greenland, at summit elevations of 3,200 meters above sea level, have revealed the presence of serious air pollution in the ancient world due to lead emissions. Lead production, owing to improvements in technology, became common around 3000 BC and then increased dramatically as a byproduct from the making of silver coins in Greek and Roman times, reaching eighty thousand metric tons per year about two thousand years ago (Hong et al. 1994).[11] The plumes of lead emissions were apparently carried thousands of miles across Europe and into the Atlantic by circulation in the middle troposphere. Similarly, core samples of copper concentrations, first produced from native copper seven thousand years ago, show heightened elevations of pollution from Roman and medieval times, especially in Europe and China (Hong et al. 1996). Hence, long-distance transport of air pollutants, a major issue in the early twentieth century, is in fact a problem that is seven millennia old.

Perhaps the most dramatic and certainly most ironic historical example of ecological collapse comes from the Fertile Crescent. This disaster was dramatic because it occurred in a region of such favorable climatic and biotic conditions (e.g., the crescent was once replete with forests) that it was not only the site of the origins of agriculture, but also of civilization itself. The collapse was ironic because the term *Fertile Crescent* is still used to identify that region, when in fact its fertility has long been lost to history.

Accompanying the ecological collapse of the Fertile Crescent was the collapse of the region's world cultural leadership as well as its millennia-long lead over Europe in social organization and cultural sophistication.

> Why then did the Fertile Crescent [currently the Mesopotamian marshlands in Southern Iraq and extending into Iran, Syria, and Turkey]…lose [its] enormous lead of thousands of years to late-starting Europe? The major factor behind these shifts becomes obvious as soon as one compares the modern Fertile Crescent with ancient descriptions of it. Today, the expression "Fertile Crescent" and "world leader in food production" are absurd. Large areas of the former Fertile Crescent are now desert, semidesert, steppe, or heavily eroded or salinized terrain unsuited for agriculture.[12]…[The] Fertile Crescent and eastern Mediterranean

societies had the misfortune to arise in an ecologically fragile environment. They committed *ecological suicide* by destroying their own resource base. (Diamond 1997, 410–411; emphasis added)

Hence, human history repeatedly has seen periods when ecological conditions presaged the coming and going of particular civilizations. But it has witnessed no era where the human species (*Homo sapiens sapiens*) was threatened in toto, where the human race itself was threatened with extinction due to a global overexploitation of ecological resources.

The pattern of ecological collapse has repeated itself many times in the prehistoric and historic past. Archaeologist Charles Redman, from his examination of a variety of archaeological case studies[13] around the globe, summarizes the fundamental causal process of these collapses: "This seemingly self-destruction [of environments] occurs repeatedly—individuals, groups, and entire societies make decisions that are initially productive and logical, but over time have negative and sometimes disastrous environmental implications" (1999, 13–14).

This record of past disasters is, nevertheless, partly counterbalanced by past success stories where societies managed to address environmental challenges and exist for lengthy periods of time. And societal successes can be found across diverse environments from ninth-century New Guinea, to sixteenth-century Germany, to seventeenth-century Shogun Japan (Costanza, Graumlich, and Steffen 2007; Diamond 2005).

Can contemporary societies take ecological lessons from past societies—from those that failed as well as those that succeeded? Are modern societies little more than a "fast-forward" of ancient societies? If so, is it the successful societies they emulate in an accelerated mode? Or are they emulating collapsed societies? Are modern societies, by using nature's capital faster than it can be replenished, exceeding their carrying capacities, placing them on the road to "overshoot" carrying capacity and perhaps even to ecological disaster? If such disasters are a feature of the global future will they occur everywhere and at the same pace?

Smooth Transition or Sharp Break?

A key aspect in the answers to these questions lies in one defining distinction between human systems and those of all other species. Humans are more effective than other species as ecosystem shapers than as ecosystem adaptors. Hence, they have ultimately modified their environments more than have any other of the planet's creatures. The modern era, on the

one hand, doubtlessly represents an extension of the evolutionary process of cyclical adaptation. On the other hand, it may mark an unequivocal break with the past—a passing of history into a *new ecological era*. The dynamics of contemporary CHANS, highlighting humans as ecosystem shapers and ecosystem adaptors, reilluminates the central question of GEC: *to what extent has time's arrow so penetrated time's cycles that the dynamics of both are threatened, thereby threatening the sustainability of the biosphere for contemporary societies?*

A New Era, a New Identity?

The marked global increase in key environmental consequences has, for a number of careful observers, signaled a sharp break with the past. This, in turn, has led some distinguished scholars to give special designations to the human species and to this new ecological era. Each designation is driven by the observation that global environmental changes threaten the carrying capacity of the planet, meaning, the number of people Earth can support.[14] Distinguished sociologist and human ecologist William Catton (1980) was one of the first to warn of this break. Wishing to highlight the magnitude of human threats to global carrying capacity, Catton (1987) designated humankind as *Homo colossus* whose diverse and excessive appetites make it the world's most "polymorphous species." And it is this specie's voraciousness that portends the overshooting of the global ecological system.[15]

Similarly, Nobel Laureate Paul Crutzen[16] and ecologist Eugene Stoermer (Crutzen and Stoermer 2000) have redefined the term *Anthropocene* to describe the period that began roughly at the time James Watt perfected the steam engine in the latter part of the eighteenth century and continues today.[17] The refinement by Crutzen and Stoermer emphasizes the impacts on the environment of industrialization and modernization. This telescoping of the modern era, this alignment with the age of modernity, underscores the astounding increase in the pace of anthropogenic exploitation of the earth's resources over the past three centuries.

Global Processes: AGE Drives GEC

Three fundamental, large, pervasive processes are driving GEC: autocatalysis (A), globalization (G), and the interconnectedness of ecosystems (E), of CHANS, around the globe—AGE for short.

Autocatalysis

Historical precedent offers at least one conceptual tool for understanding the predicament of modern societies: autocatalysis. From the beginning of human history, many of the fundamental changes impacting the environment have followed an "autocatalytic process—one that catalyzes itself in a positive feedback cycle, going faster and faster once it has started" (Diamond 1997, 111). For example, in ancient civilizations intensified food production, the development of occupational specializations, and the emergence of societal complexity stimulated each other through this autocatalytic process. Large populations, specialized and better organized, could further intensify food production and exploit other resources leading to even larger populations, new specializations, and new forms of resource exploitation.

This historical process not only extends into the modern age, it is a principal cause of GEC. Ecologically, autocatalysis is a dynamic process of accelerated, cumulative ecological impacts. The unavoidable and sobering fact is that such a process cannot continue indefinitely. Yet modern societies, by accelerating the pace of autocatalysis (through the five social variables, or driving forces, noted earlier), are de facto ignoring this reality and producing a considerable threat to their sustainability.

Globalization

The world is undergoing one of the most profound social and political changes ever to have occurred: globalization.[18] The term *globalization*, the worldwide spread of communication and commerce, of interpenetrating networks of production processes, risks, and ecosystems, and the emergence of new international challenges and regimes attracts a variety of definitions. Among these, Held and colleagues provide a characteristic and insightful one describing globalization as the "widening, deepening, and speeding up of worldwide interconnectedness in all aspects of contemporary social life" (1999, 2). While the idea of globalization is grounded in economic, social, and political processes, its main features—widening, deepening and speeding up—mean the increased spread, scale, and pace of global ecological processes. Globalization also means, as previously noted, the interpenetration of CHANS near and far, resulting in a mega-CHANS. In short, globalization underscores basic transformations on a global scale manifest in the speed of transactions, their extensive and broad reach, and the deepening patterns of their ecological interconnectedness.

