INTERNATIONAL ENVIRONMENTAL RESEARCH AND ASSESSMENT

PROPOSALS FOR BETTER ORGANIZATION AND DECISION MAKING

JULY 1992

A Report of the

CARNEGIE COMMISSION
ON SCIENCE, TECHNOLOGY, AND GOVERNMENT

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FOREWORD

Many countries have developed sophisticated mechanisms to advise and assist governmental decision making as it is affected by and affects science and technology at the national level.* In the United States such mechanisms include the White House Office of Science and Technology Policy (OSTP) directed by the President's Science Advisor, the Congressional Office of Technology Assessment (OTA), and the National Research Council (NRC). In this age of interdependence it is natural that the question of science advising at the international level also arises.

This report focuses on international needs for science advice in the field of environment. Environment and health are among the fields in which the need for information and advice, developed and provided in a multilateral way, are most obvious and pressing. One need only mention such problems

* See W. T. Golden (ed.), *Worldwide Science and Technology Advice to the Highest Levels of Government*, 1992.[1]

as stratospheric ozone depletion, climate change, loss of biological diversity, AIDS, and tuberculosis.

The report offers several proposals. Science advice will be sound over the long run only if there is a broad and deep base of knowledge on which to draw. Thus, the report recommends first that the time has come for thoughtful steps to further strengthen and interrelate the worldwide capabilities for environmental research, especially as they apply to development. Key to such movement is creation of an international Consultative Group for Environmental Research that would identify needs and mobilize resources.

To draw more effectively on what we know and what we can learn from research, the report then suggests ways to strengthen the international assessment of environmental issues and the integration of scientific and technical assessments with international policymaking. One approach is through building the advisory capacity of such international nongovernmental scientific organizations as the International Council of Scientific Unions. The second approach is through strengthening the role played in their own countries by foreign counterparts of OSTP, OTA, and NRC and by establishing or improving international links among these organizations.

These recommendations, valuable as they are in the specific context of environment, also have wider ramifications. The solutions proposed for a stronger institutional capacity for advising internationally in the environmental field should apply in other fields such as health. Thus, the value of the recommendations is enhanced.

Environmental institutions are evolving rapidly, stimulated by the June 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro. Since the Carnegie Commission's June 1990 workshop, which initiated the writing of this report, the idea of international networks of environmental research centers has gained considerable momentum. This report provides practical ways to extend the discourse and follow through on the results of UNCED.

The audience for the report includes both government officials and researchers in the United States and in other nations. In the United States, implementing the recommendations will require not only the active support of the scientific and technical community but also thoughtful and steadfast commitment by the Congress and numerous executive branch agencies. We urge responsible organizations and individuals in the United States and abroad to give careful consideration to these recommendations and then to move cooperatively to implement them.

William T. Golden, Co-Chair
Joshua Lederberg, Co-Chair

PREFACE

This report is the result of one of several activities carried out by the Carnegie Commission aimed at strengthening institutions and decision-making processes by which the use of science and technology is connected to world affairs. The Commission's international activities are overseen by an International Steering Group whose members are Rodney Nichols (Chair), Harvey Brooks, Victor Rabinowitch, Walter Rosenblith, and Jesse Ausubel (rapporteur).

The report was prepared principally by Jesse H. Ausubel and Thomas F. Malone, assisted by an *ad hoc* working group:

John F. Ahearne
Harvey Brooks
Philip W. Hemily
Rodney W. Nichols
Walter A. Rosenblith
Eugene B. Skolnikoff
H. Guyford Stever
David G. Victor
Gilbert F. White

An earlier report, prepared under the leadership of Rodney Nichols, on *Science and Technology in U.S. International Affairs* (January 1992), examines how the U.S. Government, particularly the State Department, can better mesh science and diplomacy. The Commission also sponsored a consultant report by Alexander Keynan, on "The United States as a Partner in International Scientific and Technological Cooperation: Some Perspectives from Across the Atlantic" (June 1991). In addition, the Commission's Task Force on Development Organizations, chaired by President Carter, is examining the rationale for international cooperation for development over the next decades, what such cooperation should consist of, particularly with regard to science and technology, and how the United States should organize its efforts to make the most effective contributions. The Task Force's report is expected to be published early in 1993.

The Steering Group recognized at the outset that renewing a positive long-range vision of the arrangements for cooperative activity in science and technology at the international level was essential to making reforms within the United States worthwhile. Sound U.S. policies and programs addressing such issues as global warming, deforestation, protection of marine resources, uses of outer space, and spread of infectious diseases will have little effect if the means to engage partners around the world are absent. Many problems require cooperative international data collection, monitoring, and research as well as joint action.

The Steering Group decided to take environment as a case study of the adequacy of the *multilateral* means for coordinating and conducting international research and for providing advice to governments. The choice of subject was influenced by the Commission's concern with environmental issues and the recognition that domestic progress in environmental management is inseparable from worldwide development.

The Commission has so far issued one report on environment, *E^3: Organizing for Environment, Energy, and the Economy in the Executive Branch of the U.S. Government.* That report, prepared under the leadership of Guyford Stever, stresses the need for pollution prevention and the early and deep integration of environment with other areas of government policy. The totality of environmental research and development activities of the U.S. Government is being examined by a Commission Task Force co-chaired by Robert Fri and Guyford Stever; its report will be published in late 1992.

The international case study was initiated with a Workshop on "International Environmental Organization: The S&T Dimensions" held 4–6 June 1990 at The Rockefeller University in New York (see Appendix C). Jesse Ausubel and Thomas Malone, who co-chaired the Workshop, followed the meeting with wide consultations to develop this report and benefited particularly from the continuing contributions of several of the Workshop participants who join as signatories of the report. The members of the Commission and Advisory Council made important suggestions, as did numerous reviewers, including Sylvia Earle, Alexander Keynan, Giulio Pontecorvo, Robert Socolow, and Paul Waggoner. John Perry authored an insightful paper on "International Institutions for the Global Environment" that greatly stimulated the effort at the outset. David Victor provided vigorous research assistance. Kenneth Keller, senior fellow in science and technology of the Council on Foreign Relations (CFR), which has worked closely with the Commission on its international studies, took a valuable ongoing interest in the effort. William Nitze, Richard Moss, and other participants provided insightful commentary at a CFR seminar about the draft report chaired by Richard Celeste. David Robinson and David Beckler provided thoughtful historical perspectives, and their close scrutiny of several drafts clarified its arguments. Mark Schaefer assured synergy with the Commission's other environmental studies. David Kirsch, Margret Holland, Doris Manville, and Lori Skopp provided indispensable practical help.

The report was approved by the Commission at its June 1991 meeting. This report does not seek to cover all international institutional issues relating to environment and development. As part of the process of the United Nations Conference on Environment and Development, the full suite of issues is being raised and numerous books and reports prepared. These address, for example, the reorganization of the UN system in light of new needs relating to environment and development.[2]

The subject of this report is institutions for the development of knowledge about environmental problems and for the synthesis and assessment of this knowledge for the purpose of informing policy. There is a desperate need to diffuse environmental expertise rapidly throughout the world. Environmental research capability is perhaps only an indirect benefit in the near term in many countries but is important because it is essential for the diffusion and assimilation of environmental knowledge into policy and for the development of an adequate empirical database everywhere.

To protect nature as well as we can and to get the most cleanliness for its money, humanity must act on sound knowledge about the environment. This report wastes no ink on calls for environmental action but assumes there will be action. The free passage of winds and currents, without passports, makes environmental matters peculiarly and quintessentially international. Sustained, effective international action requires that the poor develop into the rich and that the behavior of the rich with respect to the environment and resources improve. If the actors do not know their science globally, the inevitable environmental action can misfire, making matters worse or wasting money and disillusioning people.

A major reorientation is needed in many policies and institutional arrangements at international as well as national levels because the rate of [environmental] change is outstripping the ability of scientific disciplines and our current capabilities to assess and advise. . . . A new international programme for cooperation among largely nongovernmental organizations, scientific bodies, and industry groups should therefore be established for this purpose.

—The World Commission on Environment
and Development (1987), *Our Common Future*

EXECUTIVE SUMMARY

There is an unending contest between the growing burdens that humans place on the environment and the resources of knowledge and money at our disposal to modify and adjust these burdens. Growth in population and economic activity suggests that simply keeping pace with environmental needs is likely to become harder. Moreover, desire for environmental quality is rising, and environmental issues are increasingly shared and international. Developing countries are most at risk from environmental problems. The need for international action with respect to environment is particularly pressing because of the potential conflict between economic advance in developing countries and protection of the environment.

Knowledge of environment has progressed rapidly but remains tentative, partial, and insufficiently widespread. The asymmetry of knowledge is indicated by the fact that developing countries are home to 80 percent of the world's people but less than 10 percent of world research and development activities. Fortunately, the rate of growth of the total fund of human knowledge is greater than the rate of economic and population growth.

Nevertheless, much remains to be done in understanding the interaction of environment and development and translating the understanding into actions. Contributions must come from all fields of knowledge, including the physical, life, engineering, social, and human sciences, and from their combination.

There is legitimate concern that human knowledge, skills, and social organization may not keep pace with the forces leading to environmental deterioration and associated conflict. Creative interaction of an unprecedented kind and extent among science, technology, and society is needed to ensure the lasting integrity of the environment and of the natural resource base. New organizational arrangements and better processes of decision making are required to achieve this interaction.

Functionally, two requirements exist involving the scientific and technical community, which has special responsibility for the generation and diffusion of knowledge, and governments, charged with attending to matters of collective health and well-being: first, to strengthen and interrelate the worldwide capability for environmental research, especially on issues relevant to economic development and, second, to strengthen the international assessment of environmental issues and to incorporate this assessment into national and international policy.

WORLDWIDE ENVIRONMENTAL RESEARCH CAPABILITY

New international environmental networks and centers for research and training have been proposed in various forms by the International Geosphere–Biosphere Program (the "START" initiative), the April 1990 White House Conference on the Science and Economics of Global Change, the Second World Climate Conference (Geneva, November 1990), a Task Force of the Environmental and Energy Study Institute of the U.S. Congress, the November 1991 Conference on an Agenda for Science for Environment and Development for the 21st Century convened in preparation for the United Nations Conference on Environment and Development, the Third World Academy of Sciences, and the Engineering Partnership for Sustainable Development. An Inter-American Institute for Global Change Research is being created.

The purposes of the networks and centers include the strengthening of national environmental research systems; the conduct of research on long-range problems of regional and global importance on which national efforts fall short; and the broadening of national capabilities to apply the results of research to operational decisions in energy, transport, farming, and industry that affect the environment both locally and globally. It is now time to bring together the discussions about international environmental research networks and centers in a coherent, thorough evaluation.

To strengthen and interrelate worldwide capabilities for environmental research, especially as they apply to development, **we propose the establishment by potential sponsors of an international Consultative Group for REsearch on ENvironment (CGREEN).** CGREEN should serve several functions. These include

- Conduct of global and regional reviews of environmental research needs and opportunities in the context of development issues
- Creation of alliances among institutions to increase their effectiveness and to broaden coverage of urgent issues
- Facilitation of national collaborative research networks
- Stimulation of the creation of new centers and networks where gaps are found
- Mobilization and coordination of resources

The CGREEN mechanism is needed if ambitious worldwide environmental research networks and centers are to be encouraged, built, and operated within a coherent policy framework. To advance these objectives and recommendations

- **We urge the U.S. Government, the World Bank, and private foundations to initiate discussions with potential members of an international Consultative Group for Research on Environment to encourage their interest and participation in its formation.**

Among the key questions is how to involve the private sector and others responsible for the application and diffusion of knowledge.

INTERNATIONAL ASSESSMENT OF ENVIRONMENTAL ISSUES

There are two mutually supportive approaches to improving the international assessment of environmental issues and incorporating the results of this assessment into policy formulation. One is through international nongovernmental scientific and technical organizations, and the second is through networking of national counterpart organizations throughout the world.

At the international level, several nongovernmental organizations appear to have a structure and a foundation in science and technology that could support an expansion of their roles in advising governments on environmental issues at the international level on an ongoing basis. Foremost among these is the International Council of Scientific Unions (ICSU), which has served as the principal scientific advisor to the United Nations Conference on Environment and Development (UNCED). Others include the Council of Academies of Engineering and Technological Sciences, the International Institute for Applied Systems Analysis, the Third World Academy of Sciences, the International Union for the Conservation of Nature, and regional academies and similar organizations.

At the national level, mechanisms such as the National Research Council (NRC), the Congressional Office of Technology Assessment (OTA), and the Office of Science and Technology Policy (OSTP) of the White House offer institutional examples responsive to the need for balanced scientific and technical assessment and advice on issues relevant to public policy.

▪ **Steps should be taken to improve international environmental assessments and to enhance the integration of science and engineering knowledge with policymaking at the international level. This should be done through the development of systematic and well-understood relationships between the international mechanisms for provision of science assessments, on the one hand, and governments and intergovernmental bodies, on the other.**

To improve assessments:

▪ The U.S. Government should review organizations with the potential for enhanced roles at the international level with regard to science and technology advice, determine how to energize these organizations, and encourage and communicate its expanded vision of the future role of these organizations.

▪ Accordingly, U.S. representatives to and affiliates of organizations with the requisite potential should urge these organizations to review carefully their intellectual resources and their policies and procedures for the joint international conduct of assessments.

▪ U.S. organizations providing science advice, particularly the National Research Council (NRC), the Office of Technology Assessment (OTA), and the Office of Science and Technology Policy (OSTP), should enhance their capacity to carry out international studies through partnerships and alliances with counterpart organizations abroad.

▪ To encourage the creation and strengthening of counterpart organizations in other nations, the NRC, OTA, and OSTP should stimulate meetings at which counterparts and potential counterparts exchange experiences, learn from one another, and explore procedures for networking and joint efforts.

To improve coupling of science and policy:

- The United States, other governments, and the UN system should provide core funding for a fixed period of time, perhaps five years, to selected nongovernmental scientific and technical organizations for the purpose of building their capacity for international assessment and advisory functions.
- The United States Government, in association with other nations, should create agreements that provide a framework for cooperation between such organizations and national governments, the UN system, and other intergovernmental bodies for the purpose of expediting the conduct of studies when sponsoring governments or agencies request them.

