Entering the Century of the Environment: A New Social Contract for Science

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As the magnitude of human impacts on the ecological systems of the planet becomes apparent, there is increased realization of the intimate connections between these systems and human health, the economy, social justice, and national security. The concept of what constitutes "the environment" is changing rapidly. Urgent and unprecedented environmental and social changes challenge scientists to define a new social contract. This contract represents a commitment on the part of all scientists to devote their energies and talents to the most pressing problems of the day, in proportion to their importance, in exchange for public funding. The new and unmet needs of society include more comprehensive information, understanding, and technologies for society to move toward a more sustainable biosphere—one which is ecologically sound, economically feasible, and socially just. New fundamental research, faster and more effective transmission of new and existing knowledge to policy- and decision-makers, and better communication of this knowledge to the public will all be required to meet this challenge.

Scientists today are privileged to be able to indulge their passions for science and simultaneously to provide something useful to society. With these privileges, of course, comes serious responsibility. The close of a century and a millennium provides an occasion for reflection on the nature of these responsibilities and an evaluation of the extent to which we are fulfilling them.

The scientific enterprise has provided phenomenal understanding of our bodies, our minds, our world, and our universe. The advances that have emerged from space, defense, and medical research, among many other areas—all of which have depended on basic research across all disciplines—have been astounding. Space exploration, for example, has given us not only new understanding of the cosmos, and wonderful products and technologies, but also a new sense of our world and ourselves: a sense captured forever by that first photograph of the whole Earth taken against the black background of space. Scientific research is advancing explosively on all fronts. The benefits include a dizzying array of new knowledge, economic opportunities, and products—ranging from laser surgery to genetic testing, from global positioning systems to prediction of El Niño events, from the discovery of new drugs derived from natural products to new information systems.

In the United States, much of the investment that produced this wealth was a result of strong bipartisan political support and popular enthusiasm for science that began during World War II and increased substantially in the 1960s. This support was predicated in part upon an (unwritten) social contract between science and society, specifically the expectation that a substantial investment in research would result in winning the war (initially World War II and later the Cold War), winning the space race, and conquering diseases (bacterial infections, polio, and cancer). The scale of the U.S. investment in science changed dramatically during this period. Investment in science in most other developed nations is predicated upon a similar expectation of a return of knowledge and technology to society. The scientific enterprise that has produced this wealth is widely admired and envied. The question I pose is whether the enterprise that has met these past challenges is prepared for the equally crucial and daunting challenges that lie in our immediate future. The answer that I must give is "no." I assert that the immediate and real challenges facing us have not been fully appreciated nor properly acknowledged by the community of scientists whose responsibility it is, and will be, to meet them.

Part of our collective responsibility to society must include a scientific community-wide periodic reexamination of our goals and alteration of our course, if appropriate. The fact that the scientific community has responded to societal needs several times in the past century—although generally in wartime—provides encouragement that it is possible to mobilize and change course rapidly in the face of a crisis. As the geologist Marshal Kay was fond of saying, "What does happen, can happen."

Despite the plethora of reports examining the future of the scientific enterprise (*1*, *2*), I see the need for a different perspective on how the sciences can and should advance and also return benefit to society. This different perspective is firmly embedded in the knowledge of specific, identifiable changes occurring in the natural and social worlds around us. These changes are so vast, so pervasive, and so important that they require our immediate attention. Scientific knowledge is urgently needed to provide the understanding for individuals and institutions to make informed policy and management decisions and to provide the basis for new technologies.

This paper is organized around four key questions: How is our world changing? What are the implications of these changes for society? What is the role of science in meeting the challenges created by the changing world? and How should scientists respond to these challenges? My goal in communicating these thoughts is to stimulate a dialogue within the scientific community on these topics. I hope that the result will be a thoughtful reexamination of our individual and collective priorities and actions.

The Board of Directors of AAAS has initiated an electronic discussion of the relationship between science and society. A paper summarizing its deliberations along with comments from a number of scientists are posted to invite an exchange of ideas on the questions posed above. On behalf of the Board, I invite your participation (*3*).

