INTERNATIONAL JOURNAL of OCCUPATIONAL and ENVIRONMENTAL HEALTH

AN ECOSYSTEM APPROACH TO HUMAN HEALTH

Gilles Forget, DSc
Jean Lebel, PhD

Village of Brasilia Legal

Contents

On the cover: The village of Brasilia Legal on the Tapajos River in the Amazon, Brazil, where pioneering work taking an ecosystem approach to human health provided a complete new view of the origin of mercury in the environment and its effects on human health. Photo by Jean Lebel.

Supplement to
Volume 7, Number 2
April/June 2001

INTERNATIONAL JOURNAL of OCCUPATIONAL and ENVIRONMENTAL HEALTH

The INTERNATIONAL JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HEALTH (ISSN 1077-3525) is published quarterly for $78 per year (U.S. individual subscribers) by Hanley & Belfus, Inc., 210 South 13th Street, Philadelphia, PA 19107. Periodical postage paid at Philadelphia, PA, and additional mailing office. POSTMASTER: Send address changes to INTERNATIONAL JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HEALTH, Hanley & Belfus, Inc., 210 South 13th Street, Philadelphia, PA 19107.

Publication Information

EDITOR FOR THE PUBLISHER

Sandra A. Lovegrove

215/546-4656
Hanley & Belfus, Inc.
210 South 13th Street
Philadelphia, PA 19107

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Subscription rates: United States and US possessions, individuals, $78 per year, institutions, $98 per year. All other countries, individuals $88 per year, institutions $108 per year. Available back issues in conjunction with a subscription, 1/4 of applicable subscription price. Single back issues when available, $25. Subscriptions are available on a calendar-year basis only. Address orders and remittances to INTERNATIONAL JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HEALTH, Hanley & Belfus, Inc., 210 South 13th Street, Philadelphia, PA 19107; (215) 546-7293.

Missing copies will be replaced free of charge if a request for replacement is received by the publisher within two months of date of issue for domestic and Canadian subscribers and within four months of date of issue for others.

Advertising and related correspondence should be addressed to Diane Sherel (classified ads *only*, to Carol Emery), Hanley & Belfus, Inc., 210 South 13th Street, Philadelphia, PA 19107; (215) 546-4995, ext. 12.

The journal is indexed in *Index Medicus*, Medline, EMBASE, the Cumulative Index to Nursing and Allied Health Literature (CINAHL) *Chemical Abstracts*, and *Ergonomics Abstracts*.

Preface

There can be no peace, no security, nothing but ultimate disaster, when a few rich countries with a small minority of the world's people alone have access to the brave, and frightening, new world of technology, science, and of high material living standard, while the large majority live in deprivation and want, shut off from opportunities of full economic development; but with expectations and aspirations aroused beyond the hope of realizing them.

—LESTER B. PEARSON, *winner of the Nobel Peace Prize, former Canadian Prime Minister, and chair of IDRC's first Board of Governors*

The effects of relentless population growth and technologic progress now rival the forces of nature in changing the earth's climate and altering its landscape. Most of these profound changes are the result of economic expansion affecting all parts of the globe and all of its inhabitants. A number of books provide powerful critiques of the emerging global economy: Dave Korten's *When Corporations Rule the World*; Jerry Mander and Edward Goldsmith's *The Case Against the Global Economy*; William Greider's *One World, Ready or Not*; and Ralph Estes' *Tyranny of the Bottom Line: Why Corporations Make Good People Do Bad Things*. Their messages reflect the deep concern most of us share about how to protect the public health and the environment, and a deep distrust of global industry. Nothing they have said exerts any real influence over the growth of global business interests.

American journalist Thomas Friedman is the author of *The Lexus and the Olive Tree*, a book widely regarded as the best study thus far of globalization and its impact on the world and its people. When asked whether he is in favor of globalization, Friedman says that it does not matter whether he or anyone else is for or against it. Globalization is the reality of our time. It has no leadership, no government, no legal system to exercise control over it. It moves at the fastest speed possible, and waits for no one. When pressed about the impact of globalization on human health and the environment, Friedman says that, "I am keenly aware of globalization's downsides. The question in my mind is what to do about them. I believe the best way for us to deal with the brutalities of globalization is by first understanding the logic of the system and its moving parts, and then figuring out how this system can benefit the most people while inflicting the least amount of pain."

He could not have better stated the challenge before the world's public health community as industry sweeps the globe. Global economic expansion is not the only issue of concern, however. Resource depletion is also linked to the extreme poverty that characterizes many developing nations. This is another important factor in the disruption of the linked world's ecosystems. As S. Ramphal remarked in *Third World Grievances, EPA Journal*, 1990;16(4): 39-43, "The poor often destroy their own government not by ignorance but in order to survive. Poverty is both the cause and the effect of environmental degradation."

The International Development Research Centre (IDRC) is a public corporation created by the Parliament of Canada in 1970 to help developing countries use science and knowledge to find practical, long-term solutions to social, economic, and environmental problems. The IDRC has a long history of research on various levels of community participation. It believes that "sustainable and equitable human activity depends on men and women's control of their own social and economic progress, on equitable access to knowledge, and on an indigenous capability to generate and apply knowledge." It is not surprising that IDRC scientists have produced one of the more interesting and provocative proposals to date to improve public health through better natural resource management.

There can be no sustainable development unless global business interests take into account both the well-being of people and the survival of the ecosystem. The ecosystem approach to human health as proposed in this journal makes public health the central consideration of global development. The ecosystem approach attempts to identify and evaluate the importance of the various determinants of both the health of an ecosystem and the health of the people who live in it. These determinants can then be used to develop an appropriate social response and to measure the effectiveness of interventions. And even as important linkages between natural systems and human health are yet to be unravelled, "precautionary" approaches to development are more appreciated. This new approach is gaining support in the scientific and political communities as the impact of environmental change on human health becomes increasingly evident.

Early experience shows that the ecosystem approach to public health is not immediately understood or embraced even by scientists; determining systems-based interactions

has not been a typical approach of health researchers, who usually conduct empirical studies pertaining to single or narrow groups of risk factors. Nonetheless, the IDRC is undaunted in advocating a concept that they contend offers the potential for arriving at lasting solutions to many of the problems brought about by global development.

The IDRC experience indicates that a multidisciplinary approach is essential to evaluate the impact on the environment of global development. The ecosystem approach draws on science and technology as well as traditional knowledge to explain the causes and effects that harm ecosystems and public health, and especially linkages between *them*. The ultimate goal of the research process is to ensure that more proactive interventions will improve the overall living conditions of the community in the present and the future.

The IDRC research approach is particularly appropriate for developing countries because it addresses the complexity of the systems involved. The ecosystem approach to human health calls for participation by local communities. Participatory research is based on the premise that the community best takes due regard of local concerns, needs, and knowledge. Local knowledge is critical in helping researchers design interventions that will ensure sustainable and equitable development. The IDRC proposes that participatory research go beyond simply verifying hypotheses. Once the research results are in hand, the community will be expected to make the appropriate decisions and to act on them. The importance of ensuring a consideration of both men's and women's needs and aspirations in a truly gender-integrative protocol will further ensure the sustainability of any intervention.