In most of the world, there is still too little hope of building the capabilities to empower countries to deal with the environmental problems they face on a national, regional, or international basis. The initiatives outlined here could both catalyze the development of national capacity and enable nations to work together to enhance the global environment and not merely view it with alarm. We believe it is possible to create and diffuse the knowledge and technical ability to improve the human and planetary prospect substantially. *Through its own actions and commitments, we urge the United States to lead in promoting the objectives and recommendations of this report in the UN and its specialized agencies, the World Bank, and other relevant bodies.*

1

INTRODUCTION

In 1972, at the time of the United Nations Conference on the Human Environment in Stockholm, the list of environmental issues was already formidable. Many of the world's cities suffered acute air pollution, and lakes and streams were polluted with wastes and choked by lack of oxygen. To some, environmental degradation was of crisis proportion. UN Secretary General U Thant declared that "inhabitants of the world have perhaps ten years left to improve the human environment."[3] The Stockholm Conference was one major international response. It strengthened and accelerated international action against dumping of wastes at sea and trade in endangered species, and it led to the establishment of the United Nations Environment Programme (UNEP).

Meanwhile, many nations were taking independent action to preserve environmental quality through regulation, creation of domestic institutions for environmental management, enhanced research and monitoring, and public and private investment in technology. In the United States, the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and the Council on Environmental Quality were all formed in 1970, and strong Clean Air and Water Acts were legislated.

Two decades later, the number of environmental issues has increased, and several, such as stratospheric ozone depletion and loss of tropical forests, have become much more acute. Yet much progress has been made in identifying the sources and effects of environmental changes and in responding to them. Interest in the environment has surged, and public discourse has become worldwide. Along with evaluation of specific policies to prevent pollution, protect health, and conserve nature, the debate increasingly encompasses the deliberate design of organizations and decision-making procedures that provide a framework for knowledge and action. The question we seek to answer in this report is what particular innovations in international organization and decision-making processes for the science and technology dimensions of environment are needed now so that better policies may be in place 20 years hence.

We adopt this time frame partly because we are impressed by how much has occurred in the two decades since Stockholm. "Stockholm II" took place in Brazil in June 1992, and the name of the meeting, the UN Conference on Environment and Development, reflects a new awareness of the links of environmental issues to the entire way in which the human population grows and develops, both in the developing nations of the South and in the industrialized nations of the North. We also take this horizon because it takes about 20 years for institutions to grow and mature to a truly influential level. Finally, it is long enough for diffusion of knowledge and technology to make a strong contribution to the solution of current problems, for substantial progress in science, and for scientific discoveries to bear fruit in new technology. Although taking this long-range perspective, we recognize that there are urgent environmental needs that should not wait for better information and analysis before action is taken.

The focus on the potential contributions of science and engineering comes with full appreciation of the plurality of voices, professions, and communities needed to address environmental issues. Yet, science has figured so prominently in placing environment on the public agenda that it merits a special review. And so does technology, at once a source of environmental problems and an indispensable part of their solution, especially if environmental quality is to be achieved simultaneously with economic growth and other social objectives. Scientists and engineers will continue to play unique roles in the systematic study of environmental problems, their patterns and remedies. Indeed, as environment is increasingly integrated into public policy in all fields on both the national and international levels, the demands by government for the application of science and technology to environment will become larger and more insistent. This report addresses opportunities for scientists and engineers to mobilize and better organize themselves internationally in the field of environment for the global good.

2

ENVIRONMENTAL LESSONS OF THE PAST 20 YEARS

What has changed in the two decades since the first wave of institution-building for environment? A review (Appendix A) of the underlying forces of growth and development, direct indicators of the environment, and changes in management and decision making suggests the following conclusions.

THE LESSONS

■ *The burdens humans place on the environment and the resources of knowledge and money at our disposal to modify and adjust these burdens contest endlessly.* The record of recent change in environmental quality is uneven. The view that the environment is deteriorating in almost all respects is not justified. Several important trends are moving favorably as a result of applications of science and technology as well as behavioral and policy shifts in both developing and industrialized countries. For example, in the industrialized world, energy intensity, the source of many environmental problems, is decreasing, and decarbonization of the fuel mix is occurring worldwide, signifying a shift to cleaner sources. Societies have been mobilized to a remarkable extent to address environmental issues; however, there is little evidence of a new paradigm of economic and social behavior that will rapidly alleviate the environmental problems of growing population, production, consumption, and materialization. Economic and population growth continue to offset efficiency gains so that in many cases and places environmental burdens become heavier. At the most essential level, the environmental problem remains unsolved.

■ *Simply keeping pace with environmental considerations is likely to become harder.* Humans have to be much smarter, if we are more numerous and if each one of us on average is processing more materials. The net effect of changes in population, technology, and styles of economic growth and development may be environmentally favorable or not. Pressure on the environment seems bound to continue to increase. The need for innovation and diffusion of environmentally more benign technology is great now and is growing.

■ *People are demanding higher environmental quality.* The lengthening list of issues and policy responses reflects not only changing conditions and the discovery of new problems, but also changes in what human societies define as problems and needs. Environmental quality is necessary to survival. Moreover, with higher income, there appears to be a greater preference for environmental amenities. Where development succeeds, the preference for environmental goods will grow. Where development fails, environmental deterioration may become worse and may be blamed for impoverishment.

■ *Environmental issues are increasingly shared and international.* Some of the issues are international because pollutants cross borders, some because effects cross borders, and some because the sources and consequences of the problems are linked to world markets. The issues are also international because key technologies are essentially selected on a global basis, so that it is extremely difficult for a nation desiring an alternative style to maintain itself as an island of independence from the international system. Driving forces, such as the energy system, are fundamentally global.

■ *Developing countries are most at risk from environmental problems.* A range of environmental issues connected with industrialization and urbanization that have long been on the agenda in industrialized nations are now manifesting themselves intensely in the developing world. This is occurring in parallel with the worsening unsolved environmental problems connected with population growth and poverty, such as deforestation. Moreover, in some respects vulnerability of developing countries to environmental hazards may be increasing, for example, through population growth in low-lying coastal areas prone to flooding.

▪ *The need for international action with respect to the environment is particularly pressing because of the potential conflict between economic advance in developing countries and protection of the environment.* The industrialized world may well have passed through the era of "dark Satanic mills" and obtained its benefits. It would be extremely provocative for the rich North now to ask the developing world to forgo the benefits of industry so that the North can live in a neat and tidy world that it can afford and the South cannot. Science and technology can offer alternatives for environmentally sustainable development, South and North. But can the developing countries be expected to accept as equitable the proposed policies and results of investigations carried out by the "haves"?

▪ *Knowledge of environmental issues has progressed rapidly but remains tentative, partial, and insufficiently widespread.* Many environmental changes are still poorly documented, especially in developing countries. Surprises, such as the Antarctic ozone hole, continue to occur. Although progress has been made on understanding individual issues in isolation, the potential interactions and cumulative effects of problems have scarcely been studied. Moreover, data and measures of environmental progress reflect past environmental concerns and do not necessarily provide a sound basis for assessing future problems. The ability to reliably foresee environmental changes remains weak. Many countries lack the human, technical, and other resources to address their environmental problems.

IMPLICATIONS FOR SCIENCE AND THE UNITED STATES

For world science and for governments, the situation translates into a responsibility for increased cooperative efforts to anticipate and assess changes in the state of the environment and to seek solutions to environmental problems. Changes in organization and decision making, as well as resources, are required to harness the knowledge that exists and can be created. Specifically:

▪ The worldwide capabilities for environmental research, especially as they apply to development, need to be strengthened and interconnected.

▪ The international assessment of environmental issues and the integration of scientific and technical assessments with international policy-making need to be strengthened.

The United States has the broadest and deepest environmental expertise of any nation. It has enormous capability to foster environmentally sound technologies and environmentally sustainable development. By some measures, the United States is also the world's largest polluter. It is clear that the stakes for the economy and general welfare of the United States in international agreements, standards, and norms on such issues as depletion of the ozone layer, climate change, and energy are high. In the national interest and that of the globe

▪ The government of the United States and its scientific and engineering communities should take the lead in further building the international institutional frameworks for environmental research and for advice to governments on which all nations and international institutions are bound to come to rely.

3
STRENGTHENING THE WORLDWIDE ENVIRONMENTAL RESEARCH CAPABILITY

NEED FOR RESEARCH AND TRAINING

Care of the environment depends in large part on our description and understanding of the interacting physical, chemical, biological, and social systems that regulate planet Earth's unique environment for life. The most fundamental function of science for the environment is to generate such knowledge. Integral with research is education and the application of knowledge.

Pressing needs include research on the behavior of the atmosphere, oceans, and ecosystems; clarification of resource endowments, extraction rates, materials flows, and assimilative capacities for pollution; understanding of the use of economic, regulatory, and behavioral approaches for environmental protection; and development and diffusion of technologies that are environmentally beneficial.[4] With the growth in number, diversity, and interconnectedness of environmental problems, the complexity of the environmental research agenda has also increased. Yet scarcely any research effort is directed at the relationships, intersections, and cumulative effects of problems. For many issues, there are few or poor data, and for some problems data needs have not even been properly defined.

National environmental research systems remain weak in most countries. In fact, there are few if any "systems" in existence; nationally and internationally, there are components that need to be linked in a more systematic way.[5] Few countries are capable of organizing and managing the concentrated, high-quality research efforts needed to address contemporary environmental issues, although higher priority is being given to environmental research in many nations. Although there are highly qualified individual experts in many countries, in developing countries there are few sizable centers of excellence in environmental fields that can provide advanced education and training.

Progress will require the building of indigenous capacity in many more nations, especially but not only in the developing countries, which are home to 80 percent of the world population but which account for less than 10 percent of world expenditures on research and development.[6] Many countries in the developing world have little or no indigenous capability to understand and analyze environmental issues.

Even in the industrialized world, capabilities are highly uneven. In the United States, the goals, arrangements, and resources for environmental science and technology are very much in debate, as evidenced by the proposals to create a set of National Institutes for the Environment, the National Research Council's congressionally mandated study of environmental research needs, and the Carnegie Commission's review of federal organization for environmental research and development. A key question in all cases is what research the United States can perform by itself and where cooperation with other nations is required or beneficial.

In short, major efforts are needed to improve worldwide environmental research capacity, and it is timely for the United States to participate actively in these efforts.

REASONS FOR INTERNATIONAL COOPERATION

There are many reasons for a strongly cooperative international approach to environmental research. First, international coordination of national activities can bring efficiency and economies of scale.[7] While research will continue to be conducted primarily as a national enterprise, international cooperation could help to avoid unnecessary duplication of effort and optimize use of resources. Indeed, some research instruments and R&D programs are too expensive for one nation to support alone. To ensure comparability of environmental data among countries, measurements and instruments need to be standardized. Understanding and addressing some problems requires access to sites all around the globe and participation by many countries.

A second rationale for internationalizing environmental research is to accelerate the speed with which societies learn to address problems. Many of the environmental problems now being tackled in some parts of the world have long scientific and policy histories elsewhere.[8] There are always local and national innovators in environmental research and policy: the diversity of nations makes possible a variety of approaches to understanding and addressing issues. It is useful to build international cooperation in part because lessons learned in one place may have application elsewhere. International cooperation, through networks and institutions, can provide effective means for diffusion of this knowledge and hasten learning.

A third reason is that some nations cannot afford the investments needed. For smaller nations even a reasonable level of affluence may not permit them to carry out critical programs without high levels of international cooperation. In the developing world, where many of the most acute environmental problems are now evident, there are compelling priorities for development that may not include basic and applied research on the environment. Yet, there is an equally compelling argument that long-term development requires investments in the environment, including research, that promote sustainable settlements and industries.

Furthermore, it is clear that the existence of a scientific base in each country is essential to well-reasoned global as well as national approaches to environmental issues. With population growing more than ten times faster in the developing world and environmental issues involving the developing world increasing apace, it would be short-sighted to pursue environmental research only in a handful of industrialized nations. A disproportionate share of research would be done outside the developing world where many applications are needed most; if developing nations do not accept the resulting new approaches, global policies are likely to fail. Environmental research capability is a prerequisite for "informed consent" to environmental constraints in both industrialized and developing nations; it is also a check on the imprudent resource and environmental exploitation that has occurred throughout the world.

There is a broad base of mutual interest in cooperative environmental research. Those countries with the most resources should be willing to help support the efforts in developing countries because all will benefit. The task is to design institutions to perform essential functions that cannot be performed as well by individual nations alone.

EXISTING INTERNATIONAL MECHANISMS AND THE UNMET NEED

How effective are present mechanisms in environmental fields that require international research collaboration? What more or different would be useful? It is important to recognize the strengths and potential contributions of the international environmental programs and organizations that have evolved over the past two decades.[9] The UN Environment Programme (UNEP) is in a central position. The United Nations established UNEP as a systemwide environment program to coordinate and catalyze action on specific problems by the specialized agencies of the UN, such as the World Meteorological Organization (WMO), World Health Organization (WHO), Food and Agriculture Organization (FAO), UN Educational, Scientific and Cultural Organization (UNESCO), and UN Development Program (UNDP). UNEP itself leads programs on environmental law, monitoring, cleanup of regional seas, terrestrial ecosystems, and toxic chemicals. It played a major role in the negotiations to protect the stratosphere against ozone depletion.

Among the most successful programs of international environmental research have been the Global Atmospheric Research Program, led by the WMO and the nongovernmental International Council of Scientific Unions (ICSU), and its successor, the World Climate Program, in which UNEP has joined as a principal sponsor. WMO's strength is limited by the fact that the governmental representatives to it are usually the heads of national weather and hydrological services; these services have strong capabilities in monitoring and operations but narrow and often weak capabilities in research.

A key intergovernmental organization outside the UN system is the Organization for Economic Cooperation and Development (OECD). Through its Environment Directorate, OECD operates programs to convene the environment ministers of most of the science-rich nations and to collect, analyze, and compare information about environmental health and safety, relationships between energy and environment, and the integration of economic and environmental policy. The Development Assistance Committee coordinates flows of concessional assistance from OECD nations to developing countries. The OECD's Committee on Science and Technology Policy brings together the OECD nations' ministers of science or their equivalents. In practice this Committee has met infrequently at a high level and has rarely considered environmental research. At its March 1992 meeting, the Committee explored the establishment of a forum to discuss and coordinate interests in "megascience" programs that would include research on global environmental change as well as high energy physics, space, and genetics.[10]

The North Atlantic Treaty Organization (NATO) has funded influential international programs of study and exchange in environmental sciences, and the judgments of its Science Committee have had a powerful effect on national research agendas. However, NATO's programs do not connect on a continuing basis to national environmental research groups, and its ties to national governments are primarily through defense and diplomatic channels.