Global Changes and Their Causes

How is our world changing? One major way is that we now live on a human-dominated planet. The growth of the human population and the growth in amount of resources used are altering Earth in unprecedented ways. Through the activities of agriculture, fisheries, industry, recreation, and international commerce, humans cause three general classes of change. Human enterprises (i) transform the land and sea—through land clearing, forestry, grazing, urbanization, mining, trawling, dredging, and so on; (ii) alter the major biogeochemical cycles—of carbon, nitrogen, water, synthetic chemicals, and so on; and (iii) add or remove species and genetically distinct populations—via habitat alteration or loss, hunting, fishing, and introductions and invasions of species (*4*–*6*).

The resulting changes are relatively well documented but not generally appre-

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ciated in their totality, magnitude, or implications. Vitousek and colleagues have provided a succinct and dramatic summary of the extent of human domination of Earth in the following six conclusions (*4*): (i) between one-third and one-half of the land surface has been transformed by human action (*7*); (ii) the carbon dioxide concentration in the atmosphere has increased by nearly 30% since the beginning of the Industrial Revolution (8); (iii) more atmospheric nitrogen is fixed by humanity than by all natural terrestrial sources combined (*9*); (iv) more than half of all accessible surface fresh water is put to use by humanity (*10*); (v) about one-quarter of the bird species on Earth have been driven to extinction (*11*); and (vi) approximately two-thirds of major marine fisheries are fully exploited, overexploited, or depleted (*12*).

The rates and spatial scales of most of these changes are increasing. In addition, some of the changes are new. Novel chemical compounds—ranging from chlorofluorocarbons to persistent organic compounds such as DDT and PCBs—are being synthesized and released. Only a few of the thousand or so new chemicals released each year (*13*) are monitored; the biological effects of most are unknown, especially synergistic interactions of different compounds (*14*), and interference with developmental and hormonal systems (*15*).

Many of these physical, chemical, and biological changes entrain further alterations to the functioning of the Earth system, most notably causing: (i) disruptions to the global climate (*16*), (ii) depletion of stratospheric ozone (*17*), (iii) irreversible losses of biological diversity (*18*, *19*), and (iv) changes in the structure and functioning of ecosystems around the world (*6*, *20*).

The conclusions from this overview are inescapable: during the last few decades, humans have emerged as a new force of nature. We are modifying physical, chemical, and biological systems in new ways, at faster rates, and over larger spatial scales than ever recorded on Earth. Humans have unwittingly embarked upon a grand experiment with our planet. The outcome of this experiment is unknown, but has profound implications for all of life on Earth. An assessment from the Ecological Society of America entitled the Sustainable Biosphere Initiative states that "environmental problems resulting from human activities have begun to threaten the sustainability of Earth's life support systems. . . . Among the most critical challenges facing humanity are the conservation, restoration and wise management of the Earth's resources" (*21*).

The world is changing in myriad other important ways as well. Inequity within and among all nations has increased; new infectious diseases have emerged; there are dramatically more democratic governments; technology, communication, and information systems have undergone revolutionary changes; markets have become global; the biotic and cultural worlds have been homogenized; the rate of transport of people, goods, drugs, and organisms has increased around the globe; multinational corporations have emerged; and nongovernmental organizations have increased. (*22*). Most of these changes have profound implications for our future. Integration of the human dimensions of these global changes with the physical-chemical-biological dimensions is clearly needed.

The individual and collective changes described above are so different in magnitude, scale, and kind from past changes that even our best records and models offer little guidance concerning the scale or even the character of likely responses to these challenges. The future is quite likely to involve increasing rates of change; greater variance in system parameters; greater uncertainty about responses of complex biological, ecological, social, and political systems; and more surprises. The world at the close of the 20th century is a fundamentally different world from the one in which the current scientific enterprise has developed. The challenges for society are formidable and will require substantial information, knowledge, wisdom, and energy from the scientific community. Business as usual will not suffice.

Changes for Ecosystem Services and Humanity

Many of the environmental changes have serious consequences for humanity. Climatic disruption, increased ultraviolet (UV)-B radiation, or insufficient drinking water provide examples of undesirable outcomes. Many of the most serious consequences are less obvious and mediated through the functioning of ecological systems. Humans and our social and economic systems are intimately dependent upon the ecological systems now undergoing rapid changes (*21*, *23*).

Ecological systems—from wetlands, forests, coral reefs, and tundra, to grasslands, kelp beds, estuaries, and the open ocean—provide a broad range of essential goods and services to humanity. They are the life-support systems for all of life on Earth. Ecological goods and services provide a key link to understanding how changes in biodiversity, climate, land transformation, stratospheric ozone, water, nitrogen, and so forth have immediate and long-term implications for humanity. The key is simply that human well-being and prosperity depend upon diverse, functioning ecological systems in ways we are only beginning to appreciate.

