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QUERIES ON THE HUMAN USE OF THE EARTH

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■ **Abstract** The central question of my scientific work has been, what is and ought to be the human use of the earth? It has been pursued collectively, with mentor, colleagues, students, and friends as a set of research questions related to hazards, hunger, and sustainable development. Regarding hazard, I tried to understand why people persist in occupying areas subject to natural and technological hazards and how adaptation made this possible. An extended stay in Africa to research both environment and development led to new queries. Why does hunger persist amid a world of plenty, and what can be done to end it? Can there be a transition to sustainability that over the next two generations would meet human needs and reduce hunger and poverty while maintaining the essential life support systems of the planet? All three themes and the research methods used to pursue them come together in an emerging sustainability science.

CONTENTS

THE CENTRAL QUESTION

The central question of my scientific work has always been, what is and ought to be the human use of the earth? It is a grand query, derivative of my discipline of geography, with a phrase borrowed from my first teacher in graduate

TABLE 1 Invisible college

In the beginning, I had a mentor, Gilbert White, who became in turn a long-term colleague and lifetime friend. The importance of mentorship is widely recognized today, from kindergartens to workplaces. By chance and by inclination, I found mine and was able to draw on him for lifetime lessons (see, for example, 1a).

Collegial scientific effort was well established in the natural sciences when I entered graduate school at the University of Chicago in 1958, but not in the social sciences, where a humanistic tradition of "the lonely scholar in a monastic cell" equally prevailed. But having willingly joined a collective effort led by White to understand flood plain management, I found that it involved not only professors and students in the Department of Geography, but also practitioners in state and national government, and an invisible college of both on- and off-campus interdisciplinary colleagues. Rereading the acknowledgements from my own dissertation, it thanks 31 individuals for reviewing all or parts prior to publication. In addition to geographers and various practitioners, they include an anthropologist, four economists, two engineers, two hydrologists, two political scientists, a psychologist, and a sociologist.

Thus, in my earliest scientific rite of passage, I learned the virtues of questions that seem to matter as much for society as for science; pursuing them through collective research programs rather than personal projects, and seeking answers in the interstices of disciplinary traditions. I have written together with 85 colleagues, and fewer than half of my publications have been individually authored. For all of them at Clark University, the University of Dar es Salaam, Brown University, and the dispersed invisible college, a lifetime of gratitude.

school and his book of the same name (1). It has always been pursued collectively with my not-so-invisible college (see Table 1) of mentors, colleagues, students, and friends. As with most grand queries, ours is studied not grandly but in reduced ways, as a set of more specific research questions. The particular mix of these research questions that I have pursued, the subject of this essay, is peculiarly my own—a combination of contingent personal history (see Table 2), the larger context of the history and science of my times, and a vision of that of my grandchildren's.

These questions have been organized under three major headings, related to hazard, hunger, and sustainable development. Looking back, I seem to have pursued these in some six intense periods lasting about seven years of work, place, and opportunity. The periods do blend together, however; the new always begins before the old is done. The constituent questions never are fully answered; as all grand queries do, they reappear in new and profound ways. For each question, I have tried to provide a paragraph of context and links to the related questions that followed or preceded it, and as an essay experiment, I use extended quotes from the original work to pose the question, provide the answers available at that time, or give essential background.

TABLE 2 Roots

In 1981, Anne Buttimer interviewed me for a video archive of the life experience of individual geographers. Setting out that morning for the studio, my wife Ellie, then studying psychology, asked me if I was prepared for the interview. “You will surely have some surprises,” she said. And indeed, the answers I gave to questions related to my childhood surprised me. Three important characteristics that would influence my work were already then evident. There is a fascination with exploring places and nature despite a city childhood. There is a penchant for engaging in fantasy, a willingness to create imaginary worlds and to live within them. There are the depression years and the ways it marked me. Translated into my professional life, I see these as roots for exploring the human use of the earth, for a willingness to explore alternative hypotheses, views, and futures, and for the social concerns that frame much of my work.

From the video transcript:

RK: I never heard of geography until I took my first geography course. Like so many other American geographers, I think it’s such a common tale. But I discovered in many ways that I was a closet geographer. For example, I explored New York City as a child. I used to go off . . . on the subway train every Saturday . . . to some point of interest and walk around. I knew New York City, especially geographically, very well. I was [also] a boy scout and discovered that there was a world of nature that one could explore as well.

AB: Do you think that in those early years you got a love of nature as an alternative to the city?

RK: Yes. Even though we didn’t have much exposure because our big nature exposure was to go to Staten Island.

AB: Beach?

RK: No, we hiked. There are some parks there.

AB: But a look at your early childhood experiences, I mean, what were the things you valued, the things you found worth, really—of your early years, besides taking the subway around the city and going to Staten Island? What were the things you really enjoyed doing?

RK: I did a lot of fantasy. I had a pretty miserable childhood.

AS: Would you like to describe more of that?

RK: No. (Laughter)

AB: Leave it to fantasy?

RK: Yes. So I used to construct imaginary worlds. I was pretty good at that.

AB: Do you remember some of those?

RK: I often built on novels. I did an enormous amount of reading. I probably read all of Dumas [in the library] by the time I was 12 and I teethed on Robert Louis Stevenson. I often extrapolated myself into times [past] and I was one of d’Artagnan’s sidekicks. (Laughter)

AB: These times in New York must have been difficult times, this would be in the late 30s—

RK: Yes. The depression had a very—we were quite poor. My father died just when I was born, and we had a very hard time. So I am a real depression baby, and I think it has marked me in many ways for the rest of my life.

LIVING WITH HAZARD

One strategy for understanding the human use of the earth is to examine nature-society relationships in the extreme. If nature is significantly linked to humankind, it should show up first in its most important valuations—in those resources or services most essential for human sustenance and in those hazards that most threaten human life and livelihood. Indeed, one of our earliest insights was the relationship between hazards and resources. People encounter hazard, we thought, in the search for the useful. Thus, places that provide access to several ecosystems or resource locations are often sites of high natural hazard—earthquakes where mountains meet the sea, coastal storms at land's end, floodplains with fertile soils and easy access, and drought where dry lands border the damp.

My mentor, Gilbert F. White, had in his extraordinary career (2, 2a) focused equally on both resources and hazards, especially on water resources and flood plain management. When I arrived at the University of Chicago in 1958 to begin 4 years of graduate study, he had underway a major study of floodplain management in the United States. Quickly attracted to the virtues and excitement of collaborative work on a significant theme, I wrote both my master thesis and doctoral dissertation on flood plain management, although my doctoral topic, *Hazard and Choice Perception in Flood Plan Management* (3), was strongly influenced by two new areas of interdisciplinary research: systems analysis and decision science.

Systems analysis was to provide a framework for analyzing how the world works (4). Drawing on concepts from electrical engineering and biology, general systems theory sought to explain the linkages between phenomena and their resulting organization at scales ranging from atoms to the universe. This emergent quasi-discipline created broad excitement, popularized new terminology, and was eventually incorporated into the everyday practice of science so that one can hardly remember when models, inputs and outputs, and feedback did not exist. But more related to my dissertation was the second fruitful interdiscipline of decision science, or how people and institutions do or should make decisions. From it I was able to draw on and use new concepts of risk and probability (5), decision making under uncertainty (6), and, most important, Simon's bounded rationality (7), choosing particularly those concepts that seemed to broaden the narrow focus of neoclassical economics with its assumptions of almost perfect knowledge and utility-maximizing behavior.

Why do They Live There?