One of the key factors in the ecosystem approach to human health is an ongoing process of monitoring and evaluation. It allows interventions to be refined and adapted as necessary to changing conditions in the ecosystem or to shifting social values. It is evident that researchers cannot predict with certainty the consequences of their actions. What they need to do is to involve the widest possible perspective, and then monitor the results so that they discover their mistakes early while they still have time to correct them.

The overwhelming amount and complexity of information in the environmental sciences requires that researchers focus on smaller and smaller pieces of the puzzle in order to gain a mastery of the facts. Fragmentation and specialization are problems that permeate science and environmental regulation. In environmental health, toxicologists rarely communicate with epidemiologists, who also rarely talk with physicians, engineers, ecologists, and social scientists. Regulatory agencies have separate programs for air, water, pesticides, and hazardous wastes, even though these distinctions are more an artifact of history than they are useful points of separation.

Fragmentation and specialization result in a certain myopia. People forget to look for the links that interconnect our scientific disciplines and for the links that are intrinsic in all environmental systems. We ignore these links at our peril. History has repeatedly confirmed the law of unintended consequences. A narrow focus on one goal without consideration of all of the broad implications has resulted in tragedies such as massive outbreaks of parasitic disease, transformation of enormous swaths of cropland into desert, and diverse other compelling examples that fill this journal. The IDRC proposes an approach of integrated assessment that engages communities, considers the complex web of interlinked factors that are present in any environment, and takes intelligent action toward creating a healthy, sustainable environment.

The IDRC authors state with confidence, "We propose not only to preserve the state of health of a region's inhabitants by better management of the ecosystem, but actually to improve the local state of health through certain judicious interventions. Moreover, it is quite feasible for such intervention to improve the state of health at less cost than certain initiatives in the area of primary health or medical care." Read this Supplement and consider the IDRC's message, with its supporting case studies. It deserves your time and consideration.

JOSEPH LADOU, MD
Editor-in-Chief

An Ecosystem Approach to Human Health

GILLES FORGET, DSC, JEAN LEBEL, PHD

Over the last quarter century, thinking about public health has evolved towards a much more global, more ecologic approach. Similarly, natural resource management thinking has progressed and now includes environmental and social factors as well as economic parameters. Both fields have seen a move to a more integrated approach to management (whether of health or of the environment). These two currents of thought have given rise to the metaphor of the "healthy ecosystem." The ecosystem approach to human health is a new, holistic approach that flows from this metaphor—it places human beings at the center of considerations about development, while seeking to ensure the durability of the ecosystem of which they are an integral part. There can be no sustainable development unless interventions take into account both the well-being of human beings and the survival of the ecosystem. This research approach is particularly appropriate for developing countries, because it is much better able to accommodate the complexity of the systems concerned. It is not, however, an intuitive approach for researchers. It requires a considerable philosophical adjustment for those who have been trained in the strict disciplines of the reductionist paradigm long favored in Western academic instruction. Nevertheless, this new approach is now coming into its own, especially as the impact of environmental changes on human health becomes increasingly evident. Most of these environmental changes flow directly from development activities, both in the industrialized world and in developing countries. Because the relationships among living and inert components of the ecosystem are extremely complex, the simple observation of cause-and-effect consequences in these hierarchical, interlocking systems fails to give a proper picture of the impact of human intervention on either the health of the ecosystem itself or the human beings who inhabit it. Indeed, if we are to evaluate the impact of human activity on ecosystems, a transdisciplinary approach is essential. Such a strategy must also rely upon local know-how to guide researchers towards the problems perceived as having priority by the communities targeted by the research. Local knowledge is also critical in helping researchers design interventions that are likely to be accepted by those communities and incorporated into a societal response that will ensure sustainable and equitable development. Given the sharp differences between the roles and responsibilities of men and of women in most societies, the ecosystem approach must also provide for a strategy that will allow researchers to analyze data for those two groups on a differentiated basis. The IDRC's early experience shows that the ecosystem approach to human health is not intuitive for researchers trained in the reductionist school of science, but it does offer lasting solutions to development problems. *Key words*: ecosystem; health, transdisciplinarity, participatory research; gender, research.

INT J OCCUP ENVIRON HEALTH 2001;7, Supplement 1

Received from the International Development Research Centre (IDRC), P.O. Box 8500, Ottawa, Ontario, Canada K1G 3H9.

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Most people tend to think of health as the absence of disease. However, public health experts accord it a much broader meaning. Shortly after the Second World War, for example, the World Health Organization (WHO) proposed a definition of health that is now part of its charter. Health was seen no longer as simply the absence of disease, but as a dynamic process of physical and mental well-being.[1] While the definition of health has continued to evolve and has become more holistic, it remains true to its philosophical roots. It is for this reason that the original 1948 definition will be used as the basis for discussion throughout this paper.

The twentieth century saw considerable progress in the development of models for illustrating and conceptualizing the relationship between the environment and human health. Modeling of human health based on human interaction with the environment was initially colored by the experience of the biomedical world and the fight to control infectious diseases. While the germ theory of disease (tuberculosis, typhoid, plague, cholera, etc.) proposed by Koch in the late 19th century may, at first glance, appear highly reductionist, it can also be viewed as the first ecologic model in which the interactions between a single infectious agent and its host are modified by environmental conditions.[2,3]

Although this approach was largely dominated by the classic biomedical model it allowed researchers to take major steps towards understanding the causes of the diseases that affect human beings. We now have a much better grasp of the mechanisms underlying disease, and we have made spectacular progress in clinical medicine. In the United States, for example, it is estimated that every dollar spent on child immunization saves more than 20 dollars in terms of the direct and indirect costs of not vaccinating children.[4] The eradication of smallpox is no doubt one of the great public health victories of the 20th century.[3]

As Nielsen has remarked,[5] however, the world is subject to the influences of many complex factors that undermine the health of all living beings, and that cannot be resolved solely through the reductionist medical approach, despite all its sophistication. Yet the disciplinary approach inspired by the simple and reductionist thinking of Koch's time is the basis of more comprehensive models developed to explain the complexity of interactions between the health of individuals and the environments in which they live. Over the last 30 years, several global ecologic approaches have been proposed to provide a better understanding of the complex relationships between the setting in which life is lived and the state of human health (see VanLeeuwen et al.[2] for a review of these models). These global models, which have had a strong influence on public health, are based essentially on four broad components that have impacts on the health of individuals and communities, namely the biophysical setting (environment), social factors (including economic and structural aspects), behavioral aspects of individuals (lifestyle), and their genetic baggage (biologic makeup).[6,7]

There is still considerable debate over the definition of each of these basic components, the parameters for quantifying and qualifying them, and the interactions between them. Yet there is no doubt that public health practitioners now recognize that the interrelationships among the factors comprising these four components can be the direct cause of disease, just as they can act as modulators for the effects of infectious agents or of the genetic makeup of each individual and thus affect his or her well-being.[2,3] This line of thinking has also strongly influenced efforts by public health authorities to prevent disease and to promote health rather than focusing solely on treatment. From a strategy focused on clinical needs and biomedical research, we have moved to a much more comprehensive understanding of the determinants of health that goes well beyond the physiologic basis of human diseases.