Most people are well aware that humans extract goods from nature: seafood, game animals, fodder, fuelwood, timber, pharmaceutical products, and genes, for example. We buy, sell, and trade these goods. Until recently, little attention has been paid to another benefit provided by natural ecological systems, the fundamental life-support services without which human civilization would cease to thrive (*24*, *25*). These "ecosystem services" include the purification of air and water; mitigation of floods and droughts; detoxification and decomposition of wastes; generation and renewal of soil and soil fertility; pollination of crops and natural vegetation; control of the vast majority of potential agricultural pests; dispersal of seeds and translocation of nutrients; maintenance of biodiversity, from which humanity has derived key elements of its agricultural, medicinal, and industrial enterprise; protection from the sun's harmful UV rays; partial stabilization of climate; moderation of temperature extremes and the force of winds and waves; support of diverse human cultures; and provision of aesthetic beauty and intellectual stimulation that lift the human spirit (*24*).

Although these services are essential to human societies, their continued existence has been taken for granted. Never before have human actions so threatened their provision. Because these services are not traded in economic markets, society has no feedback mechanisms to signal changes in their supply or in the deterioration of underlying ecological systems that generate them. Various attempts have been made to calculate the worth of global ecosystem services; all estimate the value to be in the trillions of U.S. dollars (*24*–*27*).

As land is transformed globally, as biogeochemical cycles are modified on a grand scale, and as genetic, population, species, and ecosystem diversity are lost, the functioning of ecological systems is disrupted and the continued provision of ecosystem services is threatened (*4*, *6*, *20*, *21*, *24*). Primary threats to ecosystem services include habitat degradation or loss, changes in biodiversity, and synergistic interactions between these factors and rapid climate change, release of toxic substances, and stratospheric ozone depletion.

A recent synthesis of information about ecosystem services from the Ecological Society of America (*28*) concluded that:

Based on available scientific evidence, we are certain that:

Ecosystem services are essential to civilization.

Ecosystem services operate on such a grand scale and in such intricate and little-explored ways that most could not replaced by technology.

Human activities are already impairing the flow of ecosystem services on a large scale.

If current trends continue, humanity will dramatically alter virtually all of Earth's remaining natural ecosystems within a few decades.

In addition, based on current scientific evidence, we are confident that:

Many of the human activities that modify or destroy natural ecosystems may cause deterioration of ecological services whose value, in the long term, dwarfs the short-term economic benefits society gains from those activities.

Considered globally, very large numbers of species and populations are required to sustain ecosystem services.

The functioning of many ecosystems could be restored if appropriate actions were taken in time.

We believe that land use and development policies should strive to achieve a balance between sustaining vital ecosystem services and pursuing the worthy short-term goals of economic development.

Redefining the Environment

Recognizing the significance of the global environmental changes summarized above, E. O. Wilson suggested that humanity is on the verge of "Entering the Century of the Environment." Based on emerging information about ecosystem services and other environmental issues, I wish to take his phrase a step further and broaden the dialogue about what constitutes an "environmental issue." As we begin to appreciate the intimate fashion in which humans depend on the ecological systems of the planet, it is becoming increasingly obvious that numerous issues that we have previously thought of as independent of the environment are intimately connected to it. Human health, the economy, social justice, and national security all have important environmental aspects whose magnitude is not generally appreciated.

Human health. Human health is being increasingly recognized as having strong environmental components. Obvious examples include the importance to human health of good air quality, clean drinking water, clean food, and minimal exposure to toxic chemicals and UV-B radiation. Less apparent examples include the impact of land-use practices, climatic change, and population density on emergence and transmission of diseases (*29–31*). Recent changes in the epidemiology of Lyme disease, hantavirus, malaria, trypanosomiasis, schistosomiasis, cholera, and yellow fever are attributable to changing land-use practices (*29*, *31*). For example, the construction of roads in Amazonia to access and transport timber, coupled with higher human population densities, has increased the incidence and spread of malaria (*32*). Roads and the accompanying canals of stagnant water provide prime conditions for the numerical increase and spatial expansion of populations of mosquito vectors for the malarial parasites.