A Global CHANS

Ecological interconnectedness, the third process of GEC, comprises ecological connections and interdependencies on a global scale. Ostensible features of this process are the worldwide extraction and distribution of nature's capital, the use of nature's services over broad reaches, as well as the worldwide distribution of labor. One consequence of globally linked CHANS is that ecological problems in one part of the world have the potential to affect many other parts. One publicized example of the ecological consequences in one part of the world due to resource demand in another part is the so-called *hamburger connection*. It is claimed that nearly 40 percent of the forest cover in Central America has been destroyed to make room for the pasture needed to raise beef cattle for North America's fast-food industry (Myers 1981).

Global Dynamics: Outcomes of AGE

The three AGE processes have led to the ecological outcomes that define GEC. In particular, autocatalysis, globalization, and ecological interconnectedness have, as noted, led to an accelerated *pace* of the global ecological metabolism, an increased *scale* of ecological impact, and the global *spread* of impacts, or PaSS for short. Combined with AGE, the acronym becomes the PaSSAGE described earlier.

The pace of ecological metabolism refers to the acceleration in the rate of demand on nature's capital and services and to the marked rate of increase in human-generated environmental impact, referred to as "the Great Acceleration" (Hibbard et al. 2007). The historical pace of evolutionary processes is being superseded even in the most remote parts of the globe by a dynamic comprising systems of rapidly changing variables that may be approaching thresholds where the magnitude of their effects shift, all driven by human action that continues to accelerate with ever more profound effects.

Scale refers to demonstrable, often dramatic increases in the magnitude of the drivers of ecological impacts or in the impacts themselves. Corresponding to the systemic domain of GEC, as described previously, they are processes that occur on large spatial scales or alter the function of large systems.

The term *spread* refers to growth in the size of the distributional demands for nature's capital and services and to the growth in the distribution of environmental impacts, such as the global transfer

of environmental degradation or diseases. Corresponding to the cumulative-effects domain of GEC, similarly described, many activities are already global in spread.

PaSSAGE

There is little question that the processes driving GEC (AGE: autocatalysis, globalization, and ecological interdependency), its overall dynamic, and each element of outcome (PaSS: pace, scale, and spread) sets today's global ecological challenges apart from all past challenges. The pace of past environmental change—time's arrow—was glacial and the scale and spread of ecosystem impacts—time's cycles—were local or regional in scope. In the past few centuries how things have changed.[19]

It is important to underscore a crucial point that may be obvious, but whose importance cannot be diminished with overstatement. Neither GEC's elements of autocatalysis, globalization, and ecological interdependency nor their global outcomes of pace, scale, and spread are entirely independent of one another. Nor do either the elements or the outcomes always follow patterns of linear, temporal influence. Rather, many interpenetrate in dynamic and synergistic ways, some of which impact sustainability positively, others negatively.

Our outline of the conceptual and definitional features of GEC pace, scale, and spread provide the abstractness and generalization necessary to illuminate the discussion of anthropogenic drivers. But understanding their operation and effectiveness requires concrete examples for each GEC outcome.

Pace

Three quantitative indicators reaffirming the accelerated pace of ecological change are the rates of atmospheric CO_2 concentration (currently 35 percent above that in 1750, the beginning of the industrial age) and climate change, the rapid increase in the human population, and the rate of species extinction.[20] While these three indicators paint a far from complete picture of the accelerated pace of change, their availability and quantification provide an exemplary sketch.

CO_2 Concentrations No one doubts the importance of climatic conditions in shaping the possibilities of what humans could and did do on earth (Rosa and Dietz 1998). The various ice ages are a blunt testament to those connections. So, too, are the ecological adaptations of native

cultures around the globe. For the vast expanse of human history, over thousands of years, the concentrations of several trace gases critical to shaping the earth's climate—carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (NOx)—have remained fairly stable.

Then, beginning in the late eighteenth century,[21] atmospheric concentrations of these gases began to increase rapidly, reaching today's 35-percent-larger concentration. The coincidence of gas concentrations and the rapid expansion of industrial activities—dependent, as they were, on unprecedented amounts of fossil fuels—provide the obvious and widely accepted hypothesis that human activities had, for the first time, disturbed the approximate equilibrium of the earth's basic cycles. Time's arrow, due to the entropic increases from the burning of fossil fuels, impacted the slow cycle of fossil fuel creation and accumulation. Perhaps this well-documented spike upward in the concentrations of greenhouse gases is the most apparent indicator of the vast spread of environmental impact, the globalization of threats to CHANS.

Climate Change The accelerated pace of cumulating CO_2, the principal greenhouse gas, may be partly revealed in the most recent estimates of global climate change. The trend in global temperature over the past eighteen thousand years is estimated to be an increase of about 5°C (9°F)[22]—with estimates of a much greater warming, perhaps 10°C, 20°C, or 30°C at higher altitudes. The twentieth century alone accounts for a land-area warming of 0.74 ± 0.18 degrees Celsius (IPCC 2007). Thus, while it took eighteen millennia to produce the 5°C warming, a sizable proportion of it came in the last century alone. Since the beginning of the industrial era, emissions have accounted for five times the change in climate due to solar variation (IPCC 2007). Projections suggest that future warming from greenhouse gases may occur at an even faster pace. For example, it is expected that the climate will warm by an average of 3°C (between 1.7°C and 4.0°C) by the end of this century. The pace of warming trends is as worrisome as their magnitude, since a quickened pace produces effects that are less predictable and more pronounced and for which adaptation is constrained.

Population Growth As of this writing, there are 6.8 billion people on Earth (United Nations 2005). It took many millennia, until around 1810, for the world population to reach one billion persons. It then took only just over a century to add another billion to the total, only three and a

half decades to add a third billion, only a decade and a half to add a fourth, a mere thirteen years to add a fifth, and then twelve years to add the sixth billion in 2000 (the shortest amount of time to add a billion in human history). It is anticipated that world population will reach seven billion by about 2015, taking fifteen years to add the most recent billion, indicative of a gradual reduction in the pace of growth. Nonetheless, population is expected to continue to grow, reaching between eight and eleven billion by 2050. For the vast majority of human history, the world population grew relatively slowly. In the modern era it grew exponentially. Indeed, the world added an astounding 4.4 billion persons in the twentieth century alone.

UN projections, based upon a median fertility scenario, expect that world population will stabilize sometime after 2200 at ten billion persons—a more than 50 percent increase over the current population size. Hence, while the human population is expected to grow in the twenty-first century at a considerably slower pace than it did in the twentieth, the total number of people placing demands on environmental capital and services will be of unprecedented scale and, consequently, will present an unprecedented assault on global ecosystems.