While this evolution towards a more holistic concept of public health was taking place, a parallel process was gaining momentum in the spheres of natural resource management and the environment. For example, scientists responsible for environmental management in the North American Great Lakes Basin, an ecosystem shared by Canada and the United States, proposed a global approach to managing the watershed. The scheme would allow resources to be used for economic purposes while assuring the environmental integrity and sustainability of the watershed.[8-10] Like their colleagues in the public health field, these ecologists proposed an approach to resource management that would integrate social aspirations, human activities, and the biophysical characteristics of the Great Lakes ecosystem (fauna, flora, geography, air, water, soil) in order to ensure their integrity, continued development, and optimal utilization. This approach, known as the "ecosystem health approach," has evolved considerably since its inception and has integrated specialists' thinking from areas as diverse as anthropology, ecology, economics, medicine, and veterinary medicine.[10-12]

Here, we introduce an approach to human health that is intended to build a bridge between the strategy of integrated environmental management (healthy ecosystems) and the global/ecologic approach to human health. The *ecosystem approach to human health* offers a unique opportunity to promote human health through a more judicious management of the ecosystem. Ecosystem management, of course, involves natural resources and the biophysical environment, but it must also take into account all its anthropogenic constituents, by integrating social, economic, and cultural factors relating to human life.

The ecosystem approach to human health is complementary to the *ecologic approach to health* and the concept of *healthy ecosystems*. They are all systemic approaches that recognize that health is an inherent property of biologic systems at varying levels of complexity, from the individual to the biosphere. Moreover, the ecosystem approach places human beings squarely at the center of the ecosystem, and makes ecosystem resource management subject to the sustainable and equitable improvement of human health, as well as the health of the ecosystem itself. The ecosystem approach to human health depends on participatory and interdisciplinary research that is sensitive to the needs of different social groups and their aspirations, including the differences between men and women. As we shall see, research plays a primary role in shedding light on the impact that the interactions between natural and anthropogenic factors have on human health. We will show that research is essential in any effort to improve human health by improving the health of the ecosystem.

The ecosystem approach to human health is not a second-rate research strategy appropriate only for use in the poorer countries of the South. On the contrary, we believe that this innovative strategy is applicable throughout the world, wherever there is relentless human aggression against the environment. Yet the ideas presented here reflect the experience of the International Development Research Centre (IDRC), whose mandate is to promote international development by fostering research in developing countries, and it is for this reason that our emphasis is on the application of those ideas in the South.

The ecosystem health paradigm first evolved in North America, specifically as a response to the needs of natural resource managers responsible for the North American Great Lakes in the United States and in Canada. The *ecosystem approach to human health* is a logical offshoot from this holistic paradigm, and it has strong roots in Canada. It seems appropriate, therefore, to review the evolution of public health thinking in this country—inasmuch as it may have influenced the appearance of this new approach (Table 1). We also examine the parallel evolution of the ecosystemic approach to resource management, which has similarly strongly influenced our approach.

TABLE 1 The Evolution of Public Health Thinking in Canada and Elsewhere According to Five Key Documents Published between 1974 and 1994

Document*	Major Themes	Other Publications*
New Perspective for the Health of Canadians (Lalonde report)[13]	**A global concept of health** Four main elements: Human biology Environment Lifestyle Organization of health	Blum[6]
Objectif Santé: rapport du comité d'étude sur la promotion de la santé (Rochon report)[17]	**An ecologic approach to health** Health is the result of a process of adaptation of an individual and his or her environment Insists on the multiplicity of determinants of health and on the complexity of their interactions with respect to health	May[115] Rothman[116] Armelagos[18] Pampalon[117] Lower[118] WHO[119]
Health for all: master plan for health promotion (Epp)[20]	**Health is a resource** Three mechanisms for promoting health: Personal initiative Community support Healthy environment Three application strategies: Public participation Improved community health services Coordination of public health policies	
Ottawa Charter for Health Promotion (WHO)[22]	**Intervention to promote health** Prepare a sound health policy, create favorable environments, strengthen community action, acquire individual skills, redirect health services Looking out for others, a holistic approach, and the ecology are indispensable elements for promoting health	
Strategies for improving public health: investing in the health of Canadians (Federal/Provincial/Territorial Advisory Committee on Public Health)[23]	**Strategies for improving public health** Considers all determinants of health Applies to the entire population Five categories of health determinants: Social and economic environments Physical environment Personal lifestyle Personal capacities and skills Health services	Mustard and Frank[120] World Bank[95]

*For complete reference citations, see the reference list.

EVOLVING TOWARDS A MORE GLOBAL APPROACH TO PUBLIC HEALTH IN CANADA

The Lalonde report[13] marked an important step forward in thinking about public health in Canada and in the world at large. For the first time, the global concept of health articulated in this document recognized four major influences on health: the organization of health care, human biology, the environment, and living habits or "lifestyle," in increasing order of importance (Figure 1a). The first factor, health care organization, refers to the accessibility, availability, and quality of the services that an individual or a community can expect to receive through local institutions and the regulatory structure. Human biology relates primarily to the genetic heritage that every human being receives at birth and that influences an individual's health and longevity to varying degrees. Since the appearance of the Lalonde report, several studies have focused on the influence of heredity in the appearance of diseases, such as cancer. Prior to the report, disorders of this nature had been attributed exclusively to environmental factors.[14-16]

One interesting feature of the Lalonde report is that it pays close attention to environmental factors, as well as to living habits, in determining an individual's health. It describes the environment as embracing all the factors external to the human body that can influence health and that are wholly or partially beyond the individual's control. For the first time in a major national public health document, there is an unequivocal admission of the importance of environmental factors for human health.