Thus, in the summer of 1961, I came to LaFollette, Tennessee, then with a population of 7200, and through the center of which ran Big Creek, which had last flooded in 1950. As our team of graduate students began a series of interviews and observations related to White's larger study (8), I was reminded that (3, p. 135) "[a]lmost anyone who has studied flood problems has been asked, usually informally, the perennial query, 'But why do they live there?' The question ought not to be taken at face value. People live and work in flood plains for a variety of locational reasons including certain intrinsic advantages to flood plain location. Therefore, the question might better be rephrased as follows: 'Why do people persist in living and working in areas subject to repeated flood?'"

Over the course of the summer and after conducting extensive interviews, we elicited a set of reasons why flood plain users or residents did not seem unduly concerned about floods despite the opinions of technical personnel or even repeated flood experience. These ranged from simple ignorance to various expectations that the respondent would not experience a future flood or bear a serious loss.

Generalizing, I wrote, "This is a major finding of the study. In the face of community knowledge and experience, there is a variety of personal perceptions of hazard and potential loss that rationally leads managers to ignore flood hazard. A second major finding is that there is strong evidence for an underlying orderliness in the proportion of managers that hold a particular perception in any small urban area. It seems likely that a certainty-uncertainty scale, measuring in part the perceived frequency of flooding at a place, accounts for this observed order" (3, p. 136).

What Should We Worry About?

More than a decade would pass before I returned to the question of why people live in hazard areas and to ask in a larger sense, what should we worry about? In the interim, Ian Burton, Gilbert White, and I had been involved in studies of human response to storms, hurricanes, earthquakes, droughts, snow, and floods in the United States (9–13), as well as drought in East Africa and Australia and floods and tropical cyclones in South Asia (14). Returning from Africa to the United States in 1972, I found my colleagues at Clark University, especially Chris Hohenemser and Roger and Jeanne Kasperson, beginning to study human response to technological hazards (15). Along with psychologists Paul Slovic and Baruch Fischoff, we sought to make sense of the huge array of technological hazards. We found that hazards as varied as handguns and food coloring can have their risks assessed and compared in terms of fundamental releases of energy, materials, or information (16). But if even for risk assessors there is still no consensual agreement on comparative risk assessment, the public plight is much more difficult.

As an early participant in the emergence of the new quasi-discipline of risk assessment (17), I returned to my LaFollette thoughts with this greater experience and developed a generic hypothesis. "Stated as the 'worry-bead' hypothesis, individuals and societies have a small, relatively fixed stock of worry beads to dispense on the myriad threats of the world. They are not irrational, but are constrained in their rationality either by human limitations of cognition and judgement; by cultural, ideological or personal aversions toward certain risks and the discounting of others; by ignorance, misunderstanding or limited experience; or by the sheer number and complexity of threats to cope with. The societal capacity to worry intelligently exceeds that of individuals and it is possible to divide the labor and the anxiety. But even this expanded capacity, in this view, is less than the threats perceived, and to both individuals and societies, where and when to rub one's worry beads is baffling and difficult to rationalize even if desired" (18, p. 251).

How do We Survive, Even Prosper?

But whatever our worries, what should we do about them? How do we not only survive the myriad risks we worry about but also prosper whether we live in Big Creek, in the shadow of the Three Mile Island nuclear plant, or in the warming, more populated world of the future. A key seems to be the concept of human adjustment (or adaptation), first propounded some 60 years ago and published in what might have been the most influential dissertation in geography (19).

In his dissertation, *Human Adjustment to Floods: A Geographical Approach to the Flood Problem in the United States*, [Gilbert White] defined adjustment as . . . '"the human process of occupying or living in an area and the transformations of the initial landscape which result.' Never comfortable with abstractions, White went on to specify at least eight forms of human adjustment to floods: elevating land, abating floods by land treatment, protecting against floods by levees and dams, providing emergency warning and evacuation, making structural changes in buildings and transportation, changing land use to reduce vulnerability, distributing relief, and taking out insurance" (20, pp. 87–88).

In study after study, hazard analysts, primarily geographers, extended the concept to a variety of natural and technological hazards, demonstrating the myriad adjustments people and societies had made to survive and even prosper while living with recurrent hazards. It was these adjustments or adaptations that made possible the fruitful occupance by human societies of an enormous range of environmental settings. These analysts also found that although adjustment was common, it was rarely optimal (8); that societies in transition were particularly vulnerable to hazard (14); and that within societies even with a broad range of adjustment, individuals, groups, or locations that were impoverished or marginalized had little access to the full range (21). In time, we were able to conceptualize the causal structure of hazards (22) by separating and then linking causes, events, consequences, and human adjustment responses. We were then able to identify new or little-utilized opportunities for societal intervention to reduce or mitigate the threats (Figure 1).

A further step was to apply the causal structure of hazards to such multicausal threats as global climate change (23) and hunger (see below) and to include interactions between links in the causal chain across areal scales. The work on global climate change is a work in progress (23a) at four sites in the United States. At each site—southwest Kansas, northwest North Carolina, northwest Ohio, and central Pennsylvania—Tom Wilbanks, Rob Abler, and I, along with colleagues from six universities, try to understand the local causes or driving forces of trends in greenhouse gas emissions and what local people and firms might do, and are willling to do, to abate them.

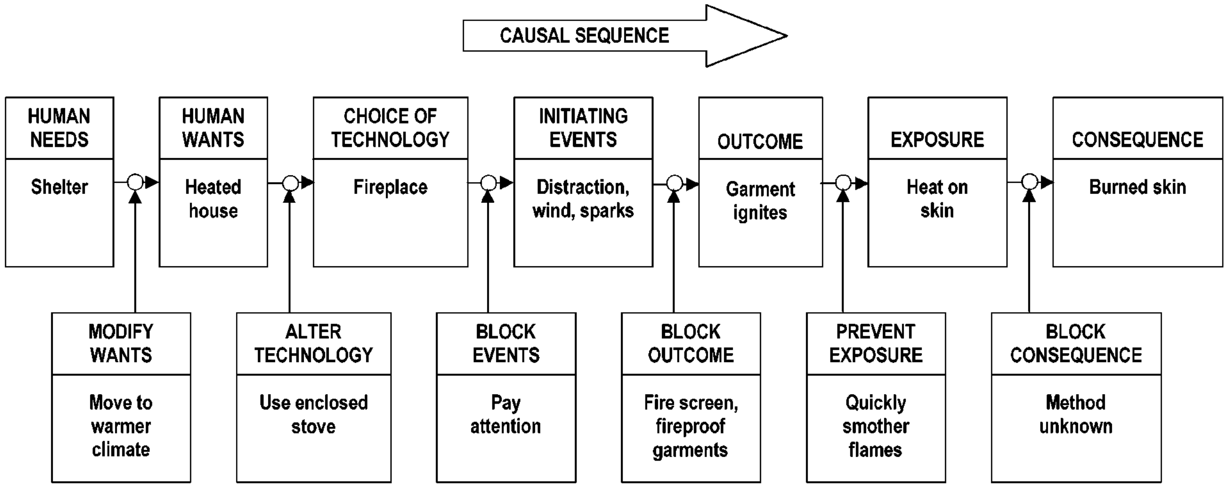


Figure 1 An example of a causal structure of a fireplace hazard beginning with human need for shelter and warmth and ending with a first-order consequence of a burn (22, p. 29). Each link in the causal chain provides an opportunity to intervene and truncate the sequence or reduce the harm.

ENDING HUNGER

In 1967, I made a sharp shift in focus, when the Rockefeller Foundation asked me to move to Tanzania to become the first director of the Bureau of Resource Assessment and Land Use Planning at the University of Dar es Salaam. With a focus on research applications in support of the development activities of government, the Bureau would be a familiar institution at an American land grant college. But along with a counterpart bureau in economics, it was a novel institution in the context of a British-Canadian–style educational system.