In principle, UNEP, through its Governing Council, which brings together ministers of environment or their equivalents, has responsibility for looking at environmental research and providing an overview of global needs. However, UNEP has attempted little with regard to research, concentrating instead—perhaps appropriately—on solution of problems emphasized by its governmental members. In part, this reflects the situation at the national level: departments or ministries of the environment often have little research capacity of their own and little interest in research, sponsoring only a minor fraction of the scientific and technological research most important for the environment. The compartmentalization of environmental concerns that hampers effective research at the national level is thus intensified at the international level in the UN system. Oceans are in UNESCO, forests in FAO, the atmosphere in WMO, environmental health in WHO, and so forth.

■ **In practice, no organizations offer regular and systematic arrangements for looking widely and deeply at programs of environmental research or provide an overview of global needs in environmental research. Especially lacking is a mechanism to review progress in environmental research in relation to developing countries and to improve research coverage and quality for these countries. A major enhancement of the mechanisms for support, coordination, and joint international conduct of environmental research and related education is needed.**

THE ROLE OF A CONSULTATIVE GROUP FOR RESEARCH ON ENVIRONMENT

The need for a more systematic worldwide approach to environmental research calls first for the establishment of an entity that can conduct an in-depth study of the adequacy of such research and possible needs for additional support of existing and new networks and centers.

■ **To strengthen and interrelate the worldwide capabilities for environmental research, especially as they apply to development, we propose the establishment by potential sponsors of an international Consultative Group for REsearch on ENvironment (CGREEN).**

One of the first tasks of CGREEN would be to organize a thorough evaluation of needs for international environmental research centers and networks, including the several initiatives for such centers and networks that are being set forward.

CGREEN should serve several functions. These include

- Conduct of global and regional reviews of environmental research needs and opportunities
- Creation of alliances among institutions to increase their effectiveness and to broaden coverage of urgent issues
- Facilitation of international collaborative research networks
- Stimulation of the creation of new centers and networks where gaps may exist
- Mobilization and coordination of sources from many resources, public and private

Members of CGREEN might include national agencies funding environmental research, bilateral development agencies, the World Bank and the regional development banks, and UN agencies such as UNEP, UNDP, FAO, WMO, and UNESCO. The World Bank's recently created Global Environment Facility might provide suitable auspices or at least an initial focal point for CGREEN.[11] CGREEN should also include or seek to mobilize industrial and other private resources. Private foundations have played key roles in comparable efforts to strengthen worldwide research capabilities in agriculture and tropical diseases.

The formally designated representatives of the member organizations of CGREEN would be responsible for the Group's direction and decision making. They would be greatly aided in carrying out their work by creation of a scientific and technical advisory committee to CGREEN whose members would be appointed on the basis of their expertise in the application of science and technology for environment. The major functions of the advisory committee would be to

- Provide comprehensive, objective reviews of the adequacy of environmental research and training systems on a global and regional global basis, through the committee's own studies and in collaboration with other qualified groups
- Organize planning and evaluation for networks and centers associated with CGREEN, including the coupling of global and regional efforts supported by CGREEN with national environmental research, extension, and training activities
- Conduct country reviews of environmental research systems in de-

veloping countries at their request for the purpose of strengthening national research capabilities

- Help assure that CGREEN is open to innovative ideas and approaches;
- Develop proposals for coordinated national and regional research programs pursuant to international assessments of environmental problems
- Help balance the goals set forth by international donors, national organizations, and the research community itself

The CGREEN mechanism is needed if ambitious worldwide environmental research networks are to be encouraged, built, and operated within a coherent policy framework and with a coherent strategy.

A model for CGREEN in some respects is the Consultative Group on International Agricultural Research (CGIAR) (see Box 1). CGIAR is a consortium of funders providing support, direction, and evaluation to designated centers of excellence in agricultural research. CGIAR was established at a time of both deep concern about food supply and a dawning recognition that the technology of the "Green Revolution" held great promise. To no small degree, the maturing CGIAR programs have helped build and distribute the practical benefits of modern agricultural science and technology to the developing world, assisting to expand the food supply and reduce hunger. Today a comparably deep and justified concern exists about the environment, again coupled with a recognition of the great promise of science and technology. Facets of CGIAR may serve as models for a more coordinated international research and training capacity for the environment.

AN INTERNATIONAL NETWORK OF ENVIRONMENTAL RESEARCH CENTERS

What may motivate creation of international environmental programs, networks, and centers? The hierarchy of environmental issues, from local to global, calls for several interrelated approaches. Diverse institutions and funding patterns may be needed to deal with each type of issue. An evaluation must consider carefully the balance of programs, networks, and centers appropriate to each case.

Different Issues, Different Institutions

On global issues, such as climate change and stratospheric ozone depletion, the main need is for global programs and not necessarily for specialized international centers. There is a need for programs that coordinate monitoring from space and ground, that draw together the results of studies of chemical reactions at numerous individual laboratories, and so forth. These programs call for coordinated international planning, like that carried out by the scientific oversight committee of the World Climate Program; centers would process and make available data and integrate and compare work, but most work would be done outside the centers. Indeed, it is important to encourage a diversity of models and approaches; this would be hard to sustain in one center. Cooperative programs and networks enable the best people, who are geographically spread, to work more effectively.

The impacts of global environmental changes will be mostly local and regional. Many will be extensions of familiar environmental problems, such as flood, drought, habitat destruction, and imprudent use of coastal areas. There is an important place for truly global studies that provide orientation and synthesis, and these are often best carried out in international institutes. However, the effort required for such studies is much smaller than is needed for the broad spread of component studies that contribute to and ramify from the global studies.

All nations and regions, however, want to ascertain for themselves the validity of global studies and to understand global issues such as climate change in a regional context. Arrangements and programs are needed so that this kind of work can be carried out. The "START" initiative gives highest priority to the establishment of regional environmental research efforts in equatorial South America and the tropical Asian monsoon region for this purpose (see Box 2).

Loss of biological diversity is an example of a global issue where a combination of programmatic and networking initiatives, as well as new centers, may be needed. Research methods and protocols need to be developed, databases established, and training intensified (see Box 3).

Regional issues, such as acid rain, transnational solid waste disposal, and quality of large international bodies of water call more clearly for co-location of researchers and a specific geographical setting. For regional problems of industrialized countries, such as acid rain in Europe, it may not be necessary to establish new research centers or devise elaborate funding mechanisms. Addressing regional research problems in developing countries, however, is likely to require international funding.

Local problems, such as air, water, and land pollution will continue to engage most national funding and research effort. Here again there is a need to consider operations separately from funding. Financial help may be important to place these problems on the agendas of the countries that are going to have to pay the extra costs both for clean-up of problems already created and for new designs to avert future problems.

Box 1. CGIAR and the International Agricultural Research Centers

The International Agricultural Research Centers associated with the Consultative Group for International Agricultural Research (CGIAR) are mission-oriented institutions that do both basic and applied agricultural research over extended periods of time in highly defined areas, as the names of the centers imply (Table 1). CGIAR evolved around a small number of autonomous centers established by the Ford and Rockefeller Foundations in the early 1960s to foster the "Green Revolution" that developed new crop strains and integrated them with advances in irrigation, agricultural chemicals, and other farming practices.[12]

CGIAR itself was formed in 1971 to coordinate fund-raising and provide strategic advice for these otherwise independent research centers. The combined annual budget of the Centers now exceeds $250 million and is provided by some 40 public and private donors. Among members of CGIAR are the World Bank, the Food and Agriculture Organization of the UN, and the UN Development Program, as well as national development cooperation organizations such as the U.S. Agency for International Development and the Canadian International Development Agency. The World Bank has lead responsibility for the funding consortium.

The original four centers, the International Rice Research Institute (Philippines), the International Center for the Improvement of Maize and Wheat (Mexico), the International Institute for Tropical Agriculture (Nigeria), and the International Center for Tropical Agriculture (Colombia), existed independently before the group's inception. However, they all relied to different degrees on the same funding sources, the Ford and Rockefeller Foundations. Over time, the membership of CGIAR grew both because other existing centers joined the Group and because the Group's secretariat and its Technical Advisory Committee (TAC) had identified a clear strategy and long-range vision for related research functions. Most recently, a decision has been taken to add centers in the area of forestry.

Although the Group's goal is broad—alleviation of hunger and poverty through expanded and improved food and fiber production—each center has conspicuously narrow objectives. Each generally focuses on one or a few particular commodities within particular landscapes. One, the International Food Policy Research Institute, integrates scientific assessments and economics into food policy studies and is one of four centers not located in a developing country. Field testing and demonstration of new varieties and farming systems in the fields of actual farms, particularly small farms, is an integral activity of most centers.

Although most evaluations of CGIAR and the institutes it supports have been strongly favorable, certain weaknesses have caused concern. These include inattention to environmental aspects of agricultural production, homogenization of agricultural systems, insufficient transfer of technology to local farmers, draining of scientific talent from developing countries to a few international centers, and growth to a scale of effort where synergies, coordination, and excellence are harder to obtain.

Table 1. The International Agricultural Research Centers

Name	Location	Principal Research Subjects	Authorized Senior Positions, 1991	Core Funding, 1991 (in millions US$)
1. CIAT Centro Internacional de Agricultura Tropical	Colombia	Beans, cassava, rice in Latin America	89	28.1
2. CIMMYT Centro Internacional de Mejoramiento de Maíz y Trigo	Mexico	Wheat, maize	91	27.1
3. CIP Centro Internacional de la Papa	Peru	Potato	87	16.4
4. IBPGR International Board for Plant Genetic Resources	Rome	Genetic conservation	31	7.7
5. ICARDA International Center for Agricultural Research in the Dry Areas	Syria	Dry area farming systems, barley, lentils	72	19.8
6. ICRISAT International Crop Research Institute for the Semi-Arid Tropics	India	Sorghum, pigeonpea, groundnut	102	29.2
7. IFPRI International Food Policy Research Institute	Washington, DC	Food policy	39	8.9
8. IITA International Institute of Tropical Agriculture	Nigeria	Rice, maize, and cassava in Africa	106	23.2

9. ILCA International Livestock Center for Africa	Ethiopia	Livestock production systems in Africa	67	20.2
10. ILRAD International Laboratory for Research on Animal Diseases	Kenya	Animal trypanosomiasis, East Coast fever	61	13.5
11. IRRI International Rice Research Institute	Philippines	Rice	78	29.6
12. ISNAR International Service for National Agricultural Research	Netherlands	National research systems	34	6.8
13. WARDA West Africa Rice Development Association	Côte d'Ivoire	Rice in West Africa	33	6.4
14. ICRAF International Center for Agroforestry	Kenya	Agroforestry	66	10.8
15. IIMI International Irrigation Management Institute	Sri Lanka	Irrigation	38	7.1
16. INIBAP International Network for the Improvement of Banana and Plantain	France	Banana, plantain	10	1.9
TOTAL			1,004	256.7

Box 2. START Network for Global Change Research

The Scientific Committee of the International Geopshere–Biosphere Program (IGBP) has proposed the establishment of a new international system of regional networks, research centers, and sites to gather data and study problems of global environmental change in their regional context. The purpose of the IGBP is to describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human action. The proposed System for Analysis, Training, and Research (START) would have five functions: research, including documentation of environmental change; training; data management; synthesis and modeling; and communications between scientists and public and private sector decision makers. It would seek to cultivate a "practical predictive capacity."

The original START proposal envisions the organization of effort around 14 regions (as well as the open ocean) defined by geography and climate, with highest priority given to initiatives in equatorial South America, Northern Africa, the tropical Asian monsoon region, temperate South America, southern and eastern Africa, and arid central Asia.[13] START would be integrated with relevant international research programs such as the IGBP, the World Climate Research Program, and the program on Human Dimensions of Global Environmental Change.

A workshop was held in January of 1992 to explore needs and opportunities for START in Southeast Asia, and other regional explorations are under way. The Scientific and Technical Advisory Panel of the Global Environment Facility under the auspices of the UN Environment Program, the UN Development Program, and the World Bank has expressed interest in the START initiative. Meanwhile, in the same spirit as START, a group of Western Hemisphere nations has undertaken to create an Inter-American Institute for Global Change Research. Among other things, the Institute would undertake interdisciplinary research on issues unique to the region and significant on a global scale and promote education of young scientists, especially from Latin America, in the sciences critical for understanding global change.

Networks and Centers of Excellence

The notion of new international environmental networks and centers has been explored and endorsed in various forms by the International Geosphere–Biosphere Program, the April 1990 White House Conference on the Science and Economics of Global Change, the Second World Climate Conference (Geneva, November 1990), a Task Force of the Environmental and Energy Study Institute of the U.S. Congress,[14] the November 1991 ICSU Conference on an Agenda for Science for Environment and Development for the 21st Century (ASCEND-21),[15] and the Engineering Partnership for

Box 3. Global Biodiversity Inventory: A Potential CGREEN Project

Visualizing the plants, animals, fungi, and microorganisms in a country as an asset to be used, cared for, conserved, and taken into account in land-use decisions is extraordinarily important for a rational approach to biological diversity. All countries will benefit from increased knowledge of the distribution and identity of species and their roles in ecosystems and of the distribution of communities and ecosytems. Few countries have carried out current national biological surveys based on modern concepts of ecology and systematic biology or have useful, accessible national biological databases for monitoring the distribution and status of species and ecosystems. Canada, Australia, and Costa Rica are among the countries that have recently initiated national biological inventories. The United States has yet to begin. A greatly enhanced and coordinated international effort is needed to multiply national efforts, make them complementary to one another, facilitate regional studies, and extend coverage to marine and other common areas so that, over time a Global Biodiversity Inventory would become available. At present there is no effective international mechanism to help stimulate these efforts, to anchor them scientifically, and to help assure that knowledge gained will be disseminated appropriately to researchers and public and private decision makers.

Sustainable Development. Proposals for the establishment of networks are in various stages of development, and a new inter-American center for the science and economics of global change is being established.[16]

We agree that both new networking arrangements to meet collective challenges and centers of excellence to speed progress toward specific environmental research goals are required. Now is the time to bring together the discussions about international environmental research networks and centers in a coherent, thorough evaluation. The evaluation of new international environmental networks and centers could be organized under the auspices of the new CGREEN, UNEP, new mechanisms that might emerge from UNCED, an *ad hoc* ministerial-level committee on environmental research policy reporting to the General Assembly of the UN, or the nascent OECD forum on megascience.