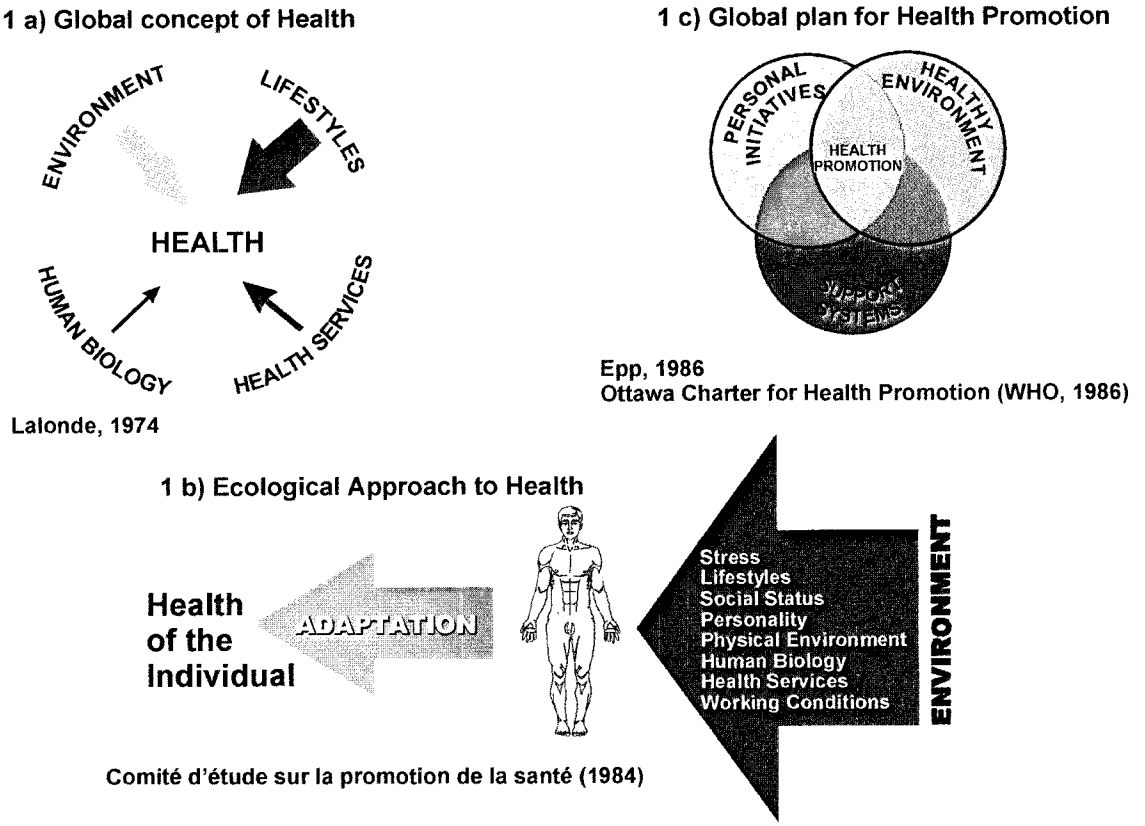


Figure 1—Evolution of public health thinking in Canada between 1974 and 1986.

a) A global concept of health as proposed by the Lalonde report (1974), whereby the state of an individual's health results from four principal groups of determinants: human biology (genetic makeup and congenital factors), the organization of health care, the physical environment, and, above all, lifestyle considerations.

b) An ecologic approach to health, as proposed by the Study Committee for the Promotion of Health (1984), whereby an individual's health is a result of his or her adaptation to the environment, considered in its broader sense to include social, cultural, and economic environments and also access to health services.

c) An overall plan to promote health, as proposed by the Epp report (1986), which recognizes the importance of a healthy environment for promoting health, but places great emphasis on community support and personal initiatives regarding lifestyle.

Living habits or "lifestyle" also have a preponderant role in an individual's state of health, according to Lalonde. They represent, in short, all the factors over which humans can exert a certain control. They are the choices individuals make that have repercussions on their health. Clearly, the authors of the Lalonde report saw people as largely responsible for their own health problems.

Though the report did, for the first time, identify the physical environment as one of the important determinants of individuals' health, it emphasized lifestyles and individual behaviors (smoking, nutrition, physical activity, etc.), and the impacts both had on health. This emphasis on individual choices has had the unfortunate effect of downplaying the important impact that the environment can have on health. In fact, the environment is much more sensitive to the impact of collective social and political decisions than to those of individuals. Despite their emphasis on the health impact of individual behavior, the authors of the Lalonde report recognized that personal *choices can be* dictated by environmental factors.

Ten years later, the Study Committee for the Promotion of Health[17] issued a document entitled *Objective: Health* (sometimes called the Rochon report), which proposed a more comprehensive view of the environment (Figure 1b) than did the Lalonde report. While stressing that the real causes of health problems are still imperfectly understood, the report suggested that the origins of many diseases can be traced to a variety of factors rather than to a single cause. The Rochon report introduced the concept of the multifactorial causality of disease, a causality that is not solely of a biologic nature (i.e., infectious microorganisms or genetic defects). The contributions of disciplines other than medicine, such as sociology and economics, were also identified as necessary elements in the practice of public health, in order to elucidate the complex nature of many health problems.

The committee went further than the Lalonde report by consolidating the different factors that can influence health under the heading "environment." Besides the physical environment considered in the Lalonde report,

it also describes the social and cultural environments, the economic environment, and the workplace. This ecologic approach to health takes account of a broad spectrum of factors that can influence health. A number of previous publications had already dealt with this concept[18] under the heading of an ecologic approach to *disease.* The approach espoused by the Rochon report is broader, and more positive, since it talks of health, which is defined as the result of a process of adaptation between the individual and his or her environment, rather than solely in terms of disease.

This distinction introduces the notion of the *human being as an integral part of the environment,* instead of the *human being in conflict with the environment.* Under this ecologic approach to health, the committee highlighted the complexity of the links between the different determinants of health, arising not only from the behavior of the individual him- or herself but from the quality of his or her living and working conditions as well. One important advantage of this proposition is that it encourages a much broader approach to disease prevention, one that is no longer based essentially on the availability of health care. It offers a systemic approach to human health that goes well beyond the simple biomedical context; an approach in which individuals are no longer held solely responsible for the states of their health, as the Lalonde report strongly suggested.

This ecologic approach to health now underlies the basic guidelines for public health policy in Quebec. A recent survey by Richard et al.,[19] while restricted to the public health district of downtown Montreal, reveals a sound integration of the ecologic approach and community participation into professional practice. It nevertheless points to certain constraints inherent in the approach: divergent priorities among partners, continued dominance of the biomedical model, the difficulty of working in a multidisciplinary setting, and the problem of public representation, for example. There is also only a limited integration of the biophysical environment.

In 1986, the Canadian government opened some new avenues in thinking about health. Epp[20] recognized that health is influenced by an individual's situation, beliefs, culture, and social, economic, and physical setting. Rather than regarding health as simply the result of the care that an individual receives or as a consequence of his or her interactions with the environment, it was suggested that health be treated as a resource, equal to other resources. Healthy people are able to exploit and even to modify their environments.

While the Rochon report identified the importance of social networks for health, the Epp report placed greater emphasis on the quality of the social support network (Figure 1c) and recommended that public health authorities pay greater attention to promoting health. As the principal elements of health promotion, Epp recommended creating a healthy environment, encouraging personal initiative (personal choices that contribute to keeping an individual in better health), and mutual support among members of society. For Epp, the environment includes the social, economic, and physical settings. This is a much more comprehensive definition than that used by Lalonde, and represents a further development of the definition proposed in the Rochon report.

Rappoport[21] would later provide a more clearly articulated definition of the human environment, as the amalgam of all physical, social, and economic components, including human beings themselves, as well as the consequences flowing from their social interactions such as their economic, political, religious, and aesthetic activities, and their tangible accomplishments, such as industrial production, transformation of the biosphere, etc.

In the opinion of the Epp report authors, the principal strategies or processes by which decisive action can be taken to meet the challenges facing health care in Canada are to encourage public participation, to improve community health services, and to coordinate public policies to promote health. The Epp report thus introduced the notion of community and individual participation as decisive elements for promoting health and preventing illness, while continuing to stress the importance of a healthy environment.

Coincident with the Epp report, the World Health Organization (WHO) proposed the Ottawa Charter for the Promotion of Health.[22] The Charter takes up many of the conclusions of the Epp report. For example, participants at this first international conference on health promotion considered health to be an important condition for fostering progress and a significant determinant of the quality of life. Moreover, the signatories to the Charter associated health promotion with protection of the environment, both natural and man-made, and the conservation of natural resources. They also stressed the importance of ecology and of taking a holistic approach to health promotion. As Rochon had done, they stressed the diversity of the "environment"—its economic and political, social, cultural, environmental, behavioral, and biologic aspects. A novel element also appeared in this document: the importance of ensuring equal participation by men and women in promoting health.