Our 3 years in Africa were important not only professionally but for our family as well. There we learned from East Africans the values of extended family, of dignity amid poverty, and of humor in the face of adversity. We experienced on campus a multicultural community of 21 nationalities; in school, my 3 children felt the warmth of their classmates even as they constituted a tiny minority; in neighboring villages, my wife learned Swahili from the primary school students she tutored in English; and everywhere, we experienced both cultural differences and the universality of humankind.

It was in Tanzania that I was first introduced to the links between environment and development as, along with Len Berry, the Professor of Geography, we undertook studies of development activities in water resources, village settlement, soil conservation, and regional planning. But it would be 3 years before I was able to pursue my earlier questions, with a comparative study of drought in Australia and Tanzania (14), and drought adjustment on the road from Mombo to Kulasi (24).

"From Mombo to Kulasi, a crow would fly the 40 kilometers (25 miles) in 3 hours, a Land Rover would labor all day, and a bus would not attempt it. Along the way the landscape shifts from dry open woodland to moist woodland, to rain forest, to dry open woodland again; the elevation more than triples . . .; the annual rainfall doubles . . .. Cutting across the western Usambara mountains of northeast Tanzania with its dense . . . smallholder farming population, [we sought] . . . a very short transect across a homogeneous population . . . to relate the variations in environmental opportunity to the well-being of the population, the adaptive capacity of local agricultural systems, the drought-hazard experience, and the adjustments undertaken to minimize drought impacts" (24, p. 105).

In Mombo I also met my first nutritionists, a German medical team, and first began to consider the links between nutrition and well-being. Fifteen years later, the road from Mombo to Kulasi would take me from Clark University to Brown University to begin a new program on world hunger.

Brown had been offered funding by a local philanthropist to address hunger, and a member of the faculty committee thought that hunger could be innovatively studied as a risk. Searching for risk assessors with development experience, they found me. Reluctant to leave Clark and overwhelmed by the magnitude of the hunger problem, I wrestled with this new query of why hunger persists amid a world of plenty and the willingness of a major university to seriously consider it. At the end, what tipped the balance of decision was the MacArthur fellowship award that I had received some years earlier. Its generous 5-year support was intended to free grantees to follow their creative inclinations, including new directions and challenges. Deeply grateful for having received it, I thought I could do no less than accept this new challenge.

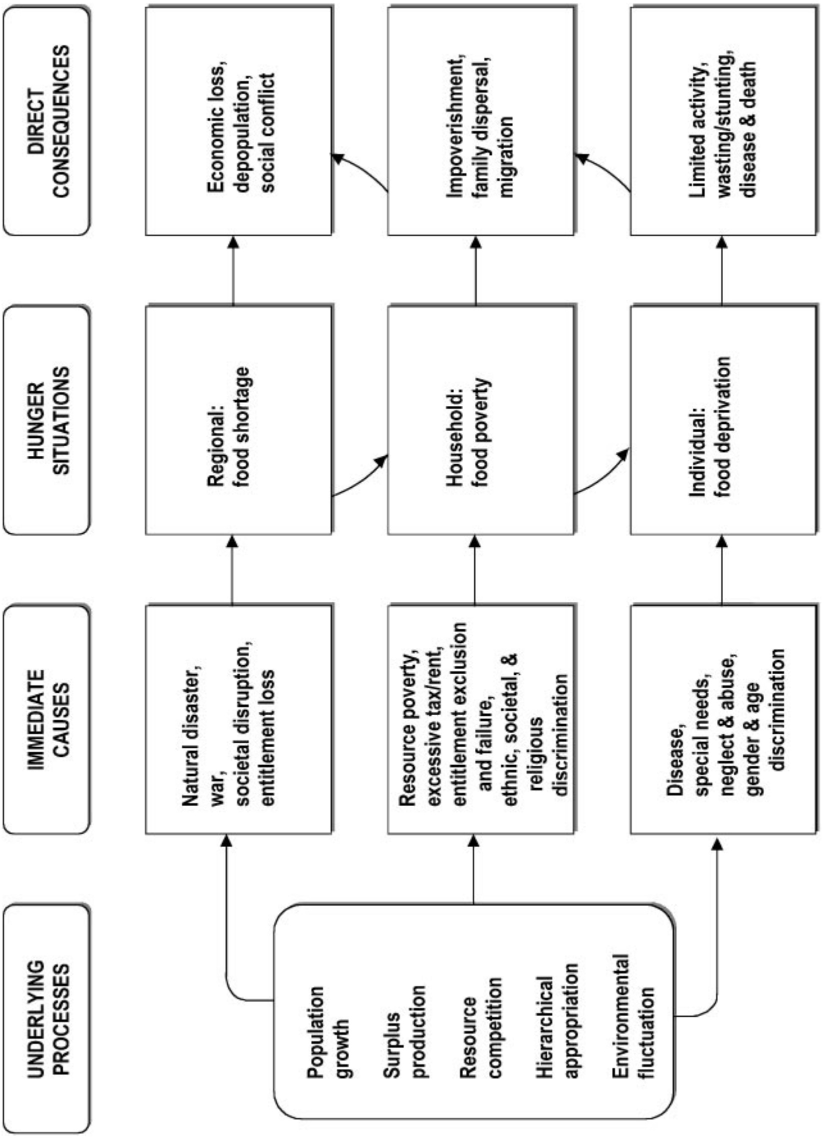
Looking back, the Alan Shawn Feinstein World Hunger Program made at least three significant contributions to the age-old task of understanding and eliminating hunger. It created a causal model of hunger that incorporated diverse perspectives on the causes, conditions, and scale of world hunger. It elaborated and documented that model with the first attempt to sketch a comprehensive history and prehistory of hunger. And it helped create a knowledge-action collaborative, bringing together diverse thinkers and doers to propose a realistic program to cut hunger in half—a seemingly audacious proposal in 1989 and now a commonplace aspiration.

Why Is There Hunger?

The very interdisciplinary group of scientists and scholars that the Program brought together (Bob Chen, Joy Csanadi, Tom Downing, Goran Hyden, Jeanne Kasperson, Ellen Messer, Sara Millman, and Peter Uvin) found in hazard modeling a conceptual framework that bridged the three common and often conflicting hunger communities. Two of these communities focus on the causes of hunger—one on actual food shortage and the other on broader socioeconomic forces. The third focuses on the consequences of hunger mainly seen as starvation, undernourishment, or illness. Hazard modeling provided a framework that introduced some analytic rigor, distinguishing between hunger and its causes and consequences, seeking to identify and document plausible chains of causation to explain the persistence of hunger. Such a framework contains a probabilistic element that mirrors the complexity and uncertainty of the real world—not all food shortage leads to hunger; not all hunger causes starvation; not all starvation leads to death. And most important, by identifying a chain of causation with multiple links, each link offered an opportunity to break or interrupt the chain by taking deliberate action to prevent hunger or to reduce its consequences.

But the Brown study group extended the traditional risk and hazard approach in two important ways (see Figure 2). It introduced scale to the usual singular linear model of cause and consequences, distinguishing between the three hunger situations of regional food shortage, household food poverty, and individual food deprivation with distinctive causes and consequences. For each, it sought to identify a set of underlying processes that lead to the immediate or proximate causes. And of course it included the myriad ways in which individuals, groups, and regions adjust or adapt to hunger (not shown in Figure 2).