Global climatic change is predicted to have direct and indirect effects on human health. Direct effects include increases in heat stress, decreases in cold-related mortality, and increases in air pollution–related pulmonary and allergic complications. Indirect effects, some mediated through interactions with land-use practices, include increases in the geographic distribution of a variety of diseases including malaria, dengue fever, yellow fever, and hantavirus (*16*, *33*).

The full consequences to human health of large-scale alterations in biogeochemical cycles are not yet known. Over the last century, human activities have more than doubled the amount of nitrogen fixed and therefore entering the global terrestrial nitrogen cycle. Nonanthropogenic nitrogen-fixation—accomplished by algae, bacteria, and lightning—totals approximately 140 Tg/year. Anthropogenic sources—the making of fertilizer, planting of legumes (over larger areas than would naturally occur), and burning of fossil fuels—now contribute more than an additional 140 Tg/year. As Vitousek and colleagues state, "Serious environmental consequences are already apparent. In the atmosphere concentrations of the greenhouse gas nitrous oxide and of the nitrogen-precursors of smog and acid rain are increasing. Soils in many regions are being acidified and stripped of nutrients essential for continued fertility. The waters of streams and lakes in these regions are also being acidified, and excess nitrogen is being transported by rivers into estuaries and coastal waters. It is quite likely that this unaccustomed nitrogen loading has already caused long-term declines in coastal fisheries and accelerated losses of plant and animal diversity in both aquatic and land-based ecosystems" (*34*).

Increased nutrients in coastal waters may also trigger population explosions of certain taxa of phytoplankton that contribute to human health problems. Increases in the frequency, spatial extent, and duration of harmful algal blooms are reported from shores around the world (*35*). Many (although not all) harmful algal blooms that involve toxic dinoflagellates and diatoms are known to respond to increases in nutrients. In one such case, outbreaks of the ambush dinoflagellate *Pfiesteria piscicida* in estuarine waters of the middle and southern Atlantic shores of the United States have resulted in the death of billions of fish (*36*) and are suspected of causing human health problems ranging from amnesia to kidney and liver impairment. Nutrient pollution from upstream sources is the suspected trigger. Prevention of further nutrient-triggered disruption of terrestrial, freshwater, and marine ecosystems and resulting health consequences will be a formidable challenge in view of the expected global increases in population, sewage, livestock, aquaculture, and use of fossil fuels.

The economy. The economy is more interlinked with the environment than is often appreciated (*23*, *37*). The false assertion that society must choose between the economy and the environment is often made. In reality, this "jobs versus the environment" choice is a false dichotomy: the real choice is between short-term gain and long-term, sustained prosperity (*23*, *37*, *38*). The insurance industry has been a leader in private sector concern about climatic change (*39*), in part because its business demands a long-term perspective. The economic consequences of increases in the frequency and severity of extreme weather events provide strong motivation to act to decrease the probability of likely causes of these anomalies.

Economic development and prosperity hinge upon maintaining an adequate flow of essential services provided by natural ecosystems. Human-engineered sources of well-being foster the widespread misconception that affluence is independent of—or possibly even hindered by—the preservation of natural ecosystems (*40*). However, as humans fill in wetlands, clear-cut forests, degrade coral reefs, drive natural populations and species to extinction, and introduce alien species, we often disrupt the functioning of the systems or lose the ecosystem entirely. When we do so, we begin to incur unanticipated and occasionally staggering costs—having now to manufacture, grow, or otherwise provide what we once got for free.

A compelling example is provided by Chichilnisky and Heal's analyses of options for the provision of drinking water for New York City (*27*). Historically, the watershed of the Catskill Mountains provided the ecosystem service of water filtration and purification. Over time, this watershed system became overwhelmed by sewage and agricultural runoff to the point that the water quality was impaired. Chichilnisky and Heal calculated and compared the costs of purchasing and restoring the watershed so that it could continue to provide the ecosystem services of water purification and filtration ($1 billion) versus the costs of building and maintaining a water purification and filtration plant ($6 billion to $8 billion in capital costs, plus annual operating costs of $300 million). This comparison provides an estimate of the replacement costs for only a single service supplied by the watershed. Other services include flood control, air purification, generation of fertile soil, and production of a range of goods from timber to mushrooms, as well as sites for recreation, inspiration, education, and scientific inquiry. Even acknowledging that not all ecosystem services can be replaced by a human-made substitute, this analysis helps put some of the tradeoffs in perspective.