Among the fundamental conditions for good health, the Charter proposed the stability of ecosystems and the sustainability of resources. One of the five action fronts proposed in the Charter was to create more favorable living conditions—referring to the physical, social, economic, cultural, and spiritual environments, and including the workplace.

In 1994, the Federal–Provincial–Territorial Advisory Committee on Public Health produced a document entitled *Strategies for Improving Public Health: Investing in the Health of Canadians,*[23] which contained a number of statements about what makes people healthy. A few key factors emerged from this study as influencing health, namely the social and economic environment, the physical environment, lifestyle and

TABLE 2 Examples of Environmental Determinants of Health, by Type

Type of Determinant	Common Descriptors for the Developing World
Physical factors	Climate variations: Temperature Precipitations Extreme events (hurricanes, floods) Housing Noise Exposure to ultraviolet radiation (reduced ozone layer)
Biological factors	Disease vectors: Mosquitoes (malaria, dengue and other arboviruses, yellow fever) Fleas (plague) Flies (fecal contamination, leishmaniasis, filariasis) Rodents (plague, Hanta virus) Viruses and microorganisms Biomedical wastes
Chemical factors	Agrochemical products: Pesticides (herbicides, fungicides, insecticides, rodenticides) Fertilizers Heavy metals (mercury, arsenic, etc.) Atmospheric pollutants Dust
Social factors	Employment, working conditions Culture, religion Income Education Racial and gender discrimination

the capacity of an individual to adapt to change, an individual's biologic constitution and genetic heritage, and health services.

Two of these categories, lifestyle and adaptive capacity on one hand and biological constitution and genetic heritage on the other, relate primarily to the individual. The other three factors have more to do with the community, but they serve to facilitate or support the "individual" factors. If we define health in these more global terms, then many of the factors that influence it go well beyond the treatment of illnesses and the health services system. It is interesting to note that qualitative indicators of health began to emerge in this document. Instead of life expectancy, the authors spoke of the number of years of healthy life or the quality of life; instead of morbidity and mortality rates, they spoke of the repercussions that health problems have on everyday life. The authors note that the level of education is a significant gauge of good health (relative to people who have little schooling) and *they also* stressed that unemployed people are generally less healthy than those who have jobs.

BUILDING A BRIDGE BETWEEN HUMAN HEALTH AND ENVIRONMENTAL SUSTAINABILITY: THE BRUNDTLAND REPORT AND UNCED

In 1987, the Brundtland Commission published its conclusions about sustainable development.[24] The report defined sustainable development as that which could satisfy the needs of today without compromising the capacity of future generations to meet their own needs. While the Brundtland Commission's mandate did not refer specifically to human health, the report clearly identified the role that human beings play in changing the environment, and it established unequivocally the impact that environmental changes, in turn, have on human health and well-being.

This theme was taken up again by the United Nations Commission on Environment and Development (UNCED) in 1992.[25] In its report, the Commission noted that health and development are intimately related. On the one hand, they claimed that underdevelopment is directly associated with poverty, a major determinant of health. On the other hand, inappropriate development leads to overconsumption of resources and degradation of ecosystems. These two circumstances, coupled with a growing world population, have the potential of causing severe environmental health problems not only in developing countries but also in those of the industrialized world. Agenda 21, the action plan for sustainable development proposed by UNCED, espoused the idea that the essential health needs of the world's people must be urgently addressed. What is more, the document recognized that in order to meet these basic needs, more attention would have to be paid to the links between health and improvement of the physical and socioeconomic environment.

The Brundtland Commission highlighted the relationship between human health and environmental change. We now recognize that there are many environmental determinants of health. Pinnock[26] classifies them under four broad categories of factors: physical, biological, chemical, and social—including economic aspects. Table 2 lists some of the environmental determinants of health that are present in the developing world.

It is difficult to attribute sole responsibility for the emergence of a health problem to one or another of these groups of determinants. In reality, human health is influenced not only by specific environmental factors, but also by phenomena resulting from the interactions between these sets of factors. Certain high-priority problems in the developing world illustrate this situation: lack or inadequacy of basic sanitation, poor water and food quality, air pollution, the emergence, re-emergence or progression of vector-borne diseases, use of hazardous chemical products, including improper waste management, and global changes. The latter include human-induced physical and chemical phenomena (climate

change, ozone layer depletion, etc.) and social factors (migrations, demographics, traffic accidents, violence, territorial conflicts, etc.).

The interactions between these various determinants create situations of risk where people are exposed to adverse environmental conditions that may affect their health. According to Smith,[27] the risks resulting from exposure to these environmental determinants of health can be divided into two broad classes: traditional risks and modern risks.

Traditional risks are those associated primarily with societies living in a pre-industrial state of development that is often heavily dominated by subsistence farming practices. Environmental risks typically flow from the consumption of contaminated foods and water, the absence or inadequacy of sanitary facilities, and exposure to vector-carried diseases and zoonoses (malaria, schistosomiasis, rabies, plague, leptospirosis, etc.), as well as the prevalence of substandard housing. These societies, where the majority of the population is typically very poor, are characterized, among other things, by high infant mortality rates and by high morbidity rates linked to communicable diseases.[28]

Risks labeled modern first appear when a society's development accelerates and economic competition increases. In the developing world, this acceleration is characterized primarily by more intensive, "modern" farming practices, by the mass industrialization of many economic activities, and by increased use of energy (fossil fuels) and mineral resources.[29] There are also externalities that can be imposed by one society on another during the modernization process. The impact of such development on the health of ecosystems and human beings is far from negligible. Pollution that can contaminate the air, water, and soil appears as the result of the massive use of chemical inputs in farming and the dumping of industrial and chemical waste products (persistent organic pollutants—POPs, metals, etc.). Economic development, at least in the richer countries, is normally associated with a pattern of mortality and morbidity that is dominated by non-communicable diseases such as heart disease and cancer.[28]

This shift from a situation where mortality and morbidity are linked to traditional risks to one where they come to be dominated by causes attributable to modern risks is called the epidemiologic transition. Theoretically, when environmental risks are well managed through an appropriate regulatory and political framework and a sound approach to economic development, the transition from a pre-industrial to a developed society should bring with it two fundamental changes. First, traditional risks should disappear almost completely, together with a sharp drop in their associated illnesses. Second, industrial and economic development can be expected to give rise to modern risks. With the use of the appropriate tools (regulatory framework, surveillance, intervention, etc.), the modern risks can be stabilized and perhaps even diminished.[27]

It is possible, then, that proper management of environmental risks during the transition phase will go hand in hand with a better quality of life thanks to economic development—traditional risks are banished and modern ones are controlled.[30] In fact, this pattern fits fairly closely with the experiences of European and North American countries during their industrialization, although there can still be major gaps between the health of individuals in any population, because of their social and economic characteristics (sex, race, income, etc.).[31]

The reality in the developing world (particularly for the poorest countries) is, however, quite different. In their quest to attain "modern" levels of development, these countries are exposed to new risks (industrial pollution, etc.) that are frequently uncontrolled because of a lack of resources—human, financial, intellectual, and structural.[26] There is thus an increase in modern risks, together with a form of development that frequently relies on the overexploitation and degradation of ecosystems. This imbalance can create, re-create or amplify conditions favorable to the re-emergence of traditional risk factors responsible for the health problems of pre-industrial societies.[28,30] The affected people find themselves caught in the worst of both worlds, beset by both traditional and modern risks.