"In sum, there is a chain of causation that begins with the long-term trends in productivity, numbers of people, economic specialization, and surplus appropriation. The chain leads via specific instances of interference with food supply or failure of access to supplies (the immediate causes) to hunger for individuals, groups, or entire populations . . . [to] the situations of food shortage, poverty, and


UNDERLYING PROCESSES
Population growth
Surplus production
Resource competition
Hierarchical appropriation
Environmental fluctuation
IMMEDIATE CAUSES
Natural disaster, war, societal disruption, entitlement loss
Resource poverty, excessive tax/rent, entitlement exclusion and failure, ethnic, societal, & religious discrimination
Disease, special needs, neglect & abuse, gender & age discrimination
HUNGER SITUATIONS
Regional: food shortage
Household: food poverty
Individual: food deprivation
DIRECT CONSEQUENCES
Economic loss, depopulation, social conflict
Impoverishment, family dispersal, migration
Limited activity, wasting/stunting, disease & death

deprivation, and the consequences of hunger for individuals, households and regions. . . . These [consequences] include, at the individual level, limits on development and activity, illness, and death; and for the households and other groupings, a range of impacts. . . . To cope with these consequences, societies develop adaptations that affect the long-term trends and short-term adjustments that include use of alternative foods, stocks, other sources, exchanges, and gifts" (25, pp. 13–14).

We also introduced a temporal scale by bringing together two dozen Brown scientists and scholars and invited experts in four study groups. Each group addressed the history or prehistory of hunger in one of four periods: ages, millennia, centuries, and decades (26). For each period, they described what was known about the regional, household, and individual conditions of hunger, their causes and consequences, and specific adjustments and adaptations, even though the nature of evidence and the disciplinary standards of knowledge differed greatly across periods. They found, not surprisingly, that "[t]he history of hunger was for the most part unwritten. The hungry rarely write history and historians are rarely hungry" (25, p. 22).

With this framework and documentation, how was the query as to the persistence and prevalence of hunger in a world of plenty answered? A paragraph-length answer describes a changing multicausal structure.

"Hunger appears when environmental change or deterioration limits what can be produced, when agricultural productivity declines or slows, when population numbers grow too quickly relative to food production, and when those in power appropriate too great a share in agricultural production or maintain large numbers at the margin of existence. These underlying causes endure, but the mix of proximate causes appears to change in important ways. Over time, natural variability as a cause of hunger diminishes, and other forms of entitlement failure come to predominate. Hunger created in the course of warfare persists, even as the scale and technology of warfare change. And while absolute scarcity [of food] diminishes, the enlargement of scale, so important to the reduction of scarcity, continues to make places marginal and makes possible catastrophes of enormous size, when errors in food-system management occur" (27, p. 399).

Can We Halve Hunger?

Then in November 1989, the Feinstein World Hunger Program helped organize a major nongovernmental initiative, "The Bellagio Declaration: Overcoming Hunger in the 1990s." Its four goals were to eliminate deaths from famine,

Figure 2 The causal structure of regional, household, and personal hunger with both immediate causes and the underlying processes that lead to them (25, p. 14). The hunger situations cascade down from region to individual and the consequences aggregate upward from person to region. For each cause, situation, and consequence there are appropriate adjustments or interventions (not shown in the diagram).

to end hunger in half of the poorest households, to cut malnutrition in half for mothers and small children, and to eradicate iodine and vitamin A deficiencies (28). Together, these goals comprised a comprehensive yet practical program to end half of the world's hunger in a decade by building on the better and best of existing programs and policies for overcoming hunger (29). The most promising programs, the Declaration found, are those that empower people to assess their own condition and to act on their own behalf, that provide short-term hunger relief while addressing deeply rooted causes, and that can be sustained over the long term.

The notion of eliminating some forms of hunger while cutting chronic hunger in half rapidly took hold in a series of international meetings, beginning with the World Summit for Children in 1990 (30) and culminating in the World Food Summit in 1996 that called for reducing the number of undernourished people by half by 2015 (31). Of the four original Bellagio goals, famine deaths have been virtually eliminated except in the presence of war and civil conflict, and major progress has been made in reducing iodine and vitamin A deficiencies. Progress in cutting malnutrition for mothers and children has been made in some regions but not in others. The numbers of underweight young children in Africa and South Asia are still growing. The most difficult goal is halving hunger among the 800 million who live in households too poor to obtain the food they need (32, 33). Yet the proportion of chronically hungry people in the world had by 1996 been almost halved in two decades (from 35% to 19%). China halved the number of poor households within the decade from 1982 to 1992 with effective social mobilization, increased food production, and economic growth (34). Reviewing this goal and other international consensual goals for education and housing, the US National Research Council Board on Sustainable Development recently proposed halving the unmet human needs of food, nurture, housing, education, and employment in each of the two generations between now and 2050 (35).

Beyond halving hunger, can we end hunger? It is possible to visualize the world of the coming century without famine, with little seasonal or chronic undernutrition, and with virtually no micronutrient deficiencies and nutrient-depleting illness. "To put a lasting end to hunger . . . there must not only be plenty of food, but food produced in ways that are environmentally sustainable, and assistance in providing increased income for those who are poor. To end famine requires not only a surplus of food and a willingness to distribute it in times of emergency, but also a widespread recognition of the human right to food, and effective mechanisms to prevent armed conflict. To reduce undernutrition to a minimum, the world must not only be more wealthy, but also more willing and able to provide food entitlements as needed to poor and vulnerable groups. To end the wasting and stunting of children and the exhaustion of their mothers requires sufficient spacing between children to allow for their own and their mothers' nutrition, and that allows for society's ability to provide the needed services, education, and jobs to support those who are born. To virtually end micronutrient deficiencies and nutrient-depleting illness requires not only more diverse diets, but also the income to support widespread access to adequate sanitation, safe water, public health and primary care services, including immunization and nutritional and health education.

"A permanent end to hunger will also need to address the great global changes now underway in environment, population, economy, and world order. The focus on women that has emerged from the 1994 Cairo Conference on Population and Development . . . can hasten the end of maternal anemia and child wasting and stunting. The painful but inexorable restructuring of the global economy may provide new sources of income to many parts of the world. The vision of sustainable development arising from the 1992 Rio Conference on Environment and Development can only encourage the effort to create a sustainable, but much enlarged food production system. The efforts to strengthen the United Nations and for collective action for human rights and international order can make the elimination of famine more feasible. . .. The rudiments of ending hunger are in place" (36, p. 11).

SUSTAINING LIFE ON EARTH

As I pondered an end to hunger, the question of sustainability was already on my list. The editors of *Scientific American*, preparing a 150th anniversary issue of the magazine in 1994, posed to me a truly grand query: Can life be sustained on earth? My answer (37) drew on work on two earlier questions: the persistence of the Malthusian dilemma, and how humans have transformed the earth.

Why does the Malthusian Dilemma Persist?

"All of us who ponder the questions of the human environment are the intellectual descendents of Thomas Robert Malthus. Whether 'neo-Malthusian', 'anti-Malthusian', or simply agnostic, we explore the equation of population with resources and technology, which distills the problem of the human environment" (38, p. 45). Ian Burton and I, just out of graduate school and putting together a reader on resource management and conservation felt very much his intellectual descendents. Thus, we began the volume with the following (39, pp. 7–8): "In 1798 Thomas Malthus, an English clergyman and teacher of political economy, published his *Essay on the Principle of Population*. Malthus' main thesis was that population always tends to increase up to the limits of the means of subsistence, which is controlled ultimately by the finite limits of the earth. . .. Was Malthus right?"