PURPOSES

The primary question for such an evaluation concerns the fundamental purposes of the networks and centers. We believe these should be

- To assist in the development and strengthening of national environmental research systems, especially in developing countries, through provision of advisory services, networking, training, and other means. If national capabilities are not developed further, international networks and centers, no matter how generously supported, will not be able to address the range of problems that must be addressed or to transfer the results to local decision-makers for incorporation into policy and regulation.
- To provide advanced training for young researchers in settings that will increase their ability to draw upon the worldwide pool of knowledge in environmental sciences.
- To conduct research on long-range problems of regional and global importance on which national efforts may fall short, especially where continuous, interactive approaches to problems by multidisciplinary teams, which are difficult to assemble in a national context, are needed.
- To broaden substantially the capability of all nations to contribute to global studies and to assess for themselves the validity of such studies and to understand regional issues in a global context.
- To help link environmental research to environmental assessment and management.
- To broaden national capabilities to apply the results of research to operational decisions in energy, transportation, agriculture, and industrial development that affect the environment both locally and globally.

Even with agreement on such purposes, many questions remain to be discussed in an evaluation (Box 4).

RECOMMENDATIONS

In view of the recommendations of the 1990 White House Conference on the Science and Economics of Global Change, the successful role of the United States in launching the Budapest regional environment center for Central and Eastern Europe, and the ongoing efforts, supported by the U.S. Government, to create a regional environmental institute for the Americas,[17]

- **We urge the U.S. Government to take a leading role and join with the World Bank and private philanthropic foundations to initiate discussions with potential members of an international Consultative Group for Research on Environment to encourage their interest and participation in its formation.**

Box 4. Questions for International Networks and Centers

- Should the strategies of the networks and centers be territorial (e.g., arid, polar, coastal, or humid tropical regions), thematic (biodiversity, materials flows and fluxes, energy-environment interactions), or methodological and disciplinary (e.g., interface of economics or health with environmental change, remote sensing)?
- What disciplines should be involved? Many fields, ranging from glaciology to economics, have demonstrated their ability to contribute to increased understanding of environmental change and of local causes, manifestations, and adaptations. What roles should engineering and social sciences play?
- What should be the balance among field and laboratory work, modeling, and policy analysis? Between understanding and mitigation of problems?
- What should be the balance of effort between creation and diffusion of knowledge? How much effort should be devoted to research, advanced education, and training?
- What should be the relationship to particular existing international research programs? Should new centers have a special relationship to programs such as the World Climate Program and the International Geosphere–Biosphere Program?
- Should membership consist of new institutions or include some existing institutions, with either little or extensive modification? What balance of networking of existing institutions and building of new institutions is required?
- What should be the balance between institutions located in the industrialized world and those located in developing nations?
- How many centers are required that would be sponsored, staffed, managed, and financed on an international basis? How large an overall effort should be contemplated for the long run?
- In centers, what should be the balance of personnel between those coming from the region and those coming from outside the region?
- How can the centers and networks be funded, and what levels will be required for effectiveness?
- What degree of coordination should be maintained on a global basis?
- What should be the relationship of the networks and centers to governments? Intergovernmental organizations? Private industry?
- How will the centers and networks foster creativity and risk taking?
- What provisions should be made for evaluation and for letting ineffective organizations leave the network?

■ Furthermore, we urge the U.S. Government to stimulate a unilateral U.S. study of needs and priorities for international cooperation in environmental research by the National Research Council or other qualified group that would be conducted in preparation for and as a contribution to the international evaluation proposed above and to convene high-level federal agency representatives to develop a coherent U.S. Government strategy for participation in international environmental research.

4
STRENGTHENING INTERNATIONAL ASSESSMENT AND ADVISORY MECHANISMS

NEED FOR INTERNATIONAL ASSESSMENT AND ADVICE

Addressing international environmental issues such as climate change, ozone depletion, and acid rain requires harnessing the knowledge of the international scientific and technical community in a timely way to provide authoritative assessments and advice useful to concerned governments and intergovernmental organizations. Governments base decisions on these and other issues in part on the assessments, options, and recommendations available from technical experts. The assessment function is distinct from the conduct of environmental research and even from provision of data for assessments. However, it will be sound over the long run only if there is a broad and deep base of knowledge on which to draw.

The pressing and evident need for environmental assessment, in fact, is one example of a generic need for such capability. Mechanisms are required at the international level for the assessment and synthesis in more usable form of what is known about many issues of a scientific and technical nature. The approaches explored in this report for the environmental field may also apply in health and other fields where international collaborative assessments are needed.

Assessments prepared jointly by experts from several or many countries are desirable for a range of reasons. One reason is that scientifically rigorous and accepted analyses and assessments to which experts from many nations have contributed can facilitate the process of negotiating and managing sound international agreements. Moreover, collective efforts, drawing on expertise and data worldwide, may be of higher quality and credibility than individual nations can achieve. The variety of critical perspectives offered by an international group can be important in producing a balanced view on issues.

Although results need to be reproduced and checked, a process that helps spread ideas and understanding, it is desirable to avoid the inefficient case where most nations perform their own comprehensive assessments, largely using the same data and duplicating one another's work. Nations will, of course, continue to interpret any international report in national terms and may sometimes carry out an associated national analysis. Only a fraction of the nations of the world have the depth and breadth of scientific expertise to provide comprehensive assessments on complex issues using their own citizens and resources. On virtually all issues, even the United States already draws for its "national" studies on experts and findings from abroad.

The intent of international assessments is not to centralize the assessment function. Rather, it is to respond to needs at the international level. Because few fully international studies are likely to be carried out, and because both their cost and their influence may be great, it is imperative to ensure that they are conducted in the best possible manner. They should be carried out through processes that can do more than simply reinforce the conventional wisdom or produce agreement on matters of minimal substance.

The question is, then, the adequacy of the current means by which the main partners of international science, namely national governments and intergovernmental organizations, acquire and use science and technology information relevant to their missions and duties with regard to the environment.[18] In existing or emerging issues, are there satisfactory means for developing assessments? And is the assessment process appropriately coupled to potential users? In light of the growing importance of the advisory function, it is timely to review ways in which organizational performance can be improved.

THE ASSESSMENT AND ADVISORY FUNCTIONS

The main charges to science and technology groups providing assessments and advice are to review what is known about actual problems and to evaluate critically from a scientific perspective the programs and plans developed to deal with them. Every issue mentioned in this report, whether marine oil spills, loss of biodiversity, or radioactive waste storage, needs to be assessed at various times for the quality of knowledge bearing on it, for needs for further research, for risks posed, and for alternative futures that may follow and their sensitivity to assumptions (see Box 5).

Using various indicators and analyses, assessment and advisory groups can also provide early warning of impending problems by identifying previously unrecognized ones and by flagging those that are known but little no-

Box 5. The Aral Sea: Need for International Assessment and Advice

Crisis conditions prevail today in the basin of the Aral Sea, which drains five republics of the Commonwealth of Independent States. The health of people and the quality of ground and surface waters, soils, and the biota are at serious risk. In a series of reports dating back to the 1950s, many facets of the region have been analyzed, and many plans have been made. Although these efforts have generated a great deal of information, it is clear that a fresh, critical view is needed that would be acceptable to the new governments of the region and that such a view would benefit from participation by experts from outside the region. A new diagnostic study has been conducted under UNEP and is being reviewed by an international group.

The area has fallen victim to the narrow views of professional resource managers, as well as to the inflexibility of central government planners, shortsightedness of government policies, rapid development, and absence of independent monitoring and evaluation of the performance of development agencies. Successful past attempts by groups of international experts to identify gross deficiencies before environmental disaster became irreversible included the Indus panel on salinity and waterlogging in 1961 and the Nile water quality study in the 1970s and 1980s. More recently, the United Nations Environment Programme has supported diagnoses of the Lake Chad and Zambezi basins, the latter carried out in collaboration with the International Institute for Applied Systems Analysis. The crisis of the Aral Sea basin provides a useful opportunity to develop better mechanisms for supporting and carrying out studies that bring to bear the rich resources of international scientific skill and experience, and the attendant public scrutiny, on major development programs.

ticed. Environmental monitoring reflects past views of what is significant in environmental processes. Key challenges are to provide foresight, to anticipate threats to the environment in order to manage them before they become crises, and to gather sufficient data to see new patterns reliably.

It is often valuable in assessments to examine both the most probable outcomes and a range of less likely outcomes of alternative policies, to explore policy alternatives, and to provide balanced alternatives on policy priorities. Successful assessments integrate knowledge from many scientific disciplines and are alert to the links among issues. Addressing one environmental problem may have opportunity costs or consequences for other environmental and nonenvironmental problems. Policy evaluation will help answer such questions as whether environmental management strategies work. Evaluation is essential to improve the design of policies to speed social learning.

The purpose should always be to clarify and inform debate. Efforts should weigh the best available scientific evidence, distill trends, and reckon with uncertainty in order to provide the most definitive possible authority on the state of knowledge of a particular topic. Critical analyses and carefully drawn recommendations should serve as guides for action.

U.S. MODELS FOR PROVIDING ADVICE TO GOVERNMENT

Nations have evolved mechanisms specific to their political systems to provide balanced scientific and technical assessments in areas of relevance to public policy. In the United States, probably the three most important formal sources of science and technology advice and assessment for government are the National Research Council (NRC), the Office of Technology Assessment (OTA) of the Congress, and the Assistant to the President for Science and Technology.[19] Many nongovernmental organizations, including professional societies, think tanks, advocacy groups, and university centers, also provide assessments and advice.[20]

The National Research Council

The group most frequently called upon is the National Research Council (NRC), the operating arm of the three leading honorific societies in America for science, engineering, and medicine, the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine. The NRC, which conducts about 200 studies per year, operates under the congressional charter of the National Academy of Sciences and thus blends the independence of action of a nongovernmental body with a tradition of public service. The NRC is perhaps the largest and most experienced body in any nation providing independent scientific and technical advice to government. In response to requests for studies, the NRC typically forms a panel of experts, who remain based at their home institutions but work together part-time for 1–2 years with a small full-time staff to study an issue and write a report. The panelists and the institution as a whole through its review process assume complete responsibility for the resulting reports.

The Office of Technology Assessment

The OTA, now 20 years old, has developed similar competence and credibility as a governmental institution. In the OTA model a primary role is played by professional full-time staff members. They work with inputs from advisory panels that include both experts and laymen, but the staff members and OTA management take final responsibility for analyses and conclusions. Because the NRC and OTA have developed reputations for high-quality assessments, their reports have considerable influence on formation of policy in the U.S. Government. Although the reports are commissioned by specific executive agencies or congressional committees, the reports are almost always made widely available. Both NRC and OTA reports circulate and sometimes have considerable influence outside the United States.

The President's Science Advisor

The needs of the President for timely and often confidential advice on particular questions are met directly or indirectly by the Assistant to the President for Science and Technology, more commonly known as the President's Science Advisor. The Science Advisor also chairs the President's Council of Advisors on Science and Technology (PCAST), a group of distinguished scientists and engineers who meet periodically to address concerns of the President. The Science Advisor directs the White House Office of Science and Technology Policy (OSTP) and leads the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET), which brings together high-level representatives of many executive branch agencies. Although the advice of PCAST and the President's Science Advisor is directed primarily to the President, their occasional public reports can also be widely influential. The intensely political environment that surrounds a head of state and the personal style and wishes of the head of state inevitably create fluctuations in the role and performance of this advisory mechanism.

ATTRIBUTES OF SUCCESSFUL SCIENTIFIC ADVISORY MECHANISMS

Several key features of the successful design and functioning of organizations conducting assessment and advisory functions at the national level are likely to apply to structures advisory to international bodies as well.

INDEPENDENCE

It is most important to be able to "speak truth to power." The NRC derives its insulation from political pressures from the structure of the National Academy of Sciences as a private, self-governing, nonprofit organization and from the traditions and prestige of the Academy.[21] OTA is buffered from political pressure by a bipartisan congressional governing board and an independent technical advisory committee. Traditionally, the membership of PCAST's predecessors remained much the same even where there was a change of the political party in power. Many countries do not have a history of permitting, much less encouraging, independent scientific review of public programs, plans, and issues.

OPENNESS TO NEW IDEAS

Processes that assure a fair hearing for new, dissident, and dissonant views are critical. It is often difficult for groups, particularly of eminent people, not simply to converge to the mean or to repeat conventional wisdom. Assuring a balanced age distribution is one strategy that is often helpful in preventing ossification.

AUTHORITY TO HELP DEFINE TASKS

Although the agenda of an organization performing assessments and the selection of topics should be strongly influenced by its funders and clients, the organization needs a robust governing body and professional norms to ensure consideration of the merits of the studies requested and approval of only those studies that address pressing concerns. It is important to decide whether the question is one that can be answered, whether there are sufficient data to allow analyses or assessments of the issue, and whether expertise can be recruited to accomplish the study. It is extremely valuable for an assessment organization to have access to enough independent or discretionary funds to enable it to explore on its own initiative selected topics that it judges to be of great importance.

Relationship to Clients

Most NRC reports result from requests made by the U.S. President, Congress, or executive agencies, with funds typically disbursed by the executive agencies, though sometimes mandated in legislation. The committees of the Congress are the exclusive client of the OTA, though its reports receive wide dissemination inside and outside government. The NRC and OTA have special contractual and statutory relationships and agreements with the U.S. Government that couple them to the needs of government yet protect their independence in the conduct of studies. Most advisory efforts at the international level would be in response to requests from groups of governments, interparliamentary groups, and agencies of the United Nations and other intergovernmental organizations. How arrangements comparably supportive of independent and objective assessments might be designed at the international level needs to be carefully considered. An experimental learning process similar to that undergone by the NRC and OTA may be required.

Access to Information and Networks

For assessment and advisory functions, access to information and networks is more important than laboratories and equipment. Organizations fulfilling the assessment function need not themselves be engaged in original research except in so far as new knowledge may be required to meet assessment needs. Efforts rely largely on the existing scientific base. When information is lacking, it is sometimes necessary to conduct surveys and assemble new data bases. Moreover, part of the function of assessment is to identify research needed for clearer understanding of the problem.

Ability To Harness Talent

The fundamental strength of an assessment or advisory mechanism must be its ability to recruit the best engineers and scientists to work on the topic under consideration. This ability will be a function of an organization's perceived independence, its record for issuing high-quality reports, and evidence that reports receive serious consideration at high levels. The organization must also have adequate staff to fulfill administrative functions, coordinate technical aspects of studies, provide data gathering and editing, and in some cases contribute to the technical work itself.

Policies and Procedures for Carrying Out Studies

Conduct of assessment studies is likely to benefit from well-defined and well-understood policies and procedures designed to ensure that reports produced are timely, objective, and technically sound (Box 6).