The impact this dual risk has on the health of the poorest populations is well illustrated by the results of new studies of morbidity and mortality, expressed in DALYs (disability-adjusted life years). The DALY is an indicator of the total burden of a disease. It includes mortality and morbidity data along with data on premature mortality, the number of years of living with a given disease, and the severity of that disease. Murray and Lopez[32] provide a detailed description of the derivation and the interpretation of DALYs. Gwatkin and Guillot[28] show that in 1990, among the 20% of the world's population living in the poorest countries, the highest DALYs were always associated with communicable diseases, malnutrition, and poor perinatal and maternal care—in other words, traditional risks. At the other end of the spectrum, the DALYs for the 20% of the world's population living in the richest countries essentially reflected non-communicable diseases associated with modern risks, such as heart disease, cancer, and neuropsychiatric disorders. They also point out, on the basis of a 30-year modeling exercise (1990–2020), that the epidemiologic transition will not occur exactly as expected in the poorest countries. In fact, they note that even if disease-related DALYs associated with traditional risks were to diminish slightly, they will still be a leading cause of death. Moreover, there will be a sharp increase in non-communicable diseases associated with modern risks. It would seem, then, that there is a fairly close relationship between high morbidity and mortality levels and environmental risks.

The literature[33] also documents a disturbing trend in re-emerging and emerging diseases in industrialized

countries. Infectious diseases, principally caused by food-borne pathogens or microorganisms that have become resistant to antibiotics, are once again on the rise. While there are numerous factors that seem to be responsible for this recrudescence of infectious diseases,[34] it is significant that it is happening at a time when society is becoming more homogeneous as a result of modern communication technology and the ease with which people move around the globe.

THE HEALTH OF ECOSYSTEMS: A GLOBAL APPROACH

The Great Lakes that lie along the Canada–United States border are among the largest freshwater bodies in the world, covering a surface area of 246,000 km^2 with a shoreline of 18,000 km, in a watershed of 523,000 km^2.[35] They represent 21% of the world's freshwater reserves. Following the Second World War, the Great Lakes Basin underwent phenomenal industrial and agricultural growth. During this era, the lakes and their surrounding territory became dumping places for both industrial and human wastes. Until the early 1970s, it was generally assumed that the ecosystem could tolerate and assimilate such pressures, given its geographic expanse and the resources it contained. A series of studies in the 1980s pointed to significant environmental degradation in terms of the destruction of habitat, fauna, and flora, and the loss of recreational use.[36]

The International Joint Commission for the Great Lakes (IJC) was established by Canadian and United States authorities to manage this water resource to meet economic, social, and health goals and to ensure the sustainability of the ecosystem. IJC scientists soon discovered, however, that conventional approaches to resource management, based on the study of the aquatic ecosystem from a reductionist point of view and rational analysis of available information, would not preserve or restore the water quality of the basin, as called for under the Great Lakes Water Quality Agreement of 1972. Scientists and government authorities recognized that they had to go beyond an approach to water-quality management based on discrete standards, such as a maximum concentration of a toxic substance in a liter of water (x mg/liter), to solve these problems. Conventional approaches also posed obstacles to finding solutions because the decision-making process and consequent interventions were conducted with no regard to the global context of the Great Lakes ecosystem.[37-39]

In 1978, the IJC began to develop an approach in which all the elements affecting the Great Lakes Basin—water, air, land, and living organisms, including humans—would be considered within an integrated program for managing water resources.[37] This shift in thinking made it necessary to visualize people as part of the ecosystem rather than treating them as a separate entity.[39] In effect, the IJC introduced the notion of an ecosystem approach to resource management that integrated knowledge generated for the individual elements affecting the overall ecosystem of the Great Lakes and accounted for the needs and aspirations of its human inhabitants. IJC experts were pioneers in applying the metaphor of healthy ecosystems in order to foster an understanding and acceptance of an integrated approach to ecosystem management on the part of scientists, regulatory authorities, policymakers, and the public at large.[37,40]

After reviewing several integrated resource-management models developed in Canada (including the one for the Great Lakes Basin), the Canadian Council of Ministers of the Environment (CCME)[41] made use of the scheme originally developed by Hancock[42] to illustrate the differences between a conventional approach to resource management and an integrated one. Figure 2 shows the classic approach to resource management where the three basic components are the economy, community aspirations, and the environment, which are treated as discrete units with varying degrees of importance. Figure 2 also shows an ecosystem approach to resource management, where the three components are merged into a Venn diagram. In adopting the latter approach, the CCME proposed that the three components be examined jointly and accorded the same importance. The point of intersection of these areas represents the health of the ecosystem.

Uncontrolled development of any one of these areas—the economy, for example—to the detriment of the other two will compromise the sustainability of the ecosystem sooner or later. This principle is particularly relevant to developing countries. Heads of state who participated in the United Nations Conference on Environment and Development in Rio de Janeiro underscored this point when they concluded that protection of the environment is an integral part of the sustainable development process.[25] Economic activity is essential to social development, but it must be pursued in a manner that is environmentally and socially sustainable. Development must be of the kind where resource use does not compromise the well-being of future generations.[43]

Undertaking development under this new set of strictures represents an important challenge. The management of resources and the environment must take into account the perspectives of many stakeholders, all of whom have unique views on how best to use and conserve environmental components. In this context, and in light of the complex problems arising from the misuse of resources, integrated management can be an important tool in planning for sustainable development. Integrated resource management offers a strategic and interactive planning approach that can reconcile the diverging interests of different stakeholders by giving each of them a voice in the decision-making process. The intention here is to develop solutions to specific problems identified by stakeholders in light of their own needs. Solutions