Malthus was not right, but Malthusian concerns persist. Over time, the focus of Malthusian concerns has shifted (Figure 3) (40). In 1798, the key ratio in the Malthusian equation was food and farmland per person. By the 1850s, the resource term expanded to include energy and other materials, urgently argued in the classic volume of British economist William Jevons (41) on the coal question. By the middle of the twentieth century, the United States would discount fears about resource scarcity and promote a new Malthusian numerator that included amenity

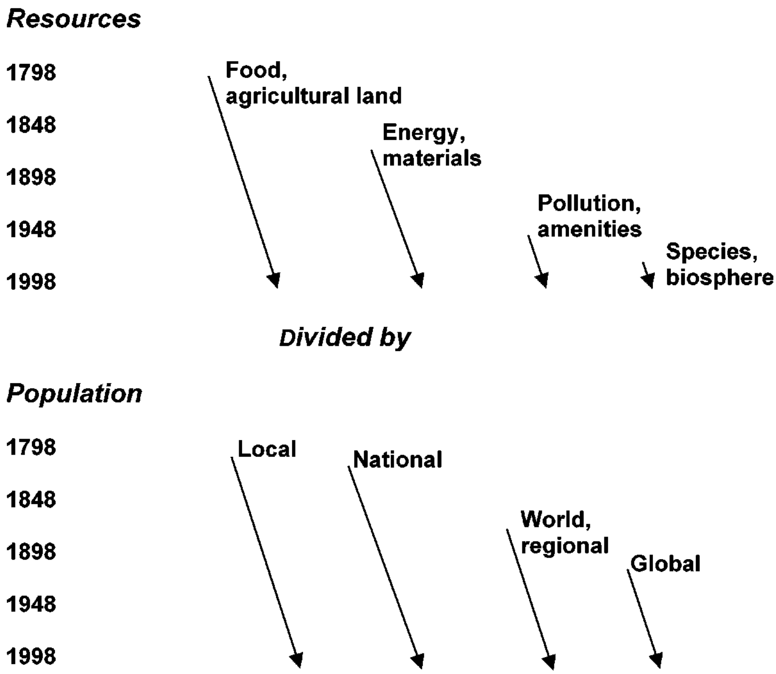


Figure 3 Over time, the Malthusian equation of resources divided by population changes (40, p. 345). The concept of resources changes from food and agricultural land to also include energy and materials, and more recently environmental concerns, while the population denominator increases from the local to the global population.

resources and the pollution-absorbing capacity of the environment (42). The UN Stockholm Conference on the Environment in 1972 enlarged such concerns to a global scale and drew attention to the basic life-support systems and the chemical cycles of the biosphere. More recently, losses in the diversity of life and genetic information have joined the earlier concerns.

"Characteristically, none of the earlier Malthusian concerns really disappear but are renewed in some larger, more international context. And for each of the different notions of critical resources, technology will make possible new reserves and new substitutions and in turn, cause new problems. Thus a continuous process of Malthusian refutation and renewal has marked the two centuries since publication of the Essay. In my own professional life, I have participated in two and a half cycles of research and argument. Currently [in 1994], I am trying to understand the roles of neo-Malthusian scientific 'Jeremiahs' and society's response to them by examining the post World War II history of jeremiads [see (43)], beginning with Vogt's [see (44)] and Brown's [see (45)] concerns with population growth, moving on to subsequent fears about food, materials, and energy availability, and the effects of toxic pollutants, and concluding with the formal synthesis of concerns in *The Limits to Growth* [see (46)].

"Over time, the population denominator has increased from a local to a national, regional, and then global scale. The requirements of each person also changes over time, from the meager demand typical of Malthus' day, to the copious consumption of the wealthy fifth of the present world population [see (47)]. Contrasts with the modest per capita usage of most residents of the less-industrialized countries show how levels of affluence and types of technology modify the Malthusian equation (38, pp. 45–46). [See (48).]

"Many of us believe that if only population growth can be held to some reasonable number, then sufficient food can be produced, even in a more crowded and warmer world. Yet this hopeful view has to grapple with two likely, connected realities: while population may more than double, production and consumption should more than double" (38, p. 64).

"We appear to be about halfway in numbers into the third great population surge, and the good news from the ages is thus some relief may lie ahead, albeit in a century or so. Twentieth-century population and consumption growth is totally unprecedented in human history, and the bad news from the millennia is that great civilizations failed to maintain much smaller rates of growth in the past. We also have no news, especially from the centuries: our science can observe but not readily explain past and existing interactions of population, technology, and resources. But like Malthus, we have theories" (38, p. 67).

How has the Earth Been Transformed?

If Malthusian concerns never seemed to be resolved except in theories, discerning the impacts of growing numbers of humans and their extensive habitation, production, and consumption on the natural systems that support human life seemed an empirical question. "Concern about such effects has a history that extends back at least a century and a half. . .. As early as 1864, George Perkins Marsh published a benchmark assessment, *Man and Nature*; *or, Physical Geography as Modified by Human Action* [see (49)]. A subsequent account entitled *Man's Role in Changing the Face of the Earth* was undertaken in 1956 [see (50)]. The most recent study, *The Earth as Transformed by Human Action*, was published in 1990 [see (51)].

"An international collaborative effort, the Earth Transformed Project [led by Billie Turner] was seven years in the planning and execution. It brought together leading scientists from 16 countries to document global and regional change over the past 300 years. We were able to reconstruct human-induced change in 13 worldwide dimensions of chemical flow, land cover, and biotic diversity: terrestrial vertebrate diversity, deforested area, soil area loss, sulfur releases, lead releases, carbon tetrachloride releases, marine mammal populations, water withdrawals, floral diversity, carbon releases, nitrogen releases, phosphorus releases and sediment flows.

"The investigators took stock of the extent of human impact, emphasizing in particular the past 300 years. To place current changes in long-term perspective, we estimated human influence on the earth over the past 10,000 years since the dawn of agriculture. In that time, humans have deforested a net area the size of the continental U.S., mostly using it for cropland. Water, in an amount greater than the contents of Lake Huron, is withdrawn every year from the hydrosphere for human use. Half the ecosystems of the ice-free lands of the earth have been modified, managed, or utilized by people. The flows of materials and energy that are removed from their natural settings or synthesized now rival the flows of such materials within nature itself" (37, pp. 116–17).

As shown in Table 3, most of this change has been recent. In 10 of the 13 changes, half of the total human-induced change accumulated in our lifetimes, and 7 have essentially doubled after 1950. Many of the changes continue to accelerate, but there are five notable exceptions that have all been subject to strenuous regulation.

Will Life be Sustained?

In 1994, in the invited article in *Scientific American*, I answered thusly (37): "If life is simply organic matter capable of reproducing itself, then the answer is almost assuredly 'yes.' Through the ages, life on earth has survived repeated catastrophes, including atmospheric change, the submergence and reemergence of continents, and collision with asteroids. Life will almost surely go on at least until the final 'dimming of the light' of a cooling sun. But if life on earth is life as we know it, the mix of living things that fill the places we are familiar with, then the answer is almost assuredly 'no.' For human-induced modifications to the environment, including to the global biogeochemical and hydrological cycles, rival nature's changes to the earth. Most of the transformations of the past 10,000 years have occurred in our lifetimes, as humans continue to alter their environment in increasingly diverse ways.

"If by life we mean us, our species and the life that supports us, then the answer is 'perhaps.' For humans, life has never really been simply a progression

TABLE 3 Recency of human-induced changes over 10,000 years for selected environmental indicators[a]

Half of total change	Rate of change still accelerating	Rate of change now decelerating
Occurred before our lifetimes	Forest area loss Soil area loss	Terrestrial vertebrate diversity
Occurred within our lifetimes	Carbon release Nitrogen release Phosphorus release Floral diversity Sediment flows Water withdrawals	Carbon tetrachloride releases Lead releases Sulphur releases Marine mammals

[a]From Reference 51.

onward and upward from the cave. Our numbers have grown by fits and starts, our civilizations have declined and fallen, and even our physique has fluctuated over time. But since the middle of the last century our population has quadrupled, and projections from the United Nations and the World Bank [in 1992] suggest that it will at least double again by the middle of the next century. Economic activity amplified by technology has already transformed the earth.

"What will be the impact of such numbers of humans, their rapidly changing patterns of habitation and their growing production and consumption, on the natural systems that support life? If we can manage the transition to a warmer, more crowded, more connected but more diverse world, there may be promise of a environmentally sustainable future" (37, pp. 114–15).

Will There be a Sustainability Transition?