While the growth rate of the human population is slowing and expected to stabilize, the declining size of households and the subsequent growth in their number continues at a rapid pace (Liu et al. 2003). The increase in households typically manifests itself in urban sprawl (a serious threat to biodiversity conservation) and places increased demands on infrastructure needs. The decline in the size of households also represents a significant increase in the consumption of resources. Along with the scale of the global population, these trends raise the question of whether there will be sufficient resources to satisfy the growing demands they embed.

Species Extinction The vast majority of species that have ever walked the earth are extinct. The bulk of these extinctions, however, are due to either astronomical or terrestrial cataclysms in geological history or to slow rates of extinction through evolutionary processes. In modern times the rates of extinction are extraordinarily faster, for some species groups one thousand to ten thousand times the evolutionary rate of extinction that existed prior to the appearance of the human species. It is estimated that as many as 137 species disappear each day, amounting to over fifty thousand species each year (Raven and McNeely 1998; Dowdeswell and Heywood 1995; Wilson 1992).

These dramatic rates of species extinction are a serious challenge to ecological sustainability because they represent disturbing assaults to symbiotic relationships among species and to complex species interdependencies, including the dependence of CHANS on the many ecosystem goods and services provided or enhanced by plant and animal species. Indeed, species extinction may be the most ostensible evidence of time's arrow disrupting time's cycles. And the primary cause of this accelerated pace is clear—habitat destruction by expanded land use, by the introduction of exotic species into ecosystems, by overexploitation of some species for commercial purposes, and, in some places, by pollution. In the future, it is expected that climate change will also be a major contributor.

Much of this change has occurred over the last half century. As the UN's recent Millennium Ecosystem Assessment (see table 1.1) puts it:

> The structure and functioning of the world's ecosystems changed more rapidly in the second half of the twentieth century than at any time in human history. More land was converted to cropland in the 30 years since 1950 than in the 150 years between 1700 and 1850. Cultivated systems (areas where at least 30 percent of the landscape is in croplands, shifting cultivation, confined livestock production, or freshwater aquaculture) now cover one quarter of earth's terrestrial surface. (UNEP 2005a, 2)[23]

Scale

What about scale consequences? In pioneering research, Vitousek and colleagues (1997) carefully estimated the scale of ecosystem impacts around the globe by examining the dominant influence of human actions in producing those impacts. As for the accuracy of their estimates of scale, the authors write: "The numbers have large uncertainties, but the fact that they are large is not at all uncertain" (1997, 495). Figure 1.1 summarizes their findings.

Land Use Land use and its transformations represent the single most influential human impact worldwide and is the primary driving force in the loss of biodiversity. Between one-third and one-half of the global land surface has been altered by humans. Other key transformations include the growing percentage of fully exploited marine fisheries (including the 22 percent of fisheries already overexploited or depleted), the 35 percent increase in CO_2 concentrations compared to the preindustrial era, and the use of more than half of all accessible surface fresh water.

Table 1.1
Comparative table of systems as reported by the millennium ecosystem assessment (C.SDM)

Note that the boundaries of these systems often overlap. Statistics for different systems can therefore be compared but cannot be totaled across systems, as this would result in partial double-counting.

System and subsystem	Area[a] (million sq. km.)	Share of terrestrial surface of Earth (percent)	Population			GDP per capita (dollars)	Infant mortality rate[b] (deaths per 1,000 live births)	Mean NPP (kg. carbon per sq. meter per year)	Share of system covered by PAs[c] (percent)	Share of area trans-formed[d] (percent)
			Density (people per sq. km.)		Growth rate (percent 1990–2000)					
			Urban	Rural						
Marine	*349.3*	*68.6*[e]	–	–	–	–	–	*0.15*	*0.3*	–
Coastal	*17.2*	*4.1*	*1.105*	*70*	*15.9*	*8.960*	*41.5*	–	*7*	–
Terrestrial	6.0	4.1	1.105	70	15.9	8.960	41.5	0.52	4	11
Marine	11.2	2.2[e]	–	–	–	–	–	0.14	9	–
Inland water[f]	*10.3*	*7.0*	*817*	*26*	*17.0*	*7,300*	*57.6*	*0.36*	*12*	*11*
Forest/ woodland	*41.9*	*28.4*	*472*	*18*	*13.5*	*9,580*	*57.7*	*0.68*	*10*	*42*
Tropical/ subtropical	23.3	15.8	*565*	14	17.0	6,854	58.3	0.95	11	34
Temperate	6.2	4.2	320	7	4.4	17,109	12.5	0.45	16	67
Boreal	12.4	8.4	114	0.1	–3.7	13,142	16.5	0.29	4	25
Dryland	*59.9*	*40.6*	*750*	*20*	*18.5*	*4,930*	*66.6*	*0.26*	*7*	*18*
Hyperarid	9.6	6.5	1,061	1	26.2	5,930	41.3	0.01	11	1
Arid	15.3	10.4	568	3	28.1	4,680	74.2	0.12	6	5
Semiarid	22.3	15.3	643	10	20.6	5,580	72.4	0.34	6	25
Dry subhumid	12.7	8.6	711	25	13.6	4,270	60.7	0.49	7	35
Island	*7.1*	*4.8*	*1,020*	*37*	*12.3*	*11,570*	*30.4*	*0.54*	*17*	*17*
Island states	4.7	3.2	918	14	12.5	11,148	30.6	0.45	18	21

Mountain	*35.8*	*24.3*	*63*	*3*	*16.3*	*6,470*	*57.9*	*0.42*	*14*	*12*
300–1,000 m	13.0	8.8	58	3	12.7	7,815	48.2	0.47	11	13
1,000–2,500 m	11.3	7.7	69	3	20.0	5,080	67.0	0.45	14	13
2,500–4,500 m	9.6	6.5	90	2	24.2	4,144	65.0	0.28	18	6
>4,500 m	1.8	1.2	104	0	25.3	3,663	39.4	0.06	22	0.3
Polar	*23.0*	*15.6*	*161*[g]	*0.06*[g]	*–6.5*	*15,401*	*12.8*	*0.06*	*42*[g]	*0.3*[g]
Cultivated	*35.3*	*23.9*	*786*	*70*	*14.1*	*6,810*	*54.3*	*0.52*	*6*	*47*
Pasture	0.1	0.1	419	10	28.8	15,790	32.8	0.64	4	11
Cropland	8.3	5.7	1,014	118	15.6	4,430	55.3	0.49	4	62
Mixed (crop and other)	26.9	18.2	575	22	11.8	11,060	46.5	0.6	6	43
Urban	*3.6*	*2.4*	*681*	–	*12.7*	*12,057*	*36.5*	*0.47*	*0*	*100*
GLOBAL	*510*	–	*681*	*13*	*16.7*	*7,309*	*57.4*	–	*4*	*38*

Source: UNEP 2005a, 31.

a. Area estimates based on GLC2000 dataset for the year 2000 except for cultivated systems where area is based on GLCCD v2 dataset for the years 1992–1993 (C26 Box1).

b. Deaths of children less than one year old per 1,000 live births.

c. Includes only natural protected areas in IUCN categories I to VI.

d. For all systems except forest/woodland, area transformed is calculated from land depicted as cultivated or urban areas by GLC2000 land cover data set. The area transformed for forest/woodland systems is calculated as the percentage change in area between potential vegetation (forest biomes of the WWF ecoregions) and current forest/woodland areas in GLC2000. Note: 22 percent of the forest/woodland system falls outside forest biomes and is therefore not included in this analysis.

e. Percent of total surface of Earth.

f. Population density, growth rate, GDP per capita, and growth rate for the inland water system have been calculated with an area buffer of 10 kilometers.

g. Excluding Antarctica.