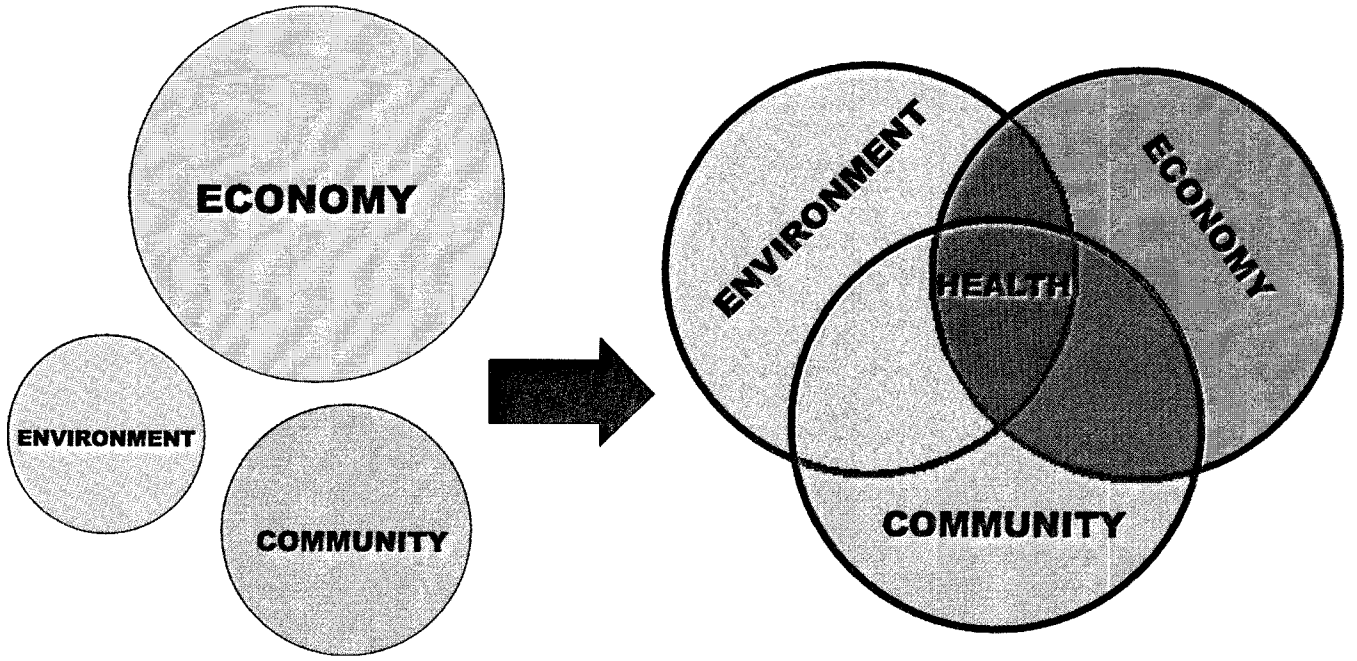


Figure 2—The ecosystem or "healthy ecosystems" approach.
a) The classic approach to resource management places greater importance on economic factors and community aspirations than on sound environmental management.
b) The ecosystem approach gives equal importance to these three areas, and promotes healthy ecosystems by managing them sustainably.

need not be perfect, but they must be the best solutions for all concerned. Therefore, to improve the state of the environment and the quality of life, it is essential that a mechanism be developed to involve stakeholders during the evaluation, planning, and implementation stages of resource-management projects.[44,45]

DEFINING THE CONCEPT OF ECOSYSTEM

The term "ecosystem" was first proposed by Tansley[46] to describe a set of living organisms and abiotic environments occupying the same place. Many recent authors[38,39,47] credit Odum[48] with developing the concept of ecosystems more fully, through his emphasis on the importance of interactions between the living and inert components of any system.

In the wake of Tansley's work, however, ecologists had problems setting geographic limits on the ecosystems they wanted to study. While ecosystems can be described according to quantitative and measurable parameters, they can also be defined as a function of the task they accomplish.[49] Odum himself[48] had suggested that the parameters of an ecosystem were defined much more by the needs of researchers than by any intrinsic characteristics. A system under study could thus be a pond, or it could just as well be the entire biosphere.

The precise definition of an ecosystem may remain the subject of controversy, but most writers agree that, as a minimum, it implies the presence of a set of different living organisms interacting with their physical environment. In fact, the IJC describes an ecosystem as an ensemble of air, soil, water, and living organisms and the interactions among these elements.[37]

While we may be able to establish the limits of an ecosystem, these limits will always be arbitrary,[10] since ecosystems exist in relation to the systems that surround them, and neither is independent of the other. Studies by Laurance,[50] for example, have shown that land use that subdivides the Amazon forest into small islands of trees separated by savannas has had a catastrophic impact on the health of wild ecosystems. The proximity of open spaces characterized by intense dry heat kills many trees that are no longer protected by the humid, dark setting of the forest. The smaller parcels may lose up to 36% of their biomass shortly after they become isolated from the main forest. While ecosystems are ecologic units, there is also a maze of interactions among these units, so that their equilibrium is influenced by neighboring systems.

According to Vayda and McCay,[51] an ecosystem is an analytic unit rather than a biologic entity. Other more recent authors also favor this definition.[52] We believe that the following working definition, proposed by the Canadian Council of Ministers of the Environment,[42] is very appropriate in the context of an ecosystemic approach to human health:

For purposes of planning and information gathering, the limits of a given ecosystem are defined by the user, according to the task at hand and the scope of the process. While in general the limits selected will circumscribe an ecological space such as a watershed or a region, we can also designate a farm, an urban subdivision or a rural community as an ecosystem.

Ecosystems are thus composed of heterogeneous units. Interactions among them can be difficult to predict, more so because they can embrace many different spatial and temporal scales. Ecosystems are intrinsically complex and this makes them particularly difficult to describe. Kay and his collaborators[53] suggest that the ecosystems that we define arbitrarily represent assemblages of entities that exist within systems of interlocking hierarchies. They propose the term "holarchies" for the interlocking networks of entities that interact with each other, and apply to them the acronym SOHO, or self-organizing holarchic open, systems. Drawing upon the complex-systems theory, they maintain that SOHO systems are more than simply the sums of their various components: in other words, they are not simply events in a straight line of cause and effect. This concept of nested hierarchies (including potentially differing temporal dimensions) is critical to the application of an ecosystem approach to human health (Figure 3).

As noted at the beginning of this section, the ecosystem approach developed by the IJC has been translated into the metaphor of the healthy ecosystem. This metaphor is a powerful and effective tool for creating awareness and promoting action against environmental degradation, because it highlights clearly the association that humans make between good and ill health, and applies it to the ecosystem.

Nevertheless, the use of this metaphor, based on a vision of the "ecosystem as a living organism," has several limitations that continue to provoke lively debate. In the first place, the analogy is based on mechanisms of homeostasis proper to living organisms: self-regulation, maximization of energy throughput, capacity to reproduce—survival strategies that promote and maintain an optimal state of equilibrium for the organism, on the basis of genetic parameters. Scrimgeour et al.[54] refuted this argument, noting that ecosystems are not structured like living beings because, despite the presence of feedback loops between different levels of organization, there is no control system to coordinate the mechanisms of the overall set of biotic and abiotic components. It is intriguing to observe that, since early humans started practicing agriculture ten thousand years ago, they may have been striving to function as such an intrinsic "control system."