The opportunity to consider a sustainability transition came in 1995 as I became vice-chair of the US National Academy of Sciences–National Research Council Board on Sustainable Development. With Shere Abbott, our executive director, Bill Clark, who cochaired the study, and the other members of the Board, we began a 4-year effort to ask what a transition might entail and how science and technology might assist in navigating such a transition. Over this period, the Board, with the help of a large number of participants in summer studies, workshops, and report reviews, defined a sustainability transition in terms of normative goals, identified major trends and the threats and opportunities they posed to a sustainability transition, assessed the methods and indicators to explore the future, and identified initial priorities for both research and action. These findings are available in a report (35) and have been further considered and elaborated at a meeting of the World Academies of Science in 2000 (52) and at a recent workshop on sustainability science (53).

"We see the sustainability transition as one in which the world must provide the energy, materials, and information to feed, nurture, house, educate, and employ many more people than are alive today—while reducing hunger and poverty and preserving the basic life support systems of the planet. Our interest in focusing on the transition over the near long-term, the coming decades in which we anticipate the greatest stress of numbers of people, extraordinary increases in energy and material throughput, and institutions just learning to cope with many new and unexpected problems, flows from our scientific understanding of trends and problems. But our judgement as to the three-fold definition of a successful transition: meeting human needs, reducing hunger and poverty, preserving life-support systems, is a normative one, both scientific and moral.

"Our science can tell us what is needed to feed, nurture, house, educate, and employ; what imperils life support systems; and how societies cannot sustain themselves over the long-term with deepening divisions in well-being. . . But to accept the burden of meeting the human development needs of unborn generations, to provide the minimal necessities to reduce hunger and poverty, and to sustain the natural world that sustains us is a moral choice for which we scientists have no special aptitude beyond our common humanity. Fortunately for science, it is not a choice we make alone, but is one made repeatedly in global conferences and world summits that choose international targets to meet human needs. These targets, some overly optimistic, do suggest that it is possible, albeit difficult, to cut hunger, child mortality, illiteracy, and the unmet needs for clean water and sanitation by half in each of the next two generations" (54, pp. 31–32). But the progress at this point is not encouraging.

"In our National Academy report [see (35)] we drew upon the various Rio + 5 assessments to note the slow pace or outright failure to implement the original Bruntland and Rio agendas on sustainable development. Our report concluded:

'As the 20th century draws to a close, however, the difficulties of actually delivering on the hopes that people around the world have attached to the idea of sustainable development have become increasingly evident. In part, these difficulties reflect political problems, grounded in questions of financial resources, equity, and the competition of other issues for the attention of decision makers. In part, they reflect differing views about what should be developed, what should be sustained, and over what period. Additionally, however, the political impetus that carried the idea of sustainable development so far and so quickly in public forums has also increasingly distanced it from its scientific and technological base. As a result, even when the political will necessary for sustainable development has been present, the knowledge and know-how to make some headway often have not'" (35, p. 2).

"As we look forward to a Rio + 10 stocktaking [2002] on the progress of sustainable development, the National Academy report [see (35)] and the recent World Academies meeting [see (52)] offers three sets of insights that provide some of this needed knowledge and know-how and can also reinvigorate the participation of science and technology in achieving a sustainability transition.

"The first is to take advantage of the demographic transition nearing conclusion to focus on a sustainability transition for the next two generations rather than the ambiguous sustainable development time horizon "now and in the future" found in the Bruntland report [see (55)]. For our 50-year time horizon, concrete targets for both environment and human development have been widely accepted. To explore these, scenarios, integrated assessment models and other scientific analyses are feasible as many of the currents of change to work with or to avoid are now evident.

"Second, we already know enough to pursue definable and measurable goals in six crucial areas. A population in 2050 with a billion less people than currently projected is readily feasible. Demographers link the [population] growth over the . . . [century] to three causes: the unmet need for contraception by families willing to use it, the still-too large desired family size, particularly in Africa and South Asia, and the extraordinary large numbers of young people in developing countries of reproductive age [see (56)]. For each of these causes, there is a wealth of experience in addressing them.

"Other directions include food production, where it is needed most—to accommodate the rapid population growth in Africa. Or develop the next generation of technologies that use less materials and are more efficient in energy production and use. Extend globally the basic framework of protection for work and environment that makes trade not only efficient but just. Develop the managed half of the world's ecosystems in ways that continue to provide the vital ecosystem services that flow from our life support systems.

"It is also possible to shift consumption to forms that are less resource-depleting or environmentally degrading. There is growing experience with . . . encouraging such substitution and its difficulties: renewable for non-renewables, toxics with less-toxics, ozone depleting chemicals with more benign substitutes, natural gas for coal. Perhaps most important in the long run, but possibly least studied, is the potential and value of substituting information for energy and materials.

"[A] most important initiative is to use the opportunity of the hundreds of new and expanded cities, more than half of which will be in Asia. The challenge that faces the planners, designers, builders, and financiers of those expanded cities is to achieve settlement patterns that make efficient use of land and infrastructure and impose reduced burdens on material and energy use while providing satisfactory levels of living. To do so, we needed to bring together the science and technology of habitability, efficiency, and environment, much of it hidden away under disciplinary covers, with the practice of planning, building, and financing the cities of tomorrow. But the trinity of goals of habitability, efficiency, and environment are separately reproduced in different practitioner organisations, academic disciplines, government agencies, and even UN organisations. And absent from these are the most important: the speculators and developers transforming the face of many Asian cities. But if we can bring them together in new knowledge-action collaboratives, the opportunity to replace and create anew much of the current infrastructure over the next two generations is a key to a sustainability transition."

"Finally there is a [third insight, the] need to change science itself, to go beyond what we already know and expand the world's capacity system for discovering new things" (54, pp. 32–34).

SUSTAINABILITY SCIENCE: AND STILL MORE QUERIES

Thus it was in Tokyo in May 2000, in a remarkable assemblage of the World Academies of Science (52), I had the chance to present the Board's vision of the emergent science needed to support a transition toward sustainability. The Academies of the world differ as much as the countries in which they are based, ranging from essentially honorific societies to major national research institutions. But here there were representatives of 52 national academies, large and small, all sharing a concern with a transition toward sustainability. "Sustainability science," a label suggested by Bruce Alberts, President of the US National Academy of Science, was already "in the air"—our Board had only sought to give structure to a widely felt need.

Thus I said: "In the last quarter century, four related, sometimes overlapping, but distinct research-based programs relevant to sustainability have developed: biological research emphasising the intertwined fates of humanity and the natural resource base on which it depends for sustenance; geophysical research focusing on the earth as a system with interconnections among the earth's climate and biogeochemical cycles, including their response to perturbation by human activities; social research, focusing on how human institutions, economics systems and beliefs shape the interactions between societies and the environment; and finally technological research, concentrating on the design of devices and systems to produce more social goods with less environmental harm. Already these have come together in what is loosely called 'global change' science.

"Sustainability science would need to be broader yet, spanning the individual branches to ask how, over the large and the long, the earth, its ecosystems and its people could interact for mutual sustenance. Our report [see (35)] does not describe the precise paths such science would take or if indeed do we know whether this ambitious rubric—sustainability science—would ever take hold. We did conclude though that many of the most problematic threats to people and their life support systems arose from multiple, cumulative, and interactive stresses resulting from a variety of human activities.

"Thus sustainability science had to be above all else integrative science committed to bridging both the barriers separating the traditional scientific disciplines and the sectoral distinctions between interconnected human activities. It would also need to integrate across geographic scales to eliminate the sometimes convenient but ultimately artificial distinction between global and local perspectives. In short, if there was no longer much doubt about whether integrative approaches to research were needed in support of a sustainability transition, how to achieve such integration in rigorous and useful research programs remained problematical. In trying to answer this question, my colleagues adopted an approach long pursued by geographers and increasingly by ecologists: integrating research for sustainability not around particular disciplines or sectors, but around the study of interactions in particular places or regions" (54, p. 34).