INTERNATIONAL MECHANISMS FOR SCIENCE ADVICE ON ENVIRONMENT

Intergovernmental Organizations

Several intergovernmental organizations both perform environmental assessment and advisory functions for member governments and are themselves clients for advice. Some intergovernmental organizations have creditable records and considerable experience in assessment activities. Within the UN system, this is true, for example, of the International Atomic Energy Agency. OECD advisory groups and NATO's Committee on Challenges of Modern Society have also contributed valuable assessments and advice on environmental matters.

The most common means for UN and other intergovernmental agencies to fulfill these functions is through reliance on *ad hoc* or standing panels of appointed experts associated directly with the agency. In some cases an *ad hoc* institutional mechanism drawing together governments is created, such as the Intergovernmental Panel on Climate Change (IPCC). The IPCC has conducted a series of assessments of the climate question on behalf of the UN Environment Program and the World Meteorological Organization.[22] Other than the IPCC, few of the organizations were created and designed primarily to advise governments on technical aspects of issues.

The expert panels associated with UN and other intergovernmental bodies sometimes perform well. However, it is questionable whether these mechanisms can retain on a regular basis enough of the features that characterize the best national advisory arrangements; if they cannot, their ability to play a much increased role in providing assessments and advice is in doubt. The inherent deficiencies of intergovernmental bodies suggest alternatives. The central problem, particularly in the UN, is too much emphasis on country representation on both advisory committees and agency staffs, aggravated

Box 6. Policies and Procedures for Conduct of Advisory Studies

- Ways to ensure that the fullest possible range of appropriate expertise is represented
- Ways to ensure proper balance between experts chosen on the basis of professional qualifications and others participating because of affiliation with groups affected by the issue to be examined
- Procedures for identifying sources of bias and conflicts of interest, including professional, political, and financial connections, public statements about the study topic, and highly visible public commitments to a particular policy position on the issue under study
- Guidelines for the status and participation of representatives of agencies and organizations that are funding the studies
- Guidelines for the authority of a chair and the conduct of committee business, including confidentiality of discussions and drafts
- Review procedures requiring individuals who are not involved in authoring the work to verify that an assessment, including conclusions and recommendations, is supported by the body of a report, and fulfills high standards of evidence and reasoning, and to evaluate whether the report is responsive to the sponsor's request, and whether it is clearly and concisely presented
- Procedures for responding to review and for cases where a consensus is not reached and for handling of dissents
- Rights of sponsoring organization to review or alter text of reports and limit publication or dissemination
- Policies for compensation and reimbursement of expenses of experts who participate in studies.

by uncertainties about when experts are speaking for themselves and basing their views on their own expert technical knowledge and when they are representing an official position of the country or group of countries from which they come. Among other generic problems of existing intergovernmental science advisory mechanisms are that they meet too infrequently, have inadequate continuing staff and therefore lack "organizational memory," and leave large gaps in the issues and subject matter covered.

The Alternatives

There are two main alternatives: to obtain advice and assessment through international nongovernmental scientific and technical organizations or through networking of national counterpart organizations. Numerous nongovernmental organizations seek to alert governments and the public about various environmental questions. Several of these organizations appear to have an organizational structure and the foundation in science and technology that could support an expansion of their roles in advising governments on environmental issues at the international level on an ongoing basis. An appraisal is needed of the effectiveness of each of these organizations, their promise as advisory bodies to governments and intergovernmental bodies, and the best way to take advantage of that promise. There are several examples of such organizations.

International Council of Scientific Unions

The International Council of Scientific Unions (ICSU) is a federation of some 75 national academies of sciences and 20 disciplinary unions representing most of the natural sciences. It comes closest at the international level to having inherent in its design the distinguished traditions of science that have been helpful to national institutions, like the NRC. ICSU has demonstrated its potential in assessment functions in several ways, including the efforts of its standing interdisciplinary scientific committees such as SCOPE (see Box 7). ICSU has also served as the designated principal scientific advisor to the United Nations Conference on Environment and Development.

Council of Academies of Engineering and Technological Sciences

The federation of national academies of engineering, the Council (CAETS) is beginning to assume the role of an engineering counterpart to ICSU. It has recently participated in an advisory study for UNEP on issues involved in transfer of technology for CFC substitutes to developing countries.

International Institute for Applied Systems Analysis

Established at the height of the Cold War at the request of the United States and the Soviet Union to work on problems common to industrialized societies, the International Institute for Applied Systems Analysis (IIASA) is a nongovernmental research institute supported by some 15 industrialized nations as well as by contracts with intergovernmental and national bodies. Its program has concentrated on global studies in fields such as energy, food, and environment. IIASA served as a scientific advisor to the Economic Commission for Europe on aspects of the acid rain question.

Box 7. The Scientific Committee on Problems of the Environment (SCOPE)

The concern that led to the 1972 Stockholm Environment Conference also generated the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU). SCOPE was created as a new international, interdisciplinary group to define problems and mobilize scientific resources. After an initial period of assisting in the preparations for Stockholm, SCOPE settled on an approach relying on national committees established in 35 countries and liaisons with 17 of ICSU's international unions and associations, which mostly follow the lines of scientific disciplines. SCOPE's first reviews focused on needs for environmental monitoring and an action plan for the Global Environmental Monitoring System of the UN Environment Program.

The role of SCOPE is to help the scientific community define the central questions, review the status of current knowledge, point out policy implications, and recommend promising lines for further research. SCOPE has now published more than 40 reports, and some 2000 scientists have taken part in SCOPE activities. SCOPE avoids standing committees and concentrates on recruiting people and funds for each problem as it is identified. SCOPE has not established permanent institutions, but has fostered groups that have taken on lives of their own. For example, the International Registry of Potentially Toxic Chemicals was proposed by a SCOPE group, and the International Ground Water Modeling Institute and the Monitoring and Assessment Research Center in London both began under SCOPE auspices.

SCOPE's contributions include

- A 1975 appraisal of methods of environmental impact assessment growing out of a meeting of developing-country scientists that was widely used and later accompanied by studies of environmental risk assessment
- Reviews of the nitrogen, phosphorus, sulfur, and carbon cycles that led to more sophisticated understanding of global biogeochemical cycles and underpinned the numerous scientific assessments of global climate change
- The first international examination of the environmental consequences of nuclear war—physical, atmospheric, ecological, and agricultural—which became the basis for a 1986 United Nations report on the subject and triggered further studies of the environmental paths and effects of radionuclides.

Data from G. F. White, 1987, "SCOPE: The First Sixteen Years," *Environmental Conservation* 14(1):7–13.

Third World Academy of Sciences

The Third World Academy of Sciences (TWAS) has a dual structure embracing both the most distinguished scientists of developing countries and the leaders of science ministries of these countries.

Box 8. The IUCN Advisory Role in Protecting Endangered Species

The International Union for the Conservation of Nature and Natural Resources (IUCN) has developed considerable expertise in the taxonomy and global abundance of various species. It serves as the secretariat to the Convention on International Trade in Endangered Species (CITES) under contract with UNEP. Through its "Red Book" studies, IUCN periodically disseminates the latest research and monitoring on species. The information is used by the CITES secretariat and by the CITES parties in deciding whether and how stringently to control trade in those species.

International Union for the Conservation of Nature and Natural Resources

The International Union for the Conservation of Nature and Natural Resources (IUCN) is also known as the World Conservation Union. IUCN is a quasi-nongovernmental organization whose membership includes nongovernmental organizations from 120 countries, international NGOs, as well as representatives of states and government agencies. Its goals are to ensure sustainable use of renewable resources, maintain essential ecological processes, and conserve genetic diversity. It has played a key assessment role with respect to endangered species (Box 8).

Regional Academies and Similar Organizations

Many assessments of environmental issues may be regional, rather than global. Thus, organizations with a regional assessment capability may have major roles. These could include the African Academy of Sciences, the Academia de Ciencias de America Latina, the Federation of Asian Scientific Academies and Societies, Pacific Science Association, and the Academia Europaea.[23]

RECOMMENDATIONS

▪ **Steps should be taken to improve international environmental assessments and to enhance the integration of science and engineering knowledge with policymaking at the international level. This should be done through the development of systematic and well-understood relationships**

between the international mechanisms for provision of scientific assessments and advice on the one hand, and governments and intergovernmental bodies on the other. Over the next decades a system of advisory structures should be developed at the international level that is more comparable in performance to what has been achieved at the national level in the United States and other countries. We recommend evaluation of additional and alternative capabilities among existing organizations whose structure and culture might enable them to meet new and expanding needs.

Steps to Improve Assessments

The following steps should be taken to improve assessments:

- The U.S. Government should review organizations with the potential to play enhanced roles at the international level with regard to science and technology assessments and advice in general and in the environmental field in particular. It should develop ideas to energize these organizations and should encourage and communicate its expanded vision of the future role of these organizations.
- Accordingly, U.S. representatives to and affiliates of organizations with the capability for international science and technology assessments and advice should urge these organizations to review carefully their intellectual resources and their policies and procedures for the joint international conduct of assessments.
- U.S. organizations providing science advice, particularly the National Research Council, the Office of Technology Assessment, and the Office of Science and Technology Policy, should develop policies and enhance their capacity to carry out international studies through partnerships and alliances with counterpart organizations abroad.[24]
- To encourage the creation and strengthening of counterpart organizations in other nations, the NRC, OTA, and OSTP should stimulate meetings at which counterparts and potential counterparts convene to exchange experiences, learn from one another, and explore formal and informal procedures for networking and joint efforts.

Steps To Improve Coupling of Science and Policy

The following steps should be taken to improve the coupling of science and policy:

■ The United States, other nations, and the UN system should provide core funding for a fixed period, perhaps five years, to selected nongovernmental scientific and technical organizations for the purpose of building their capacity for international assessment and advisory functions.

■ The United States Government, in association with other governments, should promote agreements that provide a framework for cooperation between such organizations and national governments, the UN system, and other intergovernmental bodies that would expedite the conduct of studies when sponsoring governments or agencies request them.

■ Nongovernmental scientific organizations with capabilities to provide assessments and advice should enter into discussions with the governmental partners of the international science community to make their capabilities better known.[25]

CONTINUING EVALUATION

As negotiation of international environmental agreements proceeds and nations seek to formulate policies sensitive to the international context, the potentials for assessment and advice through international and intergovernmental organizations and through networks of national bodies should be kept in mind. As the potentials are realized, governments and intergovernmental organizations should carefully evaluate how the advisory mechanisms have contributed to better decision making and what improvements are needed.

5
CODA

The current heightened interest in global environmental issues is the result of many manifestations of the scientific, technological, and socioeconomic explosion that both brings into question the prospects for humankind and the Earth and opens vistas of a better future. Discussions in all nations need to be deepened to address the driving forces of environmental change. These lie in the expansion of population and its material behavior, the industrial metabolism that converts natural resources into goods and services, disparities in development, and the dynamic character of the environment itself.

The forces driving the problems are so strong that it will take concerted efforts over decades to affect them and their results significantly. There is legitimate concern that human knowledge, skills, and social organization may not keep pace with these forces, and that environmental deterioration and associated conflict will ensue. We may be reaching a critical phase of life on Earth in regard to compatibility between human aspirations and planetary life support systems. A fundamental restructuring of the global economy may be needed to deal simultaneously with issues of distributional equity, human numbers, and sustainable economic growth.[26]

Twenty years ago the world was wise enough to identify an emerging set of environmental issues and put in place basic elements of national and international organization to address them. Now additional and stronger mechanisms for creative interaction of an unprecedented kind and extent among science, technology, and society are needed to ensure lasting integrity of the environment and natural resource base.

National capabilities are of prime importance for the better management of global ecosystems. For most of the world, there is too little hope of building the capabilities to empower countries to deal with the problems faced on a national, regional, or international basis. If nourished and attended, the initiatives outlined here could both catalyze the development of national capacity and enable nations collectively to enhance the global environment and not merely view it with alarm.

Initiatives to strengthen and interrelate worldwide capabilities for environmental research and to improve environmental assessment and its coupling to decision making are requisites for a sound and widespread understanding of the environmental challenge and effective worldwide responses and strategies. We believe it is possible to create and diffuse the knowledge and technical ability to improve the human and planetary prospect substantially.

- **Through its own actions and commitments, we urge the United States to lead in promoting the objectives and recommendations of this report in the UN and its specialized agencies, the World Bank, and other relevant bodies.**

APPENDIX A
ENVIRONMENTAL TRENDS SINCE 1970

Three perspectives help suggest the lessons (Chapter 2) that influence the urgency and specific needs for innovation in organizational arrangements and decision-making processes. The first examines indicators of the underlying forces of economic and population growth and development. The second looks directly at the condition of the environment. The third perspective focuses on changes in management and institutions. Data sources are listed at the end of the Appendix.

UNDERLYING FORCES OF GROWTH AND DEVELOPMENT

POPULATION

In 1970 global *population* was estimated at 3.7 billion. By 1992 it is believed to have reached 5.4 billion. Some 90 percent of the growth took place in developing regions. Population growth slowed in the last two decades, but only to a rate that leads demographers to hope that global population may eventually stabilize between double and triple current levels. While in 1970 almost 60 percent of world population remained rural, by 1990 55 percent of the population was concentrated in cities. *Urbanization* has been fastest in developing countries, where the cities grew by more than one billion people. The continuing heavy toll from "natural" disasters is strongly associated with large and growing populations in risk-prone areas, such as flood plains and low-lying coastal regions.

Energy Consumption

While the world and its cities and coasts became more crowded, over the same period commercial *energy* consumption grew even faster, from the equivalent of about 5 billion tons of oil during 1970 to a current annual figure of about 8 billion. Globally, per capita commercial energy consumption rose about 10 percent. Rapid energy growth shifted from industrialized to developing countries. Per capita commercial energy consumption in low-income countries more than doubled. Absolute consumption remains centered in the wealthy industrialized nations, where 15 percent of the world's population consumes about half its energy.

Not only has energy use increased, but the estimates of energy resources that might eventually be tapped have grown. Contrary to expectations that the world would begin to exhaust its so-called fossil (hydrocarbon) fuels, proven reserves of oil have increased from 600 billion barrels in 1970 to 1,000 billion at present, even though 400 billion barrels of oil have been pumped from the ground in that time. Proven natural gas reserves have expanded by a greater amount. The possibility that some environmental issues would diminish because of depletion of exhaustible resources has thus become more, not less, remote.