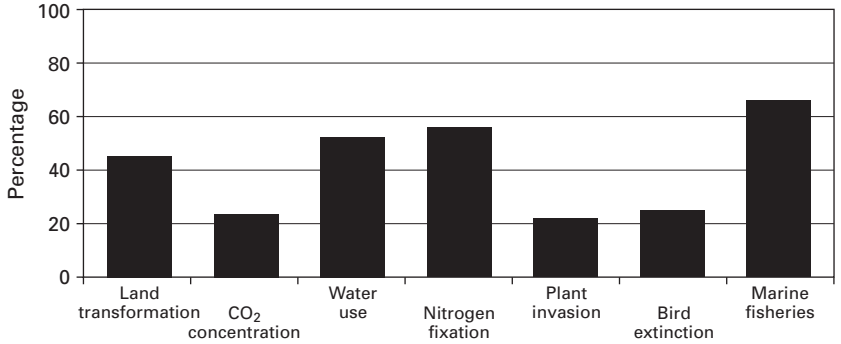

Figure 1.1
Human dominance or alteration of several major components of the Earth system, expressed as (from left to right) percentage of the land surface transformed; percentage of the current atmospheric CO^2 concentration that results from human action; percentage of accessible surface freshwater used; percentage of terrestrial nitrogen fixation that is human-caused; percentage of plant species in Canada that humanity has introduced from elsewhere; percentage of bird species on Earth that have become extinct in the past two millennia, almost all of them as a consequence of human activity; and percentage of major marine fisheries that are fully exploited, overexploited, or depleted.
Source: Vitousak et al. 1997, 495, reproduced with permission.

Other examples abound. Since 1700, the actions of humans have converted 19 percent of the world's forests and woodlands to cropland and pasture, resulting in a sizable redistribution of land uses across the globe (Richards 1990). This recent historical shift alone triggered not only changes in land uses, but also changes in biogeochemical cycles including hydrological cycles as well as in ecosystems—in short, changes in the earth system itself.

Spread

Energy Consumption Three centuries ago nations in the West started an industrial revolution that continues to spread around the globe. The fundamental practice launching the revolution was the shift in reliance from direct use of solar energy, burning of wood hydrocarbons, and direct use of photosynthetic energy fixation to a reliance on fossil hydrocarbons. In essence, the industrial revolution was a revolution in the use of fossil fuels that created a deep dependence on that form of energy—a dependence that remains unabated. The global use of fuel hydrocarbons "has increased nearly 800-fold since 1750 and about 12-fold in the

twentieth century" alone (Hall et al. 2003, 318). And the use of fossil fuels has spread everywhere. The leading form of fossil fuel, oil, is consumed by literally every nation (nearly two hundred in total) around the globe (Hall et al. 2003) and in nearly every nation, demand for fossil fuels is growing, quite rapidly in many cases.

The continued high levels of fossil fuel consumption and increased global demand threaten nature's capital in a variety of significant ways. Consumption reduces the availability of this resource for future generations (by how much is a hotly debated issue), markedly contributes to global climate change, and is responsible for smog and particulates as well as toxic substances that are harmful to health.

Deforestation One of the most obvious spreads of ecological impact around the globe is the loss of forest cover. Deforestation, once virtually concentrated in the temperate zones, has now reached all climatic zones, especially the South—which contains 77 percent of the New World's tropical forests (Rudel 1989). Globally, the 3.4 billion hectares (a hectare equals approximately 2.41 acres) of forestland that existed in 1980 had declined by 5 percent to 3.2 billion hectares just fifteen years later (FAO 1997).

The spread of deforesting practices is especially pronounced in the tropics where, for example, the amount of deforested land increased from 7.5 million hectares per year in 1979 to 13.2 million hectares in 1991, an increase of over 75 percent or an annual increase of 4.5 percent per year (Bawa and Dayanandan 1997). Worldwide, tropical forests are being lost at a rate of 14 to 16 million hectares per year. Examples of the most rapid spread of tropical deforestation include Brazil, where the Amazon region alone contains 40 percent of the world's remaining tropical rain forest. Over the last twenty-five years, Brazil has lost forest cover equivalent to the size of Germany (Mertens et al. 2002).

Closed-canopy forests (unbroken forests consisting of virgin, old-growth, and naturally regenerated woodlands) are especially valuable in countering soil erosion, desertification, and the impacts of climate change. The remaining closed-canopy forests are concentrated in only fifteen countries, nearly all in the South, making them especially vulnerable to population and development pressures (UNEP 2001).

To deforestation can be added the spread of other impacts: desertification (the conversion of arable land into desert-like conditions), soil erosion (the decline in the fertility, depth, and structure of arable land),

and salinization (where water tables rise close to the surface, water evaporates, leaving a salty residue in the soil; cf. Harrison 1993).

Urban Sprawl One of the key factors that accounts for the spread of deforested areas—as well as species loss, other forms of land degradation, and the destruction of coastal zones—is another form of spread: urban sprawl (Ewing et al. 2005).[24] The growing concentration of the human population into urban areas accompanied by the rise of megacities (cities with populations over ten million) is a long-standing, persistent demographic trajectory that is expected to continue indefinitely (United Nations 2004). Three and a half billion people now live in urban areas, over one-half of the entire human population as of mid-2007 (Wimberley and Kulikowski 2007), and will increase to over two-thirds of the population by 2030. The continued expansion of urban housing and infrastructure into open areas comes at the expense not only of their material requirements, but also of other forms of natural capital, including forest cover, and the species that are dependent upon them.

Chemicals Everywhere Remarkably enough, as noted, traces of lead and copper were discovered in Greenland that could be tracked to the golden ages of Greece and Rome and to the Northern Sung dynasty of China (tenth to twelfth century). In modern times, the problem of chemical pollution in this remote place not only persists but also is markedly worse. Body burdens (measurable amounts of chemicals in the body) of two hundred hazardous compounds have been found among the ninety thousand Inuit natives who occupy Eastern Canada and Greenland. These compounds are implicated in birth defects, lowered intelligence, and a wide variety of other health problems. Samples of the breast milk of mothers reveal PCBs (Polychlorinated biphenyls) and levels of mercury twenty to fifty times higher than levels found in the urban areas of the United States. Furthermore, the flame-retardant chemical PBDEs (Polybrominated diphenyl ethers) have been found in Inuit blood (Courtney et al. 2000).

Other evidence also indicates that chemicals have spread far and wide. A number of modern chemical marvels, taken for granted by countless users around the globe, were developed from several types of perfluoronated compounds, such as perfluorooctane sulfate (PFOS) and perfluorooctanoic acid (PFOA). Known by such brand names as Teflon, Scotchgard,[25] Stainmaster, and Gore-Tex, these chemicals have been detected around the globe—literally. They have been found in polar

bears roaming the Arctic Circle, in dolphins swimming in the Mediterranean Sea off the coast of Italy, and in gulls flying above Tokyo. Furthermore, they have been detected in the Great Lakes, the source of drinking water for nearly forty million U.S. residents. Perfluoronated compounds have been linked to cancer, development problems, liver damage, and other health problems in a number of animal studies as well as studies showing more direct implications in the health of humans (cf. Alexander et al. 2003; Butenhoff et al. 2002; Ciriolo et al. 1982; Kliewer, Lehmann, and Wilson 1999; Kroll et al. 2000).