To take these ideas further, two dozen scientists, drawn from the natural and social sciences and from across the world, convened at Sweden's Friibergh Manor in October 2000 (53). The workshop formulated an initial set of core questions that examines the character of nature-society interactions and our ability to encourage and guide those interactions along more sustainable trajectories over the generations to come (see Table 4).

These coming generations are not abstractions for me but are encapsulated in the already meaningful lives of my six grandchildren, the eldest of whom will be only 70 in the year 2050. Indeed, what all grandparents know, and in contrast

TABLE 4 Core questions of sustainability science

To clarify and encourage the development of science in support of a sustainability transition, the Friibergh Workshop created an initial set of research questions addressed both to the interactions between nature and society and ways to encourage and guide a transition.
How can the dynamic interactions between nature and society—including lags and inertia—be better incorporated in emerging models and conceptualizations that integrate the earth system, human development, and sustainability?
How are long-term trends in environment and development, including consumption and population, reshaping nature-society interactions in ways relevant to sustainability?
What determines the vulnerability/resilience of nature-society interactions for particular places and for particular types of ecosystems and human livelihoods?
Can scientifically meaningful “limits” or “boundaries” be defined that would provide effective warning of conditions beyond which the nature-society systems incur a significantly increased risk of serious degradation?
What systems of incentive structures—including markets, rules, norms, and scientific information—can most effectively improve social capacity to guide interactions between nature and society toward more sustainable trajectories?
How can today’s operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition toward sustainability?
How can today’s relatively independent activities of research planning, monitoring, assessment, and decision support be better-integrated into systems for adaptive management and societal learning?

to current economic dogma, the worth of our grandchildren’s generations is as valuable to us as our own. Thus, this self-reflective article ends as it should, with a reflective resume (Table 5), a further set of queries for the years ahead, with collaborators new and old, and with the opportunity to help shape a sustainable world for the generations to come.

TABLE 5 A reflective resume

Reflecting on 40 years of professional work, I find the high points to be a series of empirical studies, comparative analyses, methodological developments, conceptual insights, institutional initiatives, and policies advocacy, listed roughly by date of initiation. Having published with 85 different colleagues and worked with even more, all of this work is the work of many.
EMPIRICAL STUDIES Because I was trained in geography, a field-oriented observational discipline, my basic unit of inquiry has been the empirical field study, combining first-hand observation of an environment with survey research of its inhabitants or users. These have included studies of natural hazard adjustment in many states of the United States and in

(*Continued*)

TABLE 5 (*Continued*)

Australia, Bangladesh, Nicaragua, Tanzania, and West Africa; resource use studies in Tanzania and the United States; studies of environmental perception by inhabitants or users of hazard zones, climate regions, and urban and rural landscapes; and studies of technological hazards, including auto safety, chemical production, and nuclear power and reprocessing.

COMPARATIVE ANALYSES My basic mode of analysis, however, has been to ask large but relatively well-focused questions, and then to organize and employ a set of comparative observations, seeking generic answers. Over time, the questions have grown larger, and the methods have became more varied, moving from cross-sectional field study, to creation of large data sets, to historical reconstruction and analysis. Throughout, there is a preference for seeking an appropriate “natural” experiment, a set of imperfectly controlled, but suggestive, comparative observations or analogs.

Together with many others, we have compared natural hazard loss, perception, and adjustment in 20 countries; developed a taxonomy of 93 technological hazards; reconstructed the past 6000 years of population growth and decline in four regions; explored the causes of underdevelopment among 25 least-developed countries; identified and assessed the impacts of climate changes across the United States and the emissions of greenhouse gases at four sites; taken stock of the past 300 years of human-induced global environmental changes; reconstructed the history of hunger; compared agricultural intensification in population dense areas of Africa; and sought the links between poverty and environment from case studies in Africa, Asia, and Latin America.

METHODOLOGICAL DEVELOPMENTS Characteristic of interdisciplinary research is the need to extend existing or to develop new methods to address emergent societal problems. For example, the need of hazard management, urban planning, and architecture to take into account the perception and knowledge of its residents, users, or clients led to the development of ways of studying “environmental perception.” As the range of hazards expanded, I went on to prepare introductory monographs on risk assessment and, with Jesse Ausabel and Mimi Berberian, on climate impact assessment. As interest in complexity and nonlinear dynamics spread, Bill Clark and I explored ways of constructing future scenarios that are surprise-rich by combining quantitative decision science approaches to eliciting surprising future outcomes with qualitative narratives as to how these might come about.

CONCEPTUAL INSIGHTS I have always been interested in theory but felt that existing theories of either nature, society, or technology did not capture the interactive domain that characterizes the human use of the earth. In searching for conceptual insight, I have drawn flow diagrams and built models, reviewed and organized existing theory, and grasped a few important insights or theories of the middle range. These relate to the nature of hazards and resources, to the interactions between nature, society, and technology, to the prevalence and persistence of hunger, and to the human-induced transformation of the earth.

To take one example from our hazard studies, hazards and resources are uniquely related: People encounter hazard in the search for the useful. For hazards, nature, technology, and society interact to generate both vulnerability and resilience. Thus, there are no uniquely

TABLE 5 (*Continued*)

natural, social, or technological hazards, nor can hazard consequences be meaningfully examined separate from human response. Over time, the thrust of societal development is toward reducing the social costs of hazard to society (lessening hypothesis), but in periods of rapid transition, societies become peculiarly vulnerable to hazard (transition hypothesis). Successful lessening of hazard, however, may serve to increase the catastrophic vulnerability to a perturbation that exceeds the level of adjustment (levee or catastrophic hypothesis).
INSTITUTIONAL INITIATIVES None of the great questions of science or society maps easily onto disciplines, and their consideration requires not only new methods and approaches but also new forms of institutional relationships and collaboration. I have had the opportunity to develop an African university program of resource-related research applied to development policy; to help develop in the United States an interdisciplinary research program on technology, environment, and development; to begin a program of basic research addressed to world hunger; to create low-cost networks that enabled researchers, both north and south, to collaborate and exchange research findings on pests and pesticides, and another on hunger; and, more generally, to encourage meaningful collaboration between the natural and social sciences on the major issues of global environmental change and an emerging effort on sustainability science.
POLICIES ADVOCACY Finally, all the foregoing research should in some small way help change the world. Sometimes these bits and pieces of insight come together to suggest larger policy changes. These have included efforts to include disaster prevention as part of programs of international development and assistance; to make more equitable people's exposure to the hazards of technology; and to have Rhode Island become a national leader in environmental conservation and waste reduction and Maine become one in climate change prevention and adaptation. Most important has been the effort to cut world hunger in half and to encourage a transition toward sustainability.

LITERATURE CITED

1. Wagner PL. 1960. *The Human Use of the Earth*. Glencoe, IL: Free Press

1a. White GF. 1994. Reflections on changing perceptions of the earth. *Annu. Rev. Energy Environ.* 19:1–13

2. Kates RW, Burton I, eds. 1986. *Geography, Resources, and Environment*. Vol. 1. *Selected Writings of Gilbert F. White*. Chicago: Univ. Chicago Press

2a. Kates RW, Burton I, eds. 1986. *Geography, Resources, and Environment*. Vol. 2. *Themes from the Work of Gilbert F. White*. Chicago: Univ. Chicago Press

3. Kates RW. 1962. *Hazard and Choice Perception in Flood Plain Management*. *Res. Pap. No. 78*. Chicago: Univ. Chicago, Dep. Geogr.