In some respects, the global energy system has evolved in a cleaner direction. While many were predicting increased reliance on "dirty" fossil fuels such as coal and oil shale, the reverse is occurring. The share of world primary energy served by natural gas, the cleanest fossil fuel, has increased by one quarter. Compared with coal and oil, burning natural gas releases lower quantities of several major pollutants, including sulfur dioxide, carbon dioxide, and particulates.

Since the early 1970s, energy intensity, measured in energy used per dollar of gross domestic product, has decreased in 19 of the 24 advanced industrialized nations that belong to the Organization for Economic Cooperation and Development (OECD). Energy efficiency has increased. The average rate of improvement that has persisted in the OECD nations doubles efficiency in about 30 years. However, overall efficiency remains extremely low, with perhaps 90 percent of energy lost or wasted in the complete process of conversion from the raw material such as coal to the final energy service such as the light to read a book. Further large increases in energy efficiency are clearly attainable through technological progress, though there are ultimately thermodynamic limits.

Much of the expanded consumption of energy has been channeled into *electrification.* In the decade of the 1980s, world production of electricity increased by over 40 percent. Electricity consumption increased more rapidly than nonelectric energy in both industrialized and developing countries. As with growth in primary energy consumption, electrification has been more rapid in developing countries. In Africa, for example, increases in electrification have been nearly double the world rate. In contrast to the experience of industrialized countries, most electricity in Africa has been provided through expanded use of fossil fuels.

Generally, with electrification has also come a trend away from fossil fuels, primarily through expanded use of nuclear power, especially in industrialized countries. Although the future of nuclear power remains uncertain and there are important differences in national experiences with nuclear programs, in less than two decades the capacity of operating nuclear plants has increased nearly twentyfold. The world of the 1990s is much more nuclear than the world of 1970, although Chernobyl and other nuclear accidents have heightened nuclear fears that were less apparent 20 years ago. In contrast to 20 years ago, few nuclear plants are under construction. The combination of the shift from carbon-heavy fuels such as coal and oil to carbon-light gas and the growth of nuclear power account for the gradual "decarbonization" that is the central tendency of the world energy system.

TRAVEL

With more people and more energy has come more *travel.* Global affluence has vastly increased mobility. The number of motor vehicles in use worldwide has more than doubled to the imposing figure of about 540 million. Automobility in countries with rapid economic growth such as Japan has increased fastest. North America had slower but substantial relative growth, and enormous absolute growth, expanding its fleet from about 120 million motor vehicles in 1970 to about 200 million in 1990. There have been steep increases in car population in developing countries, but it remains unclear whether cars will pervade these societies as they do the North. Air travel roughly tripled, growing much faster than use of the automobile, globally and in almost all nations.

Agriculture and Food Production

With larger and wealthier populations have also come important changes in *agriculture* that affect the environment. Most of these changes have come through intensification of production, as the global area of arable and permanent cropland has changed little since 1970. Over that time application of chemical fertilizers increased by three-fourths. As with growth of energy consumption, the largest percentage increases were in low-income countries. Currently, fertilizer application rates in low-income countries are about 60 percent of those in high-income countries; in 1970 they were only 17 percent. Increased mechanization and irrigation have squeezed more product from the same plot of land. The use of pesticides does not appear to have increased in industrialized nations, and in some it has decreased. There are no aggregate data for pesticide and herbicide trends in developing countries, but use has almost certainly increased substantially.

Several cycles of more productive seeds have been bred and put into use for many crops since 1970, and the number of gene banks, the source of raw materials out of which better crops are obtained, has multiplied tenfold. Yields for staple crops such as wheat and rice have grown faster than human population. Overall, food production has kept pace with population, even in sub-Saharan Africa, where many of the world's poorest countries are located. Trade in agricultural products has expanded dramatically. Grain imports by Asia have more than doubled since 1970. The direction of *dietary behavior*, toward higher meat consumption (including fish and poultry) with higher income, has not changed.

The world catch of *fish* has grown slightly more slowly than world population. There is evidence that there is more harvesting of fish that were formerly considered undesirable, and some stocks are probably fished beyond their maximum sustainable yields. Knowledge of the conditions of stocks is poor. With wild stocks under pressure, aquaculture is beginning to play a significant role in seafood production. Fish farms now account for about one-seventh of world seafood production by weight and one-third by value.

Social Development

With more energy, travel, and food, there are some indicators of success in social facets of development. For example, since 1970 *infant mortality* in developing countries has dropped by 40 percent, and *life expectancy* at birth has increased by 5–10 years. *Enrollment in schools* has more than outpaced school-age population growth, especially in low-income countries. *Access to safe drinking water* in developing countries has grown much faster than population. The share of the OECD population served by *wastewater treatment* plants increased from 33 percent to 60 percent between 1970 and the late 1980s.

According to the United Nations Development Programme (UNDP), although the *economic gap between rich and poor* countries has widened in the last decades according to conventional monetary measures, the differences in "*human development*," a combination of indicators of literacy, life expectancy, per capita income, and other economic and social measures have narrowed overall. At the same time, some countries with high average measures of economic growth have not achieved particularly high measures in other facets of development.

Since 1970 the *composition of economic activity* has continued to shift from agriculture and manufacturing to services. In some nations, the share of the workforce engaged in agriculture and in manufacturing has dropped steeply. Some service industries such as information processing, exemplified by the personal computer, have reached levels that were not widely anticipated 20 years ago. The environmental issues of the information and services age, such as tourism and solid waste disposal, have fully joined those of manufacturing and agriculture.

Environmental protection, which has been directed primarily at reducing *health* effects of environmental degradation, is taking place in the context of increased worldwide spending on health. This is evident in developing and industrialized countries alike. The doubling of world spending on health as share of GNP since 1970 reflects changing preferences that come with economic development. Environment and health are linked through channels ranging from irrigation waters that can harbor disease-carrying snails to the ventilating systems of office buildings and homes. Remarkably little is known in any country about the magnitude and extent of human exposure to environmental pollutants in air, water, soil, and food and how this may be changing.

CONCLUSIONS

In sum, production, consumption, and population have grown tremendously since 1970. In constant (1990) dollars, annual gross world product increased from about $8 trillion to about $19 trillion. The average rate of economic growth in developing countries has exceeded growth in industrialized countries, although starting from a very low base. Globally and on average economic and human development appears to have outpaced population growth. Yet, perhaps one-fifth of the world population remains hungry. Although the relative incidence of poverty, hunger, and illiteracy has declined or remained constant, absolute numbers of deprived people have in almost every case increased. Moreover, there are major areas of the world, notably in Africa, where indices of welfare have declined.

DIRECT INDICATORS OF THE ENVIRONMENT

Indicators for environmental issues may be grouped by geographical scale, namely those associated with large areal or global issues; those primarily significant at a medium or regional level; and those at a small or local level. There are, of course, many connections among them.

GLOBAL INDICATORS

Globally, much attention has focused on projected *climatic change* because of the fears of the potentially extreme and far-reaching consequences of a drastic warming and associated sea level rise. Human-induced global climatic change is associated principally with emissions of carbon dioxide (CO_2) from burning of fossil fuels in the industrialized nations. The 1980s were an unusually warm decade, following the cool period that culminated in the early 1970s, suggesting for many that anthropogenic global warming is now evident. Since 1970, fossil fuel emissions of CO_2 have grown 40 percent, as much as population, so that per capita emissions have remained level. In some economies, including France and the United States, per capita emissions decreased as a result of improved energy efficiency and decarbonization. The United States remains by far the largest emitter of greenhouse gases. Atmospheric concentrations of CO_2 have significantly increased over the period. The abundance of other greenhouse gases has also continued to rise. Atmospheric methane has been increasing by 1 percent per year, with a large source of the increase being microbial action in rice paddies, though the sources and sinks for methane are the least well-known of the major greenhouse gases. Greenhouse gas emissions from developing countries, though still minor in the global picture, have risen steeply, and the developmental choices of these countries appear most fateful for the future composition of the atmosphere.

The second truly global environmental concern is *depletion of the stratospheric ozone layer* by chlorofluorocarbons (CFCs); this could lead to increased exposure to ultraviolet light, which is harmful to human health and affects the productivity of ocean plankton and land plants. Production and use of CFCs is concentrated in the industrialized countries. Production of these ubiquitous chemicals has grown since 1970, except during the late 1970s, when the United States and a few other industrial countries banned particular uses of CFCs. Under international protocols on substances that deplete the ozone layer, signed in 1987 and amended in 1990, CFCs will be phased out completely by 2000, with a ten-year delay for developing countries. The signing of that agreement was catalyzed by the unexpected detection in the mid-1980s of a "hole" in the ozone layer in the spring over Antarctica. Measurements from the past few years suggest that the depletion is continuing at a faster rate than predicted, and diminished concentrations appear in the Arctic and midlatitudes as well.

A third global issue is preservation of *biological diversity*, much of which is concentrated in tropical forests. Estimates of the total number of species range from 3 million to more than 80 million; the number named stands at around 1.5 to 1.8 million, and progress is being made only slowly. As vegetation is reduced in many parts of the world, as many as half the species may be at risk. However, data on species loss are poor; much of what is lost is unknown, as ecosystems are destroyed in areas that have been largely unstudied. The rate of worldwide species extinction may be known only within a factor of 10. Even in the United States, statistical problems are considerable, as evident in the government list of endangered and threatened species. Since 1970 the number has nearly doubled, but inclusion is limited to well described plants and animals. Fluctuations in the listing are partially the result of procedural and administrative forces and do not necessarily reflect changes in the natural environment. Declines in numbers of prominent species such as the African elephant and sea turtles are well documented. Loss of habitat, particularly wetlands, is well documented for many countries. *Coastal marine regions* remain under great pressure, the result of coastal population growth and development, associated changes in water quality, increased marine debris and pollution, and destruction of habitat, including mangrove forests, sea grasses, and coral reefs. The rise of interest in biodiversity stems not only from anthropocentric concern about the potential practical value of species but from ethics that emphasize the intrinsic value and right to exist of all species and ecosystems.

Closely linked to the issue of biological diversity is the question of *deforestation*, in particular in tropical regions. Globally, forest cover today appears to be about 80% of what it was 3,000 years ago, when agriculture began to expand. According to data reported by governments, wooded areas worldwide have not changed appreciably in the past 20 years. In the temperate zone, forests have generally increased during recent decades, and all but the oldest and rarest trees are harvested on a sustainable basis. Yet, it is evident that there have been significant decreases in some areas as forests are cleared for fuelwood, crops, and pastures. Removal of tropical forests has progressed at rates estimated at one percent per year and higher. Rapid growth in exports of wood-based products from developing countries further suggests depletion of forests. The proportion of the world's land surface used for farms and pastures has remained constant at about 40 percent since mid-century. Though much of the land surface has been altered by human action, less than one percent is actually covered by human artifacts.

Regional Indicators

On a regional scale, *acid deposition*, mainly caused by emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), emerged in the 1970s as a major issue in North America and Europe, and to a lesser extent in East Asia. In the United States, SO_2 emissions are primarily from utilities and have dropped by a third since 1970, though pressure for reductions probably came from concerns about the local effects of SO_2 on air quality and health rather than from concern about acid rain. NO_x emissions, primarily from utilities and automobiles, have continued to rise over many decades. Decreased emissions of SO_2 are evident in lower rainwater sulfate, but the acidity of rainwater has still generally increased in susceptible regions. Red spruce trees, among the vegetation apparently most susceptible to acid rain, show diminished growth, although there is uncertainty about the extent to which acid precipitation is the cause.

There is evidence that transboundary acid deposition occurs in Japan from Chinese and Korean emissions, but there are no long-term indicators of the extent of this problem. Emission, transport, and deposition of acid-causing emissions occur elsewhere, especially where fossil fuels are heavily used, but assessment of the problem is difficult without data and knowledge of regional meteorological conditions. The effects attributable to acid rain are difficult to estimate and isolate in the context of the numerous other natural and anthropogenic changes pressing upon ecosystems.

Another issue with regional (as well as international and local) implications is *storage and disposal of nuclear wastes.* With the rise of nuclear electrification, the volume of spent fuel and other wastes has risen substantially, but it is still small. In the United States, the volume from commercial power plants is lower than expected two decades ago because the number of plants actually constructed has not reached projected levels. Defense nuclear wastes are large contributors to the total waste volume, and the environmental problems of defense nuclear operations are only now becoming public. Earlier disposal practices, such as dumping of low-level nuclear waste at sea, have been completely stopped by formal treaty because of environment-related concerns. Improved regimes for transport, storage, and disposal of nuclear wastes have been designed but not fully tested.

LOCAL INDICATORS

On a local scale, many trends in environmental quality are well documented, because environmental policy began by addressing such issues as urban *air pollution.*

In the United States, the number of areas violating the National Ambient Air Quality Standards (NAAQS) for ozone in the lower atmosphere, where excesses are harmful, has nearly halved in a decade. The reduction was achieved through technological changes that yielded lower emissions of pollutants, such as carbon monoxide, from transportation. However, with growth of vehicle fleets and accompanying gridlock, chronic pollution of urban air has not much lessened in the United States, and in some areas it is markedly worse. In the Los Angeles area, strategies to prevent further deterioration of air quality have roughly been able to compensate for population growth. The serious problems of urban ozone pollution have not changed much since the late 1970s. In Japanese cities conditions have also roughly tracked urban growth.

The record for other air pollutants is similarly mixed. SO_2 pollution has generally lessened considerably in the cities of the industrialized world. Trends in nitrogen dioxide are mixed; in many cases concentrations have become markedly higher. Particulate concentrations have improved in many cases, but not by much, though in France there has been a dramatic drop caused by the shift from fossil fuels to nuclear power. Possible health effects of air pollutants are the main basis for air quality standards. There is still little known about the collective and cumulative effects of atmospheric pollutants on human health and about particularly sensitive groups.

In developing countries, it is clear that many of the largest cities suffer acute air pollution problems, but there are no long time-series data. In a recent year particulate levels in New Delhi exceeded World Health Organization standards on 295 days, and SO_2 levels exceeded the standard on 100 days in Teheran. In 1991 in Mexico City air quality standards were seriously violated over 300 days. As cities grow, pressures on urban air quality will become stronger.

Another problem of intense local concern is *disposal of wastes.* Municipal waste production appears to have increased linearly with time in the United States in the 1970s and 1980s and generally seems to rise in tandem with real GNP. The rate of use of some materials, such as steel, appears to be decreasing with the evolution to modern serviced-oriented economies. However, there is no firm, widespread evidence yet of "dematerialization," or decreasing intensity of materials use by societies as they develop. Gains in recycling of products such as paper have not been sufficient to offset the growth in use of materials. In many areas the limited capacity of landfills has led to rising costs for waste disposal and attempts to export wastes to more distant locations, sometimes in other nations.