The Spread of Germs One of the subtler, but potentially more devastating consequences of GEC is its impacts on human well-being. Climate change, for example, is very likely to increase the incidence and the spread of disease. Throughout history "diseases have been the biggest killers of people, [and therefore] have also been decisive shapers of history" (Diamond 1997, 197).

Recent history recapitulates—in fast-forward time—this recurrent feature of all of human history. There is clear evidence that the increased warmth and dryness of a recent ENSO (El Niño Southern Oscillation) season led to vegetation growth that sustains desert rodents. This prompted not only a growth in the rodent populations, carriers of the Hantavirus, but also a spread of rodents into human habitats. The net effect was an outbreak of an acute respiratory disease with a high death rate (the Hantavirus Pulmonary Syndrome) among humans (CCSP 2003). It is reasonable to suspect parallel processes with global warming. For example, a receding of permafrost and snowcaps will likely expand the area of mosquito breeding, which will result in the spread of mosquito-borne diseases including malaria, dengue fever, yellow fever, as well as viruses (various types of encephalitis, West Nile virus, and others).

The fast-forward of modern disease, exhibiting all the features of PaSSAGE, shows itself in the rate and consequences of disease spread: the pace of transmission is much faster, the numbers of those exposed is much greater (a vast increase in scale), and due to the variety and ease of international travel the expanse of exposure is much higher (a vast increase in spread). There is a very real potential for climate change to cause ecological changes that can be costly not only to human health, but also to human wealth and quality of life. Extreme events can have ripple effects that disrupt economies, communities, agricultural production, trade, tourism, and even the social fabric itself.

A variety of ostensible global impacts is traceable to the processes of GEC, a combination of pace, scale, and spread. What are the drivers of those processes?

Humans as Shapers of Environment and History

Jared Diamond summarizes his influential examination of the entire history of the human species succinctly: "Environment molds history" (1997, 352). Few would disagree. But to complete the causal chain, we need to add that "humans mold environments." And the residual framing approach of scientific evidence has clearly demonstrated that CHANS and the global environment are being molded in unprecedented ways.

CHANS are Janus-like. They are reciprocal, feedback systems where, on the one hand, human practices and institutions determine the availability of natural capital and services to sustain human populations. But on the other hand, the resulting changed ecosystems determine the range of options and institutions available to humankind. CHANS are dynamic, serving as both the medium and outcome of human actions—planned and unplanned. Put more succinctly, humans shape the natural ecosystems that support life but are also, in turn, shaped by those ecosystems.

Proximate Anthropogenic Drivers

The National Research Council/National Academy of Sciences report GEC92 (Stern, Young, and Druckman 1992) summarized the epistemic agreement over the probable proximate anthropogenic (or human) drivers of GEC. That scientific consensus has provided the useful checklist of factors that guided the selection of chapters in this volume: population, affluence and consumption (especially of energy and materials), technological change, changes in land cover and land use, institutional actions and responses, and culture. Recurrently, population dynamics and environmentally significant consumption, combined with direct modifications of natural systems, account for the vast majority of effects on the global environment that are traceable to human activities (Dietz, Rosa, and York 2007; Rosa, York, and Dietz 2004; York, Rosa, and Dietz 2003a, 2003b). What follows is a sketch of the dynamics of these dominating forces driving GEC: population, consumption, and technological efficiency.

Population Human population—all its dynamics—is one of the most direct and enduring forces behind land use change, energy use, and basic levels of consumption—placing increased demands on living space, food production, water use, and the flora and fauna of the planet. It has been so since the early beginnings of the human species. Archaeologist Charles Redman observed that, "in every case study," in his book of the human impacts on ancient environments, "the growing number of people is a factor creating an imbalance between society and the environment" (1999, 164).

Consumption There is little doubt (Dietz, Rosa, and York 2007; Rosa, York, and Dietz 2004; York, Rosa, and Dietz 2003a) that consumption is a key driver of environmental degradation, and that the patterns of consumption represent a sword that cuts in two directions. On the one hand, the economic fruits of modernity mean that a growing share of the world's population can look forward to material and social comforts that have historically eluded them. And improvements in sanitation, health, and education—indicators of virtually all definitions of social progress—mean that a larger share of the world's population enjoys a quality of life unreachable only a generation ago.

On the other hand, these improvements come with an environmental cost. In the short run, reductions in mortality lead to increased population growth, the key driver of impacts. Over the longer term, improvements in health, education, and opportunities fuel demographic transitions that result in slowdowns in population growth. But the increase in longevity is ineluctably an increase in the number of years individuals continue to consume—adding further to aggregate consumption, despite the decline in the rate of consumption growth as a population moves toward stabilization.

During the modern era the industrial nations were the primary benefactors of increased consumption and were the primary producers of many environmental impacts. In this era of high modernization, other nations, such as China and India, are experiencing rapid economic growth, catapulting them abruptly into the high-consumption club. As we already noted, the pace of population growth is slowing, meaning that it will eventually peak. Nevertheless, the level of that peak will reach heights unknown to history. The slowed rate of population growth could ultimately mean reduced stress to the environment. However,

such reduction could be counterbalanced or, worse, trumped by the rapid growth in consumption associated with the emergence of a global middle class (Myers and Kent 2003). Perhaps there is no better example of this than China.

China While having reduced its rate of population growth dramatically, China continues to be the most populous nation on earth.[26] It also has one of the fastest growing economies. As a result, more and more of the 1.3 billion Chinese can afford to purchase a wider array of goods. In 2003, China consumed one-half of the world's cement production, one-third of its steel, nearly one-fourth of its copper, and nearly one-fifth of its aluminum. Traditionally a large exporter of coal, China is now consuming almost all of its production while simultaneously becoming the second-largest importer of oil after the United States (Goodman 2004). And China, the fastest-growing car market in the world with purchases of 4.4 million vehicles in 2002, has replaced Germany as the third largest automobile market in the world, ranking only behind the United States and Japan (Eisenstein 2004).

What is perhaps most troubling about China's new wealth is that its rapid growth in consumption may be the harbinger of what could follow among the other poorer countries of the world (e.g., India) that are now experiencing increased economic prosperity. Indeed, the Chinese may be the paradigmatic example of what Myers and Kent (2004) refer to as "the new consumers," the rising tide of people around the world with growing incomes to satisfy their pent-up demand for goods. While there are many uncertainties over the magnitude of stress this sort of rising consumption will place on ecosystems, that there will be significant stress is entirely certain.

Technological Efficiency As economies mature, their structures undergo transformation. A number of observers (Mol and Sonnenfeld 2000; Grossman and Kruger 1995; Graedel and Allenby 1995) believe that changes in the structure of advanced economies will result in reduced impacts to the environment. One of the features of the most advanced economies is a decline in the extractive and manufacturing sectors, whose dominance is replaced by a rapidly growing service sector. Owing to this shift, some observers anticipate a demonstrable decline in the environmental impacts of mature economies despite continued economic growth.