Social justice. Social justice, too, has intimate environmental components (*37*, *41*). The consequences of environmental degradation are often borne disproportionately by racially and economically disadvantaged groups. Wealthier individuals or countries can afford to buy bottled water, move away from degraded and contaminated sites, access information about alternative choices, influence the political process, cope with environmental disasters, buy better food, and purchase quality medical services and treatments.

For example, intensive shrimp farming in Southeast Asia, India, and parts of South and Central America often brings economic benefit to a few owners (large multinational or national corporations) in the short term but in the longer term destroys mangrove forests needed by indigenous peoples to provide food, fiber, and ecosystem services such as water purification, sediment trapping, and flood control.

National security. National security is being viewed increasingly as an environmental issue, with multiple, complex connections among population growth, environmental quality, and security, including human migrations, war, disease, social disruption, political fragmentation, competition for scarce resources, and ecoterrorism (*42*). Environmental degradation and scarcity of resources (water, fuelwood, fertile land, forests, fisheries) have been identified as key contributors to economic disruption, ethnic strife, civil war, migration, and insurgency throughout the world, for example in Bangladesh, India, Mexico, Gaza, Pakistan, Rwanda, Senegal-Mauritania, South Africa, El Salvador, Honduras, Haiti, Peru, Philippines, the West Bank, and Somalia (*21*, *43*). So-called "fish wars" for scarce cod and salmon present ongoing challenges for the state departments of the United States and Canada.

During his tenure as U.S. Secretary of State, Warren Christopher initiated a new perspective when he pledged to make environmental issues "part of the mainstream of American foreign policy." In framing a bold, new perspective on national security, Christopher declared that "[t]he environment has a profound impact on our national interest in two ways. First, environmental forces transcend borders and oceans to threaten directly the health, prosperity and jobs of American citizens. Second, addressing natural resource issues is frequently critical to achieving political and economic stability and to pursuing our strategic goals around the world" (*44*). In 1997, U.S. Secretary of State Madeline K. Albright issued the State Department's first annual report on environmental diplomacy, stating that "environmental problems are often at the heart of the political and economic challenges we face around the world. . . . We would not be doing our jobs as peacemakers and as democracy-builders, if we were not also good stewards of the global environment" (*45*).

In summary, national security, social justice, the economy, and human health are appropriately considered to be environmental issues because each is dependent to some degree on the structure, functioning, and resiliency of ecological systems. Linkages among the social, political, economic, physical, biological, chemical, and geological systems present new challenges to scientists. What is the role of science in meeting these challenges?

The Roles of Science

Science is the pursuit of knowledge about how the world works, a pursuit with an established process for inquiry, logic, and validation. Scientists engage in science because we are curious about why things are the way they are, we relish the fun and challenges of problem-solving, and we wish to contribute something useful to current and future generations. Society supports science because doing so in the past has brought benefits and doing so now is expected to provide more. Traditional roles of science have been to discover, communicate, apply knowledge, and to train the next generation of scientists.

Society currently expects two outcomes from its investment in science. The first is the production of the best possible science regardless of area; the second is the production of something useful. The first goal reflects "the expectation that scientists will search . . . for the truth about how nature works . . . producing reproducible, independently verifiable results, logically consistent theories and experiments that explain patterns in nature" (*46*). An emphasis on investigator-initiated, peer-reviewed science is designed to help meet this expectation.

The second part of the contract reflects the anticipation that the investment by society will lead not only to improvements in our understanding of the world but also the achievement of goals that society has deemed important—winning wars, conquering diseases, creating products, and improving the economy. This second component often weighs heavily in decisions about the allocation of funds. As President John F. Kennedy stated, "Scientists alone can establish the objectives of their research, but society, in extending support to science, must take account of its own needs" (*47*). Hence, both the rationale for public investment in science as well as specific decisions about the allocations of resources are tied to expected outcomes that are beneficial to society.

The needs of society have changed over the years. Vannevar Bush's 1945 landmark report to the President of the United States, *Science—The Endless Frontier*, emphasizes providing help in the medical, defense, and economic arenas. Bush's very first paragraph in his Summary of the Report stated (*1*):

> Progress in the war against disease depends upon a flow of new scientific knowledge. New products, new industries and more jobs require continuous additions to knowledge of laws of nature, and the application of that knowledge to practical purposes. Similarly, our defense against aggression demands new knowledge so that we can develop new and improved weapons. This essential, new knowledge can be obtained only though basic scientific research.