4. Bertalanffy L. 1956. General systems theory. *Yearb. Soc. Gen. Syst. Res.* 1:1–10

5. Savage LJ. 1954. *The Foundations of Statistics*. New York: Wiley
6. Edwards W. 1954. The theory of decision making. *Psychol. Bull.* 51:380–417
7. Simon H. 1957. *Models of Man: Social and Rational*. New York: Wiley
8. White GF. 1964. *Choice of Adjustment to Floods*. *Res. Pap. No. 93*. Chicago: Univ. Chicago, Dep. Geogr.
9. Kates RW. 1965. *Industrial Flood Losses: Damage Estimation in the Lehigh Valley*. *Res. Pap. No. 98*. Chicago: Univ. Chicago, Dep. Geogr.
10. Burton I, Kates RW, Snead RE. 1969. *The Human Ecology of Coastal Flood Hazard in Megalopolis*. *Res. Pap. No. 115*. Chicago: Univ. Chicago, Dep. Geogr.
11. Russell CS, Arey DG, Kates RW. 1970. *Drought and Water Supply: Implications of the Massachusetts Experience for Municipal Planning*. Baltimore, MD: Johns Hopkins Univ. Press
12. Kates RW. 1970. Human adjustment to earthquake hazard. In *The Great Alaska Earthquake of 1964: Human Ecology*, pp. 7–31. Washington, DC: Natl. Acad. Sci.
13. Haas J, Kates RW, Bowden M, eds. 1977. *Reconstruction Following Disaster*. Cambridge, MA: MIT Press
14. Burton I, Kates RW, White GF. 1993. *The Environment as Hazard*. New York: Guilford. 2nd ed.
15. Kates RW, ed. 1978. *Managing Technological Hazard: Research Needs and Opportunities*. Boulder: Univ. Colo. Press
16. Hohenemser C, Kates RW, Slovic P. 1983. The nature of technological hazard. *Science* 220:378–84
17. Kates RW. 1978. *Risk Assessment of Environmental Hazard*. *ICSU/SCOPE Rep. No. 8*. Chichester, UK: Wiley Int.
18. Kates RW. 1977. Assessing the assessors: the art and ideology of risk assessment. *Ambio* 6:247–52
19. White GF. 1945. *Human Adjustment to Floods*. *Res. Pap. No. 29*. Chicago: Univ. Chicago, Dep. Geogr.
20. Kates RW. 1977. Human adjustment. In *Ten Geographic Ideas That Have Changed the World*, ed. SE Hanson, pp. 87–107. New Brunswick, NJ: Rutgers Univ. Press
21. Wisner BG Jr. 1977. *The human ecology of drought in Eastern Kenya*. PhD thesis. Clark Univ., Worcester MA
22. Hohenemser C, Kasperson RE, Kates RW. 1985. Casual structure. In *Perilous Progress: Managing the Hazards of Technology*, ed. RW Kates, C Hohenemser, JX Kasperson, pp. 25–42. Boulder, CO: Westview
23. Wilbanks TJ, Kates RW. 1999. Global change in local places: how scale matters. *Clim. Change* 43(3):601–28
23a. Assoc. Am. Geogr. GCLP Res. Group 2002. *Global Change and Local Places*. Cambridge, UK: Cambridge Univ. Press. In press
24. Heijnen J, Kates RW. 1974. Northeast Tanzania: comparative observations along a moisture gradient. In *Natural Hazards: Local, National, Global*, ed. GF White, pp. 105–14. New York: Oxford Univ. Press
25. Millman S, Kates RW. 1990. Toward understanding hunger. See Ref. 26, pp. 3–24
26. Newman LF, Crossgrove W, Kates RW, Mathews R, Millman S, eds. 1990. *Hunger in History: Food Shortage, Poverty, and Deprivation*. Oxford, UK: Blackwell
27. Kates RW, Millman S. 1990. On ending hunger: the lessons of history. See Ref. 26, pp. 389–410
28. The Bellagio Declaration: overcoming hunger in the 1990s. 1990. *Food Policy* 15:352–58

29. Brown Univ. Faculty. 1990. Overcoming hunger: promising programmes and policies. *Food Policy* 15:286–98
30. United Nations. 1990. *The World Summit for Children*. New York: UNICEF
31. World Food Summit. 1996. *Rome Declaration on World Food Security and World Food Summit Plan of Action*. Rome: FAO
32. Shane M, Teigen L, Gehlar M, Roe T. 2000. Economic growth and world food insecurity: a parametric approach. *Food Policy* 25:297–315
33. Hanmer L, Healey J, Naschold F. 2000. *Will Growth Halve Global Poverty By 2015? Poverty Brief. 8*. London: Overseas Dev. Inst.
34. Uvin P. 1996. The state of world hunger. In *The Hunger Report: 1995*, ed. E Messer, P Uvin, pp. 229–45. Amsterdam: Gordon & Breach
35. Natl. Res. Counc., Board Sustainable Dev. 1999. *Our Common Journey: A Transition Toward Sustainability*. Washington, DC: Natl. Acad.
36. Kates RW. 1996. Ending hunger: current status and prospects. *Consequences* 2(2):3–11
37. Kates RW. 1994. Sustaining life on the earth. *Sci. Am.* 271(4):116–23
38. Kates RW. 1996. Population, technology, and the human environment: a thread through time. *Daedalus* 125(3):43–71
39. Burton I, Kates RW, eds. 1965. *Readings in Resource Management and Conservation*. Chicago: Univ. Chicago Press
40. Burton I, Kates RW. 1986. The great climacteric, 1798–2048: the transition to a just and sustainable human environment. See Ref. 2a, pp. 339–60
41. Jevons WS. 1865. *The Coal Question: An Inquiry Concerning the Progress of the Nation on the Probable Exhaustion of Coal*. London: Macmillan
42. President's Mater. Policy Comm. 1952. *Resources for Freedom*. Washington, DC: Gov. Print. Off.
43. Kates RW. 1995. Labnotes from the Jeremiah experiment: hope for a sustainable transition. *Ann. Assoc. Am. Geogr.* 85(4):623–40
44. Vogt W. 1948. *Road to Survival*. New York: Sloane
45. Brown H. 1954. *The Challenge of Man's Future*. New York: Viking
46. Meadows DH, Meadows DL, Randers J, Behrens WW III. 1972. *The Limits to Growth*. New York: Universe Books
47. Wernick IK, Herman R, Govind S, Ausubel JH. 1995. Materialization and dematerialization: measures and trends. *Daedalus* 125(3):171–98
48. Kates RW. 2000. Population and consumption: What we know, what we need to know. *Environment* 42(3):10–19
49. Marsh GP. 1965 (1864). *Man and Nature. Or, The Earth as Modified by Human Action*, ed. D Lowenthal. Cambridge, MA: Belknap
50. Thomas WL Jr, ed. 1956. *Man's Role in Changing the Face of the Earth*. Chicago: Univ. Chicago Press
51. Turner BL II, Clark WC, Kates RW, Richards JF, Mathews JT, Meyer WB, eds. 1990. *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years*. Cambridge, UK: Cambridge Univ. Press
52. World's Sci. Acad. 2000. *Transition to Sustainability in the 21st Century (Tokyo Summit of May 2000)*. http://interacademies.net/intracad/tokyo2000.nsf/all/sustainability_statement
53. Kates RW, Clark WC, Corell R, Hall JM, Jaeger CC, et al. 2001. Sustainability science. *Science* 292:641–42
54. Kates RW. 2000. Navigating the future: a transition toward sustainability. In *The Sustainable Future of the Global System III. Proc. Int. Conf. Sustainable Future of Global Syst., 24–25 May*, ed. F Lo, H Tokuda, NS Cooray, pp. 25–35. Tokyo: United Nations Univ.

55. World Comm. Environ. Dev. 1987. *Our Common Future*. New York: Oxford Univ. Press

56. Bongaarts J. 1994. Population policy options in the developing world. *Science* 263:771–76