Electronic Age That expectation is challenged on several grounds. One such challenge comes from the growth in the personal computer market. The most significant technological change enabling and supporting a service economy is the personal computer, whose unit sales totaled one billion (nearly one computer for every six people in the world) by the end of 2002 (Kuehr and Williams 2003). But, contrary to expectation, computers seriously impact the environment. The manufacture of each computer requires an astounding amount of energy and materials. One desktop computer and monitor, averaging fifty-three pounds, requires at least ten times its weight in fossil fuels and chemicals, making it more materials intensive than an automobile or refrigerator[27] (Kuehr and Williams 2003).

The materials burden of the desktop computer is magnified by the facts that computers have a short lifespan and that many of the chemicals in their manufacture, such as lead, are toxic. Many of these toxic chemicals pose serious risks not only during their manufacturing stage, but also when they are discarded. And contrary to optimistic predictions of "paperless" offices a few decades ago, personal computers have led to a marked increase in paper consumption (Senior 2007).

The examples reviewed here are merely the pixels of a much larger picture. What are the contours of that picture?

Human Dimensions of GEC: The Big Picture

Human dimensions of GEC are a conceptual framing of global CHANS that produces questions about the role of humans in ecological change on a global scale. As noted, there has been a scientific consensus for over two decades about the probable anthropogenic drivers or human factors that account for global environmental change. Given that long-standing consensus, it becomes appropriate to ask: what is our state of knowledge about the human dimensions of GEC? Over the last decade or so, major international research programs have greatly enhanced our understanding of global CHANS.

For the first time, it is realistic to speak of a science of sustainability that is devoted to "coupled human-environment systems" (Clark 2007) or CHANS, with their dominance by human dimensions. One of the clearest indicators of the institutionalization process was the decision by the U.S. National Academy of Sciences to devote a section of its prestigious journal, *Proceedings of the National Academy of Sciences*, to

sustainability science (Clark 2007). Another prestigious scientific society, the American Association for the Advancement of Science, established a resource website on sustainability that highlights research and programs investigating CHANS (http://sustainabilityscience.org).

GEC, the global context of CHANS, has generated formally organized and coordinated research programs, mostly through the International Human Dimensions Programme (http://www.ihdp.org/). Other research programs were the spontaneous convergence of researchers scattered about the globe addressing common intellectual themes. Still other research represents a refocusing of traditional disciplinary interests on GEC topics. In this volume, we offer a carefully selected sample of "state of the science" reviews of these these major research efforts.

The remaining chapters are devoted to some but not all of the consensual themes of GEC's human dimensions: population, consumption, land cover and land use, institutional actions, and culture. The chapters provide a broad, exemplary picture of these themes while also summarizing our cumulative understanding of this complex topic, offering an unprecedented vantage point for understanding CHANS and how they are networked and interrelated globally.

We have not attempted to assemble examples of all types of human dimensions research. Our goal, instead, has been to be simultaneously more modest, by limiting the breadth of coverage, and more ambitious, by bringing the greater depth of well-developed, illustrative works to the attention of the larger scientific and policy audiences. These works exemplify core issues addressed by interdisciplinary research that combines social science and ecology.

The authors in this volume do not always speak exactly the same language, or always share assumptions about the dynamics of the human dimensions of GEC, or hold the same opinions of which methods are most appropriate for understanding global CHANS. But aligning rather than ignoring the disparate approaches is exactly the goal of the volume. GEC work in the physical and biological sciences has been an enterprise of a truly global community, as it must be to study worldwide phenomena. We believe the same is true for the social sciences. To understand the human dimensions of global environmental change requires a framing that brings the various traditions together so that currently disparate approaches can be forged into a common language to ensure an authentic global effort.

In examining approaches to understanding CHANS, we find a strong divide between the Continental and North American research traditions

in the social sciences. Rather than ignore this work, or represent only one side of this divide exclusively, as is often done, we include two chapters that combine the two traditions (chapter 6 by McCay and Jentoff and chapter 7 by Kasperson, Kasperson, and Turner) and one exemplar of the Continental tradition (chapter 2 by Beck). Our intentions are to inform readers and begin facilitating communication between traditions that normally do not talk to one another and to promote research that becomes more synthetic and richer than would otherwise be the case.

Galison (1997), a distinguished historian of science, notes that even in as seemingly narrow a field as high-energy physics, researchers from different disciplines or specialties have distinct languages. Hence, they must first develop a "pidgin" language so that they can communicate across specialty areas. The inclusion of a chapter representing the Continental tradition in the social sciences is an initial effort to lay out the parent languages from which such a pidgin can be formed. The remaining chapters tap the consensual themes of research—population; consumption; land cover and use; institutional actions, culture, and consequences—in the human dimensions of GEC as well as methodological issues relevant to understanding these themes. By reading across them one learns not only the state of social science thinking on these issues, but also the conceptual language and alternative approaches being brought to bear on this complex topic. This is a necessary step in the essential task of developing the integrated approaches needed to understand GEC.

Research Traditions and Directions: The Substantive Chapters

Continental social science, not only a dominant perspective in mainland Europe, but also a major force in parts of the United Kingdom and its Commonwealth as well as South America and elsewhere, differs from American social science in its very foundations. The Continental tradition emphasizes the view that humans are neither passive recipients of environmental knowledge and options, nor merely objects to be studied via scientific methods by those interested in human-nature dynamics. Rather, this tradition notes that values, beliefs, norms, attitudes, and stories about the environment are all actively—and in many cases, strategically—constructed. As such they become the focus of investigation, not the "objective" conditions of nature.[28] This view is one of the cornerstones of much of the Continental approach and often a source

of tension between the Continental and Anglophone traditions, since it has implications for epistemology especially. An exemplar of the Continental tradition is the theorizing of German sociologist Ulrich Beck in chapter 2.

Risk Worldview

A fundamental characteristic of GEC is the extent to which our understanding of the biosphere and related human influences is fraught with uncertainty. For more than two decades, uncertainty has been understood as a central feature of all environmental issues. A substantial literature has emerged to address uncertainty, reconceptualized as risk. This literature ranges from highly sophisticated toxicology and exposure modeling to sociological studies of risk organizations and psychological studies of how perceptions of uncertainty are shaped and move through society. Perhaps the most provocative and influential line of argument within this growing literature on risk is the idea that risk itself has become a major foundation of twenty-first-century society, displacing to some extent older foundations such as class, social location, fundamental belief systems, or ethnic identity.

In chapter 2, Ulrich Beck, the major architect of this new "risk worldview," recapitulates and extends in new directions his original "risk society" argument (Beck [1986] 1992). He not only distinguishes his theoretical argument from competing continental perspectives (e.g. cultural theory) but, more important, also provides a conceptual lens to focus our understanding of fundamental, reinforcing changes in social structures and human ecosystems. The emergence of PaSS, reflecting the human system part of CHANS, generated a remarkable increase in the magnitude and scale of risks and their spread around the globe. PaSS created a "world risk society" that bifurcates modernity into two distinct phases: in the first phase, modernity comprises all the features characteristic of rational calculus (Jaeger et al. 2001); in the second, modernity comprises risks and vulnerabilities that elude rational calculus. Furthermore, Beck articulates the pervasive socialization of nature and its transformation from an ontological entity into an idealization. Owing to this idealization ecological debates are no longer about nature per se, but about competing cultural and political concepts of nature. It follows, then, that concerns about global environmental change are unavoidably bound up with a panoply of constructed representations of nature, facilitated by the media and political actors. Here Beck explains

how global climate change, one of GEC's principal systemic changes, is so bound up.