Forty-five years later, Erich Bloch, director of the National Science Foundation (NSF) (established in response to Bush's report), acknowledged the changing political landscape and highlighted the economic benefits of fundamental research and the primacy of knowledge as a critical resource (*48*):

> The National Science Foundation was a product of the Cold War and of a national policy decision that the contribution of research to national strength was too valuable to be limited to the years of armed conflict. In recent years, the rationale for supporting science and engineering research and education has been changing. As political conflict among the great powers diminishes, the major arena for world competition is increasingly becoming economic, and in this new global economy, which runs on ideas and innovation, knowledge is the critical resource.

In more recent years, as funding for science has gotten tighter and other needs for funds expanded, there has been an even greater emphasis on the need for new knowledge to generate new products and processes, for example, to fuel technological advances, provide a competitive edge in the global marketplace, or develop new medical treatments (*2*, *49*). In this sense, public funding of science is often argued to be an investment that brings monetary returns. A different application of scientific knowledge is emerging as equally important in today's world: knowledge to inform policy and management decisions (*49–51*).

The latter focus on the role of science in informing decisions is emerging as one of the critical unmet needs of society at the end of the millennium (*21*, *49*, *50*). A better understanding of the likely consequences of different policy options will allow more enlightened decisions. Many of the choices facing society are moral and ethical ones, and scientific information can inform them. Science does not provide the solutions, but it can help understand the consequences of different choices.

The plethora of biological, physical, chemical, social, and economic changes summarized earlier point to the myriad ways in which society's needs for scientific knowledge are changing. A wide range of studies focusing on environmental challenges all point to (i) the urgent need for improved understanding, monitoring, and evaluation to protect, manage, and restore the environment; (ii) more effective communication of existing knowledge to the public and policy arenas; (iii) the desirability of developing new technologies (manufacturing and waste reduction, for example) to minimize the ecological footprints of human activities; and (iv) better guidance about decision-making in the face of uncertainty (*50*, *51*).

In summary, the roles of science—to discover, communicate, and use knowledge and train the next generation of scientists—have not changed, but the needs of society have been altered dramatically. The current and growing extent of human dominance of the planet will require new kinds of knowledge and applications from science—knowledge to reduce the rate at which we alter the Earth systems, knowledge to understand Earth's ecosystems and how they interact with the numerous components of human-caused global change, and knowledge to manage the planet (*4*).

A New Social Contract for Science?

Recognizing that the world is changing in new and different ways, at faster rates and over larger scales than ever before recorded, and recognizing the urgent need for knowledge to understand and manage the biosphere, I propose that the scientific community formulate a new Social Contract for science. This contract would more adequately address the problems of the coming century than does our current scientific enterprise. The Contract should be predicated upon the assumptions that scientists will (i) address the most urgent needs of society, in proportion to their importance; (ii) communicate their knowledge and understanding widely in order to inform decisions of individuals and institutions; and (iii) exercise good judgment, wisdom, and humility. The Contract should recognize the extent of human domination of the planet. It should express a commitment to harness the full power of the scientific enterprise in discovering new knowledge, in communicating existing and new understanding to the public and to policy-makers, and in helping society move toward a more sustainable biosphere.

Science alone does not hold the power to achieve the goal of greater sustainability, but scientific knowledge and wisdom are needed to help inform decisions that will enable society to move toward that end. A sustainable biosphere is one that is ecologically sound, economically feasible, and socially just. Scientific understanding can help frame the questions to be posed, provide assessments about current conditions, evaluate the likely consequences of different policy or management options, provide knowledge about the world, and develop new technologies. The Contract would reflect the commitment of individuals and groups of scientists to focus their own efforts to be maximally helpful. Each individual, each panel, each agency, each congressional committee, each nation makes choices; these choices should reflect a greater focus on the most critical issues of our day.

Fundamental research is more relevant and needed than ever before. The Contract is absolutely not a call to abandon fundamental research; on the contrary, it should be a call to invest in fundamental research in a broad spectrum of areas where new knowledge is urgently needed. Just as the Manhattan Project involved a major investment in fundamental research, adequately addressing broadly defined environmental and social needs will require substantial basic research (*50*, *51*).