There is no clear overall trend in *marine and water pollution. Oil spills*, as measured by the fraction of oil consumed in the United States that was spilled, appeared to be about the same in the mid-1980s as in the early 1970s. The number of tanker accidents was lower in the 1980s than 1970s. Although commanding less public attention than spills, "normal" operational discharges of oil into the sea, primarily from washing tanks and discharging ballast water, are the largest source of marine oil pollution and remain hard to assess. Inland water bodies, such as the Aral Sea in Central Asia, groundwaters, and many rivers in both developing and industrialized regions have continued to experience major problems as a result of combinations of imprudent irrigation, diffuse pollution sources such as urban runoff, nitrogenous fertilizers and pesticides used in agriculture, and seepages from contaminated industrial sites, as well as industrial discharges. There are also successes in reclaiming water bodies. For example, on average the availability of dissolved oxygen in the rivers of the OECD nations improved over the past two decades, though much remains to be done to achieve a high level of water quality.

Several environmentally *hazardous materials* appear to have diminished considerably in prevalence. The incidence of strontium-90 has dropped sharply worldwide since the 1960s, when atmospheric testing of nuclear weapons was banned. In the United States, levels of PCBs (used as coolants in power transformers) and lead (used in various forms in gasoline, cables, pipes, paint, and industrial chemical processes) have declined dramatically in the last decades as adverse health and environmental consequences have been identified and policy responses formulated and implemented. Previous disposal of these and other hazardous wastes has contaminated many locations around the world, and the catalogue of these sites has grown. Data on rate of creation of new sites are not available.

CHANGES IN MANAGEMENT AND DECISION MAKING

The source of some of the successes in decreasing environmental risks is evident in indicators of environmental management and institutions. Among such indicators are the number of laws and regulations governing environmental matters, the level of expenditure on environment, the creation of institutions to deal with environmental issues, zoning and reservation of land, and the application of technology to environmental problems.

Laws and Regulations

In the United States, the number of federal *laws for environmental protection* has more than doubled since 1970. Compliance with laws is also reportedly increasing, though data are sparse. The number of acts and regulations relating to environment in the United Kingdom increased from 6 in 1885, to 21 in 1945, to about 100 in 1970, and has tripled since then to about 300. The environmental directives and decisions of the European Economic Community were initiated about 1970 and have grown to almost 200 in 20 years. The number of international conventions on environment, which totaled about 50 in 1970, appears likely to reach around 200 in the mid-1990s. The point of maximum activity in the process of making rules for environment appears to have occurred about 1980. It may be that many nations, including the United States, are reaching the end of the period of heaviest reliance on legal and regulatory approaches to environmental protection and entering a period of greater reliance on economic or "market-based" incentives that complement and in some cases replace regulation.[27]

Expenditure

Spending is a second indicator of response to environmental issues. In the United States, real spending on pollution abatement has increased by more than half since 1970 and exceeds $100 billion. Most spending is within industry.

Creation of Institutions

In tandem with increased expenditures has gone the *creation of institutions*, governmental and nongovernmental, devoted to environmental protection. Globally, the number of ministerial-level departments of environment has increased from fewer than 10 in 1970 to over 100. Green political parties have formed in many countries. UNEP has grown to be a substantial organization engaged in information exchange, monitoring, and coordination of national programs for environmental protection. The increase in nongovernmental environmental organizations (NGOs) has also been steep, roughly tripling in the United States between 1970 and 1990.[28] The number of NGOs registered at the NGO Environmental Liaison Center in Nairobi associated with UNEP passed 1,000, and several thousand have been involved in preparations for UNCED. The nongovernmental Scientific Committee on Problems of the Environment (SCOPE), the premiere international scientific network of environmental scientists, has published more than 40 authoritative reviews since its founding in 1969 by the International Council of Scientific Unions. New domestic institutions that bridge the public and private sectors to address particular issues such as clean-up of hazardous waste sites have also been created.[29] Numerous proposals are appearing for new international organizations, for example, for the "START" system of regional networks, research centers, and sites.

Zoning and Reservation of Land

One of the most important strategies for environmental protection has been the use of *zoning and reservation of land*. National forests, nature parks, and similar areas represent resources set aside, with various levels of restrictions, to conserve the environment. In most countries, the area of protected land has continued to increase. Because of a few large acquisitions, the area of the national park system in the United States has more than doubled since 1970.

Technology

A common approach to pollution control has been to mandate *abatement technologies*, whose diffusion provides another indicator of trends in environmental protection. One example is flue gas desulfurization (FGD), which removes SO_2 before it is released to the atmosphere. In Japan, capacity for FGD has increased nearly thirtyfold since 1970. Germany has imposed strict FGD requirements as a result of concerns about the forest. Another example is catalytic converters for automobile exhausts. In the United States these were introduced in the mid-1970s and are now found on more than 90 percent of the vehicle fleet. In many countries, auto emission controls are not yet required.

Technological solutions can also help reduce threats to water quality. In the United States, the fraction of the population served by wastewater treatment plants has doubled since 1970 to above 80 percent of the population. As noted earlier, increases in access to safe drinking water, due in large part to applications of science and technology, have more than kept pace since 1970 with world population growth, though many people remain unserved.

SOURCES

Data on world population by geographical region are collected by the United Nations from national reports and presented in United Nations, *Statistical Yearbook* (New York: UN, 1988), and earlier editions. Population divided along lines of economic development is reported by the World Bank, *World Development Report: 1990* (New York: Oxford University Press, 1990). Urban and rural populations are disaggregated in United Nations Development Programme, *Human Development Report 1990* (New York: Oxford University Press, 1990). A complete survey of world commercial energy is British Petroleum, *BP Statistical Review of World Energy* (London: BP, 1990); but the World Bank's *World Development Report* conveniently aggregates energy consumption according to level of economic development. Energy intensity for the United States and other OECD countries is reported in Organisation for Economic Co-operation and Development, *OECD Environmental Data: Compendium 1989* (Paris: OECD, 1989). On efficiency, see R. U. Ayres, "Energy Efficiency in the U.S. Economy: A New Case for Conservation," RR-89-12 (Laxenburg, Austria: International Institute for Applied Systems Analysis, 1989). Data on electrification (including nuclear energy) is compiled in World Resources Institute, *World Resources 1990–91* (New York: Oxford, 1990). On decarbonization see J. H. Ausubel, "Industrial ecology: Reflections on a Colloquium," *Proc. Nat. Acad. Sci. US* 89(3):879–884, 1992. The best source for the number of vehicles worldwide is Motor Vehicle Manufacturers Association (MVMA), *Motor Vehicle Facts and Figures '90* (Detroit: MVMA, 1990), and earlier issues; air travel data are from the United Nations' *Statistical Yearbook.*

The OECD *Compendium* compiles data from many sources on arable and permanent cropland; fertilizer usage and total caloric intake are from the World Bank's *World Development Report.* Trends in the mechanization of agriculture are reported in the UN *Statistical Yearbook*; pesticide data are sketchy, but data for the United States are reported by the Council on Environmental Quality, *Environmental Quality* (Washington: U.S. Government Printing Office, 1990). Trade in agricultural products is from the Food and Agriculture Organization, and selected data are printed in the UN *Statistical Yearbook*; see also UN Conference on Trade and Development, *UNCTAD Commodity Yearbook* (New York: UN, 1990). Growing use of gene banks is discussed in D. L. Plucknett *et al.*, "Crop Germplasm Conservation and Developing Countries," *Science* 220, 163–169, 1983. Production and yield of rice are from the International Rice Research Institute, *World Rice Statistics 1987* (IRRI is, incidentally, one of the CGIAR institutions). Dietary data are available in the UN *Statistical Yearbook*; detail on the changing diet of the U.S. population is compiled by U.S. Department of Commerce, *Statistical Abstract* (Washington: U.S. Government Printing Office, 1990). Data on the world catch of fish are presented in the OECD *Compendium*; aquaculture statistics are from OECD, *State of the Environment* (Paris: OECD, 1991).

Infant mortality and school enrollment are in the *World Development Report*; the UNDP's "human development index" which combines economic and social indicators is explained and reported in the *Human Development Report* (which also includes the data on access to safe drinking water). Trends in the portion of economic activity in services are from the World Bank's *World Development Report*; data on the number of personal computers sold and in use are reported in the U.S. Department of Commerce's *Statistical Abstract.* Spending on health as a percentage of GNP is reported in UNDP's *Human Development Report.* The Gross World Product is *estimated* from 1965 and 1988 data and average growth rates reported in the *World Development Report.*

Production of CO_2 from fossil fuels and cement is from G. Marland *et al.*, *Estimates of CO_2 Emissions from Fossil Fuel Burning and Cement Manufacturing, Based on the United Nations Energy Statistics and the U.S. Bureau of Mines Cement Manufacturing Data*, ORNL/CDIAC-25, NDP-030 (available from Oak Ridge National Laboratory, 1989). Concentrations of greenhouse gases are from the Mauna Loa station (CO_2) and other measuring stations and are conveniently reproduced in the U.S. Council on Environmental Quality's *Environmental Quality* and in World Resources Institute's *World Resources 1990–91* (along with some data on emissions). These two reports also reproduce data on production of CFCs from company reports to the Chemical Manufacturer's Association. Methane data are in R. J. Cicerone and R. S. Oremland, "Biogeochemical Aspects of Atmospheric Methane," *Global Biogeochemical Cycles* 2:299–327, 1988. A summary of statistics on the loss of ozone over Antarctica and at high latitudes is found in R. T. Watson *et al.*, *Present State of Knowledge of the Upper Atmosphere 1988: An Assessment Report*, (NASA Ref. Publ. 1208, 1988). A recent paper on the loss of ozone worldwide is R. S. Stolarski *et al.*, "Total Ozone Trends Deduced from Nimbus 7 TOMS Data," *Geophysical Research Letters* 18, 1015–1018, 1991. Data on species are found in K. J. Gaston and R. M. May, "Taxonomy of Taxonomists," *Nature* 356, 281–282. The number of endangered and threatened species on the U.S. list is from the U.S. Department of the Interior, Fish and Wildlife Service, Office of Endangered Species. Wetlands data for the U.S. are from the U.S. Council on Environmental Quality's *Environmental*

Quality. Wooded areas data are from the OECD *Compendium*, which also includes information on export of wood products such as panels from all countries. Some data on changes in forest cover (and, as a result, in CO_2 emissions) are reported in *World Resources 1990–91*, but these are controversial. One estimate of the increase in pastures (and decrease in forests) in Costa Rica is found in N. Myers, *The Primary Source: Tropical Forests and Our Future* (New York: Norton, 1984), p. 132. Global land use data are in A. Gruebler, "Technology and Global Change: Land-Use, Past and Present" (Laxenburg, Austria: International Institute for Applied Systems Analysis, 1992).

Emissions of sulphur dioxide and nitrogen oxides in the United States are also from *Environmental Quality*. Sulphate concentration and acidity of rainwater can be found compiled in the OECD *Compendium*. Trends in the growth of red spruce trees are for the period 1970 to 1980 and are reported in National Research Council, *Acid Deposition: Long-Term Trends* (Washington: National Academy Press, 1983). The volume and radioactivity are from *Environmental Quality*; dumping of nuclear waste at sea is from OECD's *Compendium*.

Data on the number of violations of the ozone standard from the National Ambient Air Quality Standards are from Environmental Protection Agency, *Environmental Progress and Challenges: EPA's Update* (Washington, DC: U.S. Government Printing Office, 1988). Emissions and average daily maximum concentrations are reported in Environmental Protection Agency, *National Air Quality and Emissions Trends Report*, EPA-450/4-90-002, 1990. Similar (but less extensive) data on the Japanese environment are found in Environment Agency of the Government of Japan, *Quality of the Environment in Japan*, 1988. Data on New Delhi and Teheran exceeding WHO standards from United Nations Environment Program, Global Earth Monitoring System (GEMS), cited in L. R. Brown *et al.*, 1990, *State of the World 1990* (New York: Norton, 1990). Municipal waste production in the United States is from the U.S. Council on Environmental Quality, *Environmental Trends* (Washington, DC: U.S. Government Printing Office, 1989). On dematerialization, see R. Herman, S. A. Ardekani, and J. H. Ausubel, "Dematerialization," in *Technology and the Environment*, J. H. Ausubel and H. E. Sladovich (eds.) (Washington, DC: National Academy Press, 1989) pp. 50–69. Trends in recycling for some countries are published in the OECD *Compendium*. The U.S. Council on Environmental Quality's *Environmental Quality* includes data on the volume and number of oil spills as well as a sample of data on the levels of PCBs, Sr-90, and lead in the environment. Other marine and water data are in the OECD *Compendium*.

The number of environmental protection laws in the United States is reported by R. E. Balzhiser in J. L. Helm (ed.), *Energy: Production, Consumption, and Consequences* (Washington, DC: National Academy Press, 1990). International treaties on the environment, as well as domestic spending for air and water environmental protection, are summarized in the U.S. Council on Environmental Quality's *Environmental Quality*. Further information on international agreements and organizations is found in L. K. Caldwell, *International Environmental Policy: Emergence and Dimensions* (Durham: Duke University Press, 1990), P. Brackley (ed.), *World Guide to Environmental Issues and Organizations* (Harlow, Essex: Longman, 1990), and the 1987 *European Environmental Yearbook* (Washington, DC: BNA). Acreage of the U.S. national park system is in the U.S. Department of Commerce's *Statistical Abstract*; the area of protected lands worldwide is in the OECD's *Compendium*. Flue gas desulphurization capacity in Japan is from the *Quality of the Environment in Japan* report. The U.S. population served by waste water treatment plants is summarized in the U.S. Department of Commerce's *Statistical Abstract*. Data on access to safe drinking water in developing countries are from the UNDP's *Human Development Report 1990*.

APPENDIX B
BIOGRAPHIES OF PRINCIPAL CONTRIBUTORS

John F. Ahearne is executive director of Sigma Xi, the Scientific Research Society. Headquartered in Research Triangle Park, North Carolina, Sigma Xi has 110,000 members and over 500 chapters and clubs and publishes the magazine *American Scientist.* Educated in physics at Cornell and Princeton, Dr. Ahearne served in the Defense Department as deputy assistant secretary for manpower and in the Energy Department as deputy assistant secretary for power applications. From 1978 to 1983 he was a member of the Nuclear Regulatory Commission and served as chair from 1979 to 1981, immediately following the Three Mile Island accident. From 1984 to 1989 Dr. Ahearne was vice president of Resources for the Future. He has also chaired the principal advisory board of the Department of Energy concerned with nuclear safety.