Population and Consumption

In contrast to the grand sweep of Continental thinking is a research program devoted to understanding the anthropogenic drivers of GEC. An advanced and systematically developed line of research, this program, labeled "STIRPAT," focuses on other primary drivers of human impacts on the environment, especially those of population and consumption (www.stirpat.org). STIRPAT is a CHANS-focused approach devoted to the question of why nation-states and other entities differ in their impact on the environment. With the nation-state as its principal unit of analysis to date, STIRPAT provides a suite of macrofindings that should complement the microfindings from the case studies that now dominate CHANS research (Liu et al. 2007a). STIRPAT research draws on theory in ecology and social science and on methods in the social sciences, where macrocomparative analysis is a long-established tradition. But it also attends to the tradition in the physical and natural sciences of using relatively simple accounting equations to understand the driving forces of global change, and deploys emerging measures of human environmental impact. The resulting research is referred to as Structural Human Ecology (SHE). In chapter 3, Thomas Dietz, Eugene A. Rosa, and Richard York, principal STIRPAT architects, review SHE's approaches and theories and STIRPAT results to date. Their findings are consistent with general arguments that are centuries old, but are much more disciplined and robust, and point to population size and consumption as key factors resulting in environmental impacts.

Land Use and Land Cover

One of the most important and stimulating challenges of the last decade of work on human dimensions of global change is finding ways to integrate questions and methods from the social sciences with those of the physical and biological sciences. A particularly advanced and systematically developed topic in this line of investigation is research on land-use and land-cover change.

Changes in how land is used and resulting changes in landscape cover and ecology are among the most profound of human influences on the earth, and are major drivers of climate change, deforestation, biodiversity losses, and alteration of biogeochemical cycles. So it is not

surprising that an international program of research on Land Use Cover and Change (LUCC) was the first of the systematic human dimensions programs to emerge. In chapter 4, Emilio F. Moran reviews the progress in our understanding of land use change over the last decade. He shows that the cumulative literature on the topic underscores how decisions concerning the use of land and other resources are nested in the context of community practices, spatial distributions of populations, state policies, and international forces. He anticipates a considerable refinement in this literature over the next decade with a deeper understanding of the structure of landholding, the influence of tax and insurance regulations, the cost of alternatives for protecting land resources, and effective management practices.

Institutional Structures and Practices

One culmination of the long, repeated historical process of institution building is the nation-state. Except for Antarctica, all inhabitable areas of the globe are defined and ruled by territorially defined states—approximately two hundred in total. Because the nation-state is so pervasive, it is easy to forget that the idea of the nation-state, now the universal, large-scale political form, is of relatively recent origin, a product of modernization. As recently as 1500 AD, only a small fraction (less than 20 percent) of the world's land area was territorially bounded into states.

International Environmental Regimes That the nation-state is the principal agent of collective decision making leads to one unequivocal challenge of GEC: global impacts to CHANS do not respect national borders. For example, air pollution generated by coal-fired plants in the Midwest of the United States does not stop upon reaching the Canadian border, and nor does air pollution generated in East Asia stop at the Pacific Ocean but travels freely over water to contribute to air quality problems on the West Coast of the United States.

This incongruity between the ecological boundaries of GEC and the political boundaries of collective action doubtless represents one of the most difficult institutional challenges of GEC. It has led to the increased importance of international environmental agreements of the sort Oran R. Young reviews in chapter 5. Here the research is an organized and systematic effort to understand how institutional regimes, especially at

the international level, come into play and what effect they have. Young provides an assessment (what he terms a "mid-term" report) of the extent to which the creation and growth of international regimes is an effective response to the challenges of GEC. He concludes with both hope and caution. Hope lies in the effectiveness of emergent regimes in mitigating a number of GEC problems. Caution lies in the realization that neither a common model nor a "simple recipe" is the appropriate strategy to pursue. Rather, the most effective international environmental regimes will be those that evolve from in-depth understanding of individual cases.

Common Pool Resources

The research agenda of international institutionalism intersects with a centuries-old problem concerning the tension between unlimited human demands and nature's finite resources. At least since the writings of classical economist David Ricardo in the eighteenth century, scholars have pondered this problem of "diminishing returns." In modern times the question is at the heart of a decades-old research program on the human governance of common pool resources. This modern version of the problem was largely stimulated by a germinal article with a provocative title, "The Tragedy of the Commons," in the journal *Science* (1968). In this article, biologist Garrett Hardin argued that the solution to the problem of a growing population pushing against finite resources could not be found in technical solutions.

A rich tradition of contemporary research, more synthetic than in the past, has drawn attention to a variety of nuances to the problem and to a range of solutions that eluded Hardin's overly simplistic version (Dietz, Ostrom, and Stern 2003). Bonnie J. McCay and Svein Jentoft, in chapter 6, label Hardin's approach as "thin" and abstract, resulting in various tenuous conclusions. They provide a "thick" or ethnographically rich alternative that reveals the limitations of Hardin's abstractness while uncovering numerous adaptive institutions that affect the resilience of the environment. They show that local and regional resources around the globe are threatened by cumulative environmental change—change that is governed at least in part by local behavior, but is also influenced by globalization. With this foundation McCay and Jentoft go on to review our substantial knowledge of commons and do so in a way that respects both the Anglophone and Continental traditions of scholarship.

Ecological Consequences: Vulnerability

Scholars have become increasingly aware of at least one lesson of history—that CHANS in many circumstances are particularly vulnerable to environmental change (Kasperson, Kasperson, and Turner 1995; Gunderson and Holling 2002; Turner, Kasperson et al. 2003; Turner, Matson et al. 2003). Indeed, many past societies did not ease into stages of ecological insustainability, but experienced abrupt collapse (Diamond 2005). This recognition has produced a spontaneous tradition of research that engages both the Continental and American social scientific traditions and focuses on the comparative vulnerability of societies around the world. The critical importance of determining the types, locus, and scale of human vulnerability to environmental change has led to increased efforts to coordinate and promote this research. Chapter 7, by Jean X. Kasperson, Roger E. Kasperson, and B. L. Turner II, provides an overview of the theoretical underpinnings and the state of the science in this rapidly changing and very critical area.

But more important, the idea of vulnerability explored by Kasperson, Kasperson, and Turner provides the dynamic link between time's cycles and time's arrow in CHANS. The ecological cycles of societies lacking the resilience to overcome the stresses of vulnerability are prone to "criticality," a level of endangerment whereby time's arrow overwhelms nature's regenerative cycles (Kasperson, Kasperson, and Turner 1995). This crucial point is summarized by Kasperson, Kasperson, and Turner: "'Criticality' is a function of the speed and intensity of environmental degradation, the vulnerability of people and ecosystems affected, and coping capacities and resilience . . . environmental criticality emerges historically through a series of stages in which the decisive attributes are the regenerative capacities of affected ecosystems and the buffering and mitigative costs incurred by affected societies."