Because the environment is so broad a topic, research across all disciplines is needed to provide the requisite knowledge base. Efforts similar to those devoted to past societal wants and needs—for example to space, medicine, and defense—are needed to focus more intensely on the challenges we know lie ahead. These challenges encompass many of the earlier ones, but expand them in new directions. The setting of priorities about which science to fund cannot be done in a social vacuum. The needs of society for scientific knowledge should be an integral part of the decision-making process.

The Contract should also be a strong call for new research and management approaches. For example, innovative mechanisms are needed to facilitate the investigation of complex, interdisciplinary problems that span multiple spatial and temporal scales; to encourage interagency and international cooperation on societal problems; and to construct more effective bridges between policy, management, and science, as well as between the public and private sectors. A number of recent reports have recommended ways to accomplish many of these goals (*50*, *51*). The Corson Committee of the National Research Council, for example, evaluated the U.S. environmental research establishment, found it lacking in numerous ways, and recommended a number of steps to effect cultural and organizational changes in the environmental research enterprise (*51*).

There is a concomitant requirement to train interdisciplinary scientists and to provide the skills and savvy to work at the policy-science or management-science interface. Changes in university curricula and the reward system for professional scientists within and outside universities would greatly facilitate achieving these goals.

The new Contract should extend well beyond research and training activities. Some of the most pressing needs include communicating the certainties and uncertainties and seriousness of different environmental or social problems, providing alternatives to address them, and educating citizens about the issues. In parallel to initiating new research, strong efforts should be launched to better communicate scientific information already in hand. All too many of our current environmental policies and much of the street lore about the environment are based on the science of the 1950s, 1960s, and 1970s, not the science of the 1990s. Most of our efforts to address economic and social problems are as yet mostly devoid of ecological knowledge. Clearly, the interfaces between the environment, human health, the economy, social justice, and national security are ripe for developing and entraining into the policy arena. In view of the overarching importance of environmental issues for the future of the human race, all graduates from institutions of higher learning should be environmentally literate.

Powerful tools in communicating knowledge to inform policy and management decisions are scientific assessments from credible groups of scientists. Assessments such as the Intergovernmental Panel on Climate Change (*16*), the Ozone Assessment, and the Global Biodiversity Assessment (*19*) have provided excellent guidance to policy-makers, especially when they summarize certainties and uncertainties and specify the likely outcomes of different options.

The whole system of science, society, and nature is evolving in fundamental ways that cause us to rethink the way science is deployed to help people cope with a changing world. Scientists should be leading the dialogue on scientific priorities, new institutional arrangements, and improved mechanisms to disseminate and utilize knowledge more quickly.

All sciences are needed to meet the full range of challenges ahead. It is time for the scientific community to take responsibility for the contributions required to address the environmental and social problems before us, problems that, with the best intentions in the world, we have nonetheless helped to create. It is time for a reexamination of the agendas and definitions of the "grand problems" in various scientific disciplines.

We can no longer afford to have the environment be accorded marginal status on our agendas. The environment is not a marginal issue, it is **the** issue of the future, and the future is here now. On behalf of the Board of AAAS, I invite you to participate vigorously in exploring the relationship between science and society and in considering a new Social Contract for Science as we enter the Century of the Environment.

Bill Watterson has summarized this challenge quite eloquently in the following Calvin & Hobbes cartoon dialogue (*52*):

Calvin and Hobbes are riding along in their red wagon, careening through the woods:

Calvin: "It's true, Hobbes, ignorance *is* bliss!

Once you know things, you start seeing problems everywhere . . .

. . . and once you see problems, you feel like you ought to try to fix them . . .

. . . and fixing problems always seems to require personal change . . .

. . . and change means doing things that aren't fun!

I say phooey to that!"

Moving downhill, they begin to pick up speed.

Calvin (looking back at Hobbes): "But if you're willfully stupid, you don't know any better, so you can keep doing whatever you like!

The secret to happiness is short-term, stupid self-interest!"

Hobbes (looking concerned): "We're heading for that cliff!"

Calvin (hands over his eyes): "I don't want to know about it."

They fly off the cliff:

"Waaaugghhh!"

After crash landing,

Hobbes: "I'm not sure I can stand so much bliss."

Calvin: "Careful! We don't want to learn anything from this."

References and Notes

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