Jesse H. Ausubel is director of studies of the Carnegie Commission on Science, Technology, and Government and a fellow in Science and Public Policy at

The Rockefeller University. From 1977 to 1988 Mr. Ausubel was associated with the National Academy complex, serving as a fellow of the National Academy of Sciences, a staff officer with the National Research Council Board on Atmospheric Sciences and Climate, and director of programs for the National Academy of Engineering. He was one of the main organizers of the first UN World Climate Conference and is the author of numerous publications on technology and environment.

Harvey Brooks served as dean of engineering and applied physics at Harvard University from 1957 to 1975. A solid state physicist, he worked in atomic power for the General Electric Company before joining Harvard. After his tenure as dean, Dr. Brooks became Peirce Professor of Technology and Public Policy and was one of the founders of the program in science, technology, and public policy at the Kennedy School of Government. Dr. Brooks has served on the President's Science Advisory Committee and the National Science Board and is a member of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Philip Hemily is responsible for international organizations and programs at the National Research Council in Washington, DC. A retired senior foreign service officer, Dr. Hemily served as deputy assistant secretary general for scientific affairs (1976–1982) of the North Atlantic Treaty Organization and as science counselor to the U.S. Mission for the Organization for Economic Cooperation and Development (1965–1974). From 1957 to 1965 he worked for the National Science Foundation, where he helped create the international office. Dr. Hemily received his BS in mechanical engineering from the University of Michigan and his PhD in physical chemistry and crystallography from the University of Paris.

Thomas F. Malone is a former foreign secretary of the National Academy of Sciences. The editor of the *Compendium of Meteorology*, Dr. Malone received his PhD from MIT, where he was a member of the faculty from 1943 to 1956. From 1956 to 1970 Dr. Malone was with the Traveler's Insurance Company, where he became a senior vice president. Dr. Malone was the founding secretary general of the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU) and was also vice president of ICSU. Dr. Malone is currently based at the Department of Marine, Earth, and Atmospheric Sciences of North Carolina State University. His interests focus on sustainable and equitable development in relation to population, resources, and environment.

Rodney W. Nichols is chief executive officer of the New York Academy of Sciences. Mr. Nichols served as vice president and executive vice president of The Rockefeller University from 1970 to 1990, following several assignments in the Office of the Secretary of Defense. Trained in applied physics at Harvard, he has been involved in many studies of the application of technology for civilian and military purposes. He has had full-time and consulting experience with industry, and has been a frequent advisor to the U.S. Government. One of the leaders of the U.S. delegation to the 1979 UN Conference on Science and Technology for Development, he also served on the UN Advisory Committee on Science and Technology for Development. During 1990–1992 Mr. Nichols served as a scholar-in-residence with Carnegie Corporation of New York.

Victor Rabinowitch was trained as an avian ecologist, receiving his advanced degrees from the University of Wisconsin in Madison. He received a PhD in the unusual combination of zoology and international relations. Dr. Rabinowitch served as director of the National Academy of Sciences' Board on Science and Technology for International Development (1970–1981), Committee on International Security and Arms Control (1985–1987), and Office of International Affairs (1981–1990). Currently, he is Vice President for Programs for the John D. and Catherine T. MacArthur Foundation.

Walter A. Rosenblith is a former foreign secretary of the National Academy of Sciences and provost emeritus of the Massachusetts Institute of Technology. Dr. Rosenblith's major fields of interest are brain research and biophysics, science and technology in the university and society, and international science, its structure and partners. He served as Vice President of the International Council of Scientific Unions from 1984 to 1988, and he chairs the advisory panel for the World Bank's Chinese University Development Project. Dr. Rosenblith is a member of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Eugene B. Skolnikoff is professor of political science at Massachusetts Institute of Technology; he directed its Center for International Studies from 1972 to 1987. He served on the White House staff in the Science Advisor's office in the Eisenhower and Kennedy administrations. Originally educated as an electrical engineer, Professor Skolnikoff studied economics and politics at Oxford on a Rhodes Scholarship and later received a PhD in political science at MIT. His work has focused on the interaction of science and technology with international affairs.

H. Guyford Stever is a member of the Carnegie Commission on Science, Technology, and Government, and has chaired its task forces on environment and energy and on environmental research and development. Trained at Colgate and the California Institute of Technology, Dr. Stever was a professor of aeronautical engineering at MIT from 1946 to 1965, taking leave in 1955–56 to serve as chief scientist of the Air Force. From 1965 to 1972 Dr. Stever was President of Carnegie-Mellon University, and from 1972 to 1976 he was director of the National Science Foundation; he was also science and technology advisor to President Ford (1976–77). Dr. Stever is a member of the National Academy of Sciences and the National Academy of Engineering, where he served as foreign secretary (1984–1988).

David G. Victor is a graduate student in political science at MIT interested in international environmental policy. Mr. Victor was a member of the summer program for young scientists at the International Institute for Applied Systems Analysis near Vienna, Austria (1989) and the National Center for Atmospheric Research (1991). He has served as a consultant to the Environmental Protection Agency on the issue of carbon taxes and helped organize the Bellagio Conference on institutional aspects of international cooperation on climate change. His articles have been published in *Nature* and the *International Journal of Hydrogen Energy.*

Gilbert F. White is a geographer specializing in the study of natural hazards, especially drought and flood, and director emeritus of the Institute for Behavioral Sciences at the University of Colorado. Dr. White is a member of the National Academy of Sciences, where he chaired the Commission on Natural Resources and the Environmental Studies Board. Dr. White was chair of the board of Resources for the Future (1973–1979) and president of the Scientific Committee on Problems of the Environment of the International Council of Scientific Unions (1976–1982). Dr. White has served as scientific advisor to the administrator of the UN Development Program and numerous other intergovernmental and nongovernmental international programs and organizations concerned with environment and development.

APPENDIX C
PARTICIPANTS, WORKSHOP ON INTERNATIONAL ENVIRONMENTAL ORGANIZATION: THE S&T DIMENSIONS, JUNE 4–6, 1990

The following individuals participated in a three-day workshop held at The Rockefeller University in June 1990. Affiliations are correct as of that date.

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NOTES AND REFERENCES

1. W. T. Golden (ed.), *Worldwide Science and Technology Advice to the Highest Levels of Governments* (Oxford: Pergamon Press, 1991, and Washington, DC: American Association for the Advancement of Science, 1992).

2. See, for example, L. A. Kimball, *Forging International Agreement: Strengthening Intergovernmental Institutions for Environment and Development* (Washington, DC: World Resources Institute, 1992).

3. R. Repetto (ed.), *The Global Possible* (New Haven: Yale, 1985), p. 97.

4. For surveys of environmental research needs, see, for example, National Research Council, *Research Strategies for the U.S. Global Change Research Program* (Washington, DC: National Academy Press, 1990); Ecological Society of America, "The Sustainable Biosphere Initiative: An Ecological Research Agenda," *Ecology* 72(2):371–412, 1991; J. C. I. Dooge, G. T. Goodman, J. W. M. La Riviere, J. Marton-Lefevre, T. O'Riordan, and F. Praderie, *An Agenda of Science for Environment and Development into the 21st Century* (Cambridge, UK: Cambridge University Press, 1992); Preparatory Committee for the United Nations Conference on Environment and Development, "Science for Sustainable Development," Section IV, Chap. 3 of Agenda 21 (New York: United Nations, 23 March 1992); and papers from a Colloquium on Industrial Ecology, *Proc. Nat. Acad. Sci. US* 89(3):793–884, 1992.

5. For a discussion of what is "environmental R&D" and a description of the U.S. federal environmental R&D effort, see S. J. Kafka, "Federal Environment Research and Development Pro-

grams: Organizational Policy Issues for the 1990s and Beyond" (New York: Carnegie Commission on Science, Technology, and Government, 1991). In the United States, nine agencies support substantial environmental R&D with no agency providing more than 20 percent of the total federal effort. It remains difficult to obtain information on the scope and direction of the U.S. Government effort; information on industry's efforts, which are enormous in fields such as toxicology, is even harder to obtain.

6. J. Annerstedt, "The Global R&D System: Where is the Third World?" *in* J. Annerstedt and A. Jamison (eds.), *From Research Policy to Social Intelligence: Essays for Stevan Dedijer* (New York: MacMillan, 1988), pp. 129–141.

7. For a general discussion of advantages and disadvantages of R&D networks, see Organization for Economic Cooperation and Development (OECD), "Scientific and Technological Relations with Developing Countries—R&D Networks for Developing Countries: A Conceptual Study," Directorate for Science, Technology and Industry, DSTI/SPR/86.39 (Paris: OECD, September 1986).

8. E. A. Parson and W. C. Clark, "Learning to Manage Global Environmental Change: A Review of Relevant Theory," in J. Kildow (ed.), *Global Environmental Problems and Solutions* (Cambridge: MIT, 1992).

9. Philip M. Hemily, "Major International Organizations Concerned with Environmental Research, Monitoring, Policy Development, and Implementation," provides a brief review of UNEP, WMO, UNESCO, FAO, IAEA, UNIDO, WHO, World Bank, UNDP, OECD, ICSU, IIASA, and IUCN programs. (Background paper prepared for the Carnegie Commission on Science, Technology, and Government, May 1990.)

10. The March 1992 meeting included representatives from OECD non-member countries such as Russia and international non-governmental organizations such as ICSU. Such representation will be key to the effectiveness of the forum.

11. The International Group of Funding Agencies, an informal intergovernmental group of funders of the International Geosphere–Biosphere Program, also provides a potential focal point for discussions, as may the UN's internal coordinating committees for international environment (the "CIDIE" and "DOEM," both likely to be restructured in connection with UNCED) or the OECD.

12. W. C. Baum, *Partners Against Hunger: The Consultative Group on International Agricultural Research* (Washington, DC: World Bank, 1986).

13. J. A. Eddy, T. F. Malone, J. J. McCarthy, and T. Rosswall (eds.), "Global Change System for Analysis, Research and Training (START)," Report of a meeting at Bellagio 3–7 December 1990 (Boulder CO: UCAR Office of Interdisciplinary Earth Studies, 1991).

14. Environmental and Energy Study Institute Task Force, "Partnership for Sustainable Development: A New U.S. Agenda for International Development and Environmental Security" (Washington, DC, May 1991).

15. J. C. I. Dooge, G. T. Goodman, J. W. M. La Riviere, J. Marton-Lefevre, T. O'Riordan, and F. Praderie, *An Agenda of Science for Environment and Development into the 21st Century* (Cambridge, UK: Cambridge University Press, 1992).

16. There are also already institutions with some of the needed characteristics. Internationally funded and governed institutes in the environmental field include the International Institute for Applied Systems Analysis (IIASA, Laxenburg, Austria) and the Stockholm Environment Institute. There are also emerging regional organizations such as the Regional Environmental Center for Central and Eastern Europe in Budapest and the Institute for European Environmental Policy. There are numerous national universities and institutes that play a global role, such as the Massachusetts Institute of Technology and the U.S. National Center for Atmospheric Research (Boulder, Colorado) and more are stating their intentions to do so—the new Japanese Research Institute of Innovative Technology for Earth (RITE) is one of the largest. The Brazilian National Institute for Amazonian Research includes some 280 researchers, of whom one-fifth are foreign, and funding comes from both Brazilian and international sources.

17. The "Inter-American Institute for Global Change Research" is likely to be launched during 1992.

18. Industry as well as various nongovernmental organizations are also important partners of international science. For a discussion, see "Report of the Conference on International Science and Its Partners," *Science International* (Paris: International Council of Scientific Unions, July 1990).

19. Other important governmental mechanisms include science advisory committees to individual agencies, holders of "chief scientist" positions within agencies, and congressional hearings. These will be discussed in the final report of the Carnegie Commission, to be published in 1993. See also B. L. R. Smith, *The Advisers: Scientists in the Policy Process* (Washington, DC: The Brookings Institution, 1992).

20. See the report of the Task Force on Nongovernmental Organizations in Science and Technology, W. D. Carey and C. McC. Mathias, co-chairs (New York: Carnegie Commission on Science, Technology, and Government, 1992).

21. The attributes of the National Academy of Sciences and nongovernmental organizations in general in their relations with government are discussed in the Report of the Task Force on Nongovernmental Organizations in Science and Technology, W. D. Carey and C. McC. Mathias, co-chairs (New York: Carnegie Commission on Science, Technology, and Government, 1992).

22. The IPCC and its predecessors, the Villach meetings of experts and the Advisory Group on Greenhouse Gases of the WMO, would provide an illuminating case study of the accomplishments and hazards of the international advisory process as it now tends to operate.

23. Other organizations of potential relevance include the International Federation of Institutes for Advanced Study (IFIAS), an association of some 40 institutions in various fields of research in different countries that has coordinated international studies on such subjects as "drought and man"; the World Federation of Engineering Organizations (WFEO), a federation of 92 national engineering associations; the Union of International Technical Associations (UITA), an assembly of some 30 international groups focused on specific domains of technology; and the International Social Science Council, which brings together 14 international associations representing the social science disciplines.

24. See Carnegie Commission on Science, Technology, and Government, *Science, Technology, and Congress: Analysis and Advice from the Congressional Support Agencies*, October 1991, p. 50, for further discussion of international challenges for the Office of Technology Assessment.

25. For discussion of the relations between the international scientific community and intergovernmental organizations, governments, and industry, see International Council of Scientific Unions (ICSU), "Report of the Conference on International Science and Its Partners," *Science International* (Paris: ICSU, July 1990).

26. Sigma Xi, "Summary, Conclusions, and Recommendations from Global Change and the Human Prospect: Issues in Population, Science, Technology, and Equity," Conference held 16–18 November 1991, Washington, DC (Sigma Xi, Research Triangle Park, NC).

27. Carnegie Commission on Science, Technology, and Government, *E^3: Organizing for Environment, Energy, and the Economy in the Executive Branch of the U.S. Government* (New York, 1990).

28. The growing role of domestic nongovernmental organizations in science and technology is analyzed in the report of the Task Force on Nongovernmental Organizations, W. D. Carey and C. McC. Mathias, co-chairs (New York: Carnegie Commission on Science, Technology, and Government, 1992).

29. Charles W. Powers, "The Role of NGOs in Improving the Employment of Science and Technology in Environmental Management," Working Paper (New York: Carnegie Commission on Science, Technology, and Government, 1991).

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