In sum, the concept *vulnerability* provides a basis not only for earmarking threatened ecosystems but also for understanding the unsustainable transformation of CHANS globally—Mega-CHANS.

What Lies Ahead?

The elaboration of the pivotal issues we have outlined lies in the chapters that follow. In them, the authors provide a state-of-the-art assessment of how far human dimensions research has come in the past several decades. They also map out the most promising paths to take

toward a fuller understanding of the complex challenges of coupled human and natural systems in the context of global environmental change.

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Notes

1. The ecological communities surrounding deep ocean geothermal vents—"smokers"—and deep underground microbial communities may be the exceptions that prove the rule.

2. GEC92 is often referred to as the "Rainbow Book" in the human dimensions community because of its multicolored dust jacket.

3. We follow GEC92 in referring to key aspects of human action as "proximate human drivers" or "proximate anthropogenic drivers." The Millennium Ecosystem Assessment (UNEP 2005a; Alcalmo et al. 2003) refers to these factors as *indirect drivers* while using the term *direct drivers* to refer to factors such as land-use change, species introduction, and use of technology. In the MEA, direct drivers are defined as factors that "unequivocally influence ecosystems" and include climate variability and change, plant nutrient use, land conversion, and biological invasions and diseases. The GEC92 and the MEA frameworks are internally consistent but care must be taken in moving across them to avoid confusion of terms.

4. The term *biosphere* is generally associated with Russian geologist Vladimir Ivanovich Vernadsky ([1924] 1998) from the title of his book *The Biosphere*.

5. In adopting the terms *time's arrow* and *time's cycles*, we mimic Stephen Jay Gould's (1987) phrasing and framing of history in long glances.

6. Origination of the phrase "arrow of time" rests with physicist Sir Arthur Eddington who, holding the second law of thermodynamics to be supreme, pointed to it as the only unassailable indicator of evolution of the physical world (Eddington [1935] 1958).

7. In this regard, global environmental research is like astronomy or many of the social sciences where the theory-to-experiment-to-theory cycle that exemplifies scientific research cannot be applied because it is not possible to conduct controlled experiments on the key phenomena being studied.

8. For example, *Homo erectus* used fire at least four hundred thousand years ago, long before the appearance of our species, *Homo sapiens sapiens* (Gouldsblom 1992).

9. More extensive analysis of such linkages can be found in Costanza, Graumlich, and Steffen (2007).

10. Roughly at the end of the Pleistocene Era.

11. Rome had its share of other environmental problems due to its growing population and rising standard of living. Demand increased for timber—as building material, fuel for cooking, energy for industrial purposes, and heat source for private and public buildings. Farmers eagerly cut trees for timber to meet this demand, thereby accelerating deforestation while increasing arable land available for cropping (Gouldsblom 1992). Adding to Rome's environmental problems was its considerable air pollution traceable to chariot traffic on the city's dusty streets and to the smoke from the funeral pyres on the outskirts of the city. Tainter and Crumley (2007) discuss how the dynamics of the Roman Empire were driven in part by climate change, so the feedback between the Empire and the natural environment ran in both directions.

12. Landsat assessments in 2003 showed that 90 percent of the Mesopotamian marshlands have disappeared (UNEP 2003). A United Nations Environment Programme project, funded by the government of Japan, reflooded the marshlands resulting in a 40 percent recovery of the marshlands in just two years (UNEP 2005b).

13. Archaeological records are essential to understanding the impacts of past societies and civilizations on ecosystems because they often cover a sufficient amount of time to provide a basis for differentiating human impacts from impacts due to natural cycles.

14. Note that while the human-carrying capacity of the planet is difficult to define and estimate, the human population has already exceeded a third of all estimates of carrying capacity ever developed (Cohen 1995).

15. There are numerous examples where societies and civilizations (Easter Island is the paradigmatic example) have overshot their ecological limits in the past, resulting in their own demise. What is different in Catton's framework is his analysis of ecological exploitation at a global scale.

16. Crutzen shared the 1995 Nobel Prize in Chemistry with Mario Molina and Sherwood Rowland for basic discoveries of the effects of chlorofluorocarbons (CFCs) on the earth's ozone layer.

17. The entire Holocene (Recent Whole) era, consisting of the last twelve thousand years or so, is sometimes labeled as the Anthropocene (meaning recent *Homo sapiens sapiens*) to reflect, somewhat incorrectly, the emergence, survival, and dispersal of humans around the globe. Actually humans had evolved and dispersed all over the world prior to twelve thousand years ago. Furthermore, ecological disasters up to three centuries ago tended to be isolated and localized, not a threat across the globe.

18. While there is widespread agreement over the idea of globalization, there is considerable debate on when the process of globalization began. Held et al. (1999) identify three schools of thought pursuing the idea: hyperglobalization,

"skeptics," and transformationalists. Hyperglobalizers view globalization as the signature of an entirely new, unprecedented era where far-reaching transformations around the world are rendering the institutions and culture of modernism obsolete. Skeptics, observing similar patterns in the not-too-distant history, draw a much different conclusion and argue that not much is changing. Transformationalists view globalization as the efflorescence of a slow, long-term historical process. An even more far-reaching transformationalist view is that of world-systems theory (WST), which sees globalization as the extension of processes that had their origins in the sixteenth century (Wallerstein 2004). Yearley (2007) discusses the links between globalization and global environmental change, although he addresses neither the distinctions among theories of globalization offered by Held et al. (1999) nor the widely accepted conceptualization of global environmental change developed by Turner et al. (1990). Gallagher (2009) provides an excellent review of the conceptual links between globalization and environmental change, and reviews the evidence for the major claims.

19. Vitousek et al. (1997, 498) summarize their estimates of global human impacts this way: "The rates, scales, kinds, and combinations of changes occurring now are fundamentally different from those at any other time in history: we are changing the Earth more rapidly than we are understanding it."

20. Hibbard et al. (2007) provide further evidence of these recent rapid changes.

21. The beginning of "The Anthropocene" (Crutzen and Stoermer 2000).

22. This seemingly low value may appear innocuous, but it is anything but. This is precisely the average surface temperature of the globe that brackets the climate of the ice ages and the warm interglacial periods.

23. The problem is exacerbated in parts of the world that follow shifting cultivation practices, such as slash-and-burn agriculture. With increasing population pressure and with increased demand for raw materials, fallow periods are cut short, thereby reducing the replenishment of the soil and accelerating the rate of soil erosion.

24. The impacts of urbanization on deforestation are not uniform throughout the world. In Africa, for example, deforestation appears to be driven as much by rural population growth as by urbanization (Bawa and Dayanandan 1997).

25. In 2000 the 3M company, maker of Scotchgard, phased out the PFOS-based version of the product and substituted a formula free of PFOSs.

26. Expected to be overtaken by India in the next several years.

27. In particular, a desktop computer with a seventeen-inch CRT monitor requires at least 530 pounds of fossil fuels, fifty pounds of chemicals, and 3,330 pounds of water to manufacture. The amount of materials required for its manufacture equals roughly the weight of a sports utility vehicle (Kuehr and Williams 2003).

28. For continental theorists, noting that no place on earth is without a human footprint, the term *natural* no longer means a passive, pristine environment. There are no natural environments, only socialized ones.

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