Early in the debate, Vayda and McCay[51] pointed out

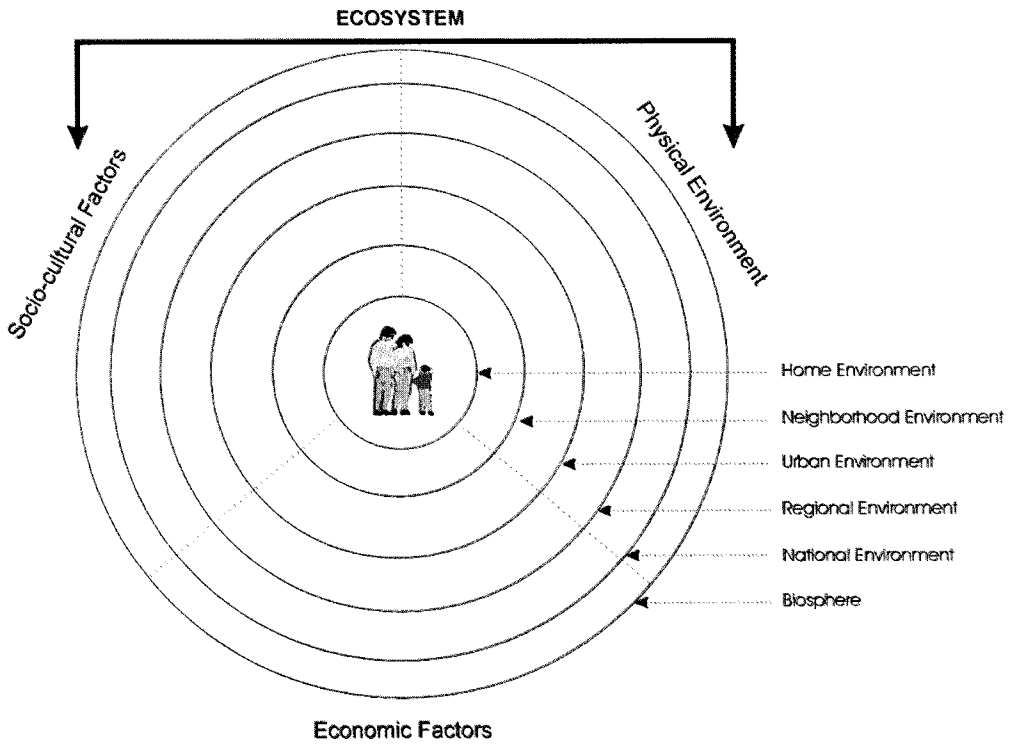


Figure 3—Nested hierarchies constituting an ecosystem. The ecosystem approach to human health is a systemic approach that considers the ecosystem as an analytic concept. This example shows the various elements that interlock and influence each other and that can have an impact on health: home environment, neighborhood environment, municipal environment, etc. Each of these elements has its own cultural, economic, and environmental factors that can modulate each other and can also influence elements of other elements. (Inspired by Mergler, 2000, unpublished data.)

that the sustainability of ecosystems is simply a consequence of synergy between the individual strategies for survival and reproduction of living organisms that share a common space. Moore[55] notes that in ecology there is no "community spirit" and that any notion of cooperation and altruism is an illusion, the simple expression of the action of selfish genes. Yet the interdependence of species within an ecosystem is often highly complex.

A second objection invoked is the difficulty of sustaining this metaphor because of the absence of clearly defined frontiers, such as exist in human affairs, when we attempt to describe the ecosystem, and because of the ecosystem's inability to "vocalize" whether it is doing poorly or well.[56] This argument has sparked debate over the difficulty of making a diagnosis of the state of an ecosystem's health on the basis of a "clinical examination," given the interests of the observer performing the diagnosis. It is true that this argument would also hold for veterinary medicine or pediatrics, but it is probably fair to say that practitioners have a better understanding of the symptoms presented by their charges than do ecologists (or politicians) of what ails an ecosystem. This question also underlies the debate on setting decision-making criteria for determining whether an ecosystem is "sick."[57] Interested readers will find a good discussion of the debate, linked to the use of the "healthy ecosystem" metaphor, in the summaries offered by Rapport,[11] Eyles et al.,[58,59] and Ross et al.[39]

As noted by Ross et al.,[39] it is time to stop arguing over the validity of using the "healthy ecosystem" metaphor, because in practice it is becoming part of the language of researchers, policymakers, managers, and the general public in discussing issues of environmental degradation. From being just a metaphor, the healthy ecosystem has come to represent a global approach to resource management that can be understood by reference to a very intimate human experience: health. Recalling the work of the IJC discussed earlier, the main point to bear in mind is that the use of this metaphor has served to mobilize scientists and public authorities around an approach that can be understood by all, and this has done much to re-insert the human element into nature.

Several definitions of healthy ecosystems have been proposed. It is our contention that an ecosystem approach to human health is better served by adopting the definition of a healthy ecosystem proposed by Costanza et al.[60] They posit that an ecosystem is healthy and not suffering from "distress syndrome" as long as it is sustainable; in other words, as long as it remains active and can maintain its organization and its autonomy over time, and rebound from stress. This definition is important because it does not necessarily refer to the "initial" qualities of an ecosystem, and it is perfectly adaptable to ecosystems that have been heavily influenced by human activity, such as agro-ecosystems, urban ecosystems, or any other ecosystem subject to anthropogenic influence (industrial activities). Human beings are peculiar in that they are not content with adapting to the constraints imposed by nature, but insist on modifying the environment that shelters and nourishes them. For Bell,[61] the integrity of ecosystems in the context of the 20th century could be interpreted as meaning the capacity of nature to continue to serve human beings. Given this concept, which values material well-being above all, it is not surprising that the health of an ecosystem should be diagnosed in terms of its productivity.[10] In fact, society is generally in favor of modifications to the ecosystem that will enhance the productivity of nature in the short-term service of human needs. And for the same reason, such an approach to ecosystem management also seeks stability in its yield. This is what natural resource-management specialists sometimes refer to as the sustainability of ecosystems.

MANAGING ECOSYSTEM RESOURCES

Society's aspirations, then, depend on a certain stability of the ecosystem and on its yield (farming, forestry, hydroelectric output, etc.). Yet turbulence is one of the prevalent characteristics of nature. The most stable ecosystems are not necessarily the healthiest or most vigorous ones. Many types of ecosystems owe their resilience to the life-giving effect of periodic disturbances. In North America, for example, we know that forest fires are essential for the long-term health of forest ecosystems.[62-64] In fact, we can gauge the health of the ecosystem by the vigor with which it rebounds from such a disturbance.

But for a community that draws its sustenance from forest resources, such an event may well be a catastrophe unless it is built into a longer-term resource-management plan or use pattern. It is for this reason that, as a general rule, society regards such disturbances as not having any part in "well managed" ecosystems,[10] and resource managers seek to eliminate them at all costs in order to enhance the system's stability.[11]

Paradoxically, it is likely that the more we attempt to intervene to stabilize an ecosystem through the use of external inputs (irrigation or drainage works, use of fertilizers and pesticides, damming watercourses, land reclamation), the more we diminish its intrinsic recovery capacity—and perhaps greatly increase the risk of catastrophe. The more we try to compensate for this reduced capacity by increasing inputs and by managing resources ever more intensively, the more we weaken the ecosystem. Such ecosystems may still be productive over the short term, thanks to human interventions that offset a loss of elasticity or damage to the environment through the addition of inputs, such as pesticides or fertilizers in the case of intensive agro-ecosystems, but they will be extremely vulnerable to natural disturbances or those that flow from increasing productivity demands or rising demographic pressures.

Indeed, it may well be that enlightened ecosystem management will have to come in the form of a better

approach to the management of human activity rather than of the environment. This is the view of several experts in this area.[65,66] Ecosystem management, therefore, requires a well-integrated system of management methods and policies that draw the connection between human beings and the ecosystem in which they live. This is very important, because humans maintain their dominance of an ecosystem through deliberate behavior. This behavior is less predictable than the behaviors of other organisms that make up the ecosystem, since humans are capable of acting maliciously or simply shortsightedly. Our goals do not always coincide with the needs of the ecosystems that we dominate, and by the same token we may involuntarily upset the stability of the ecosystems on which we depend.[67]

As noted earlier, UNCED in 1992 produced an action plan—Agenda 21—for achieving sustainable and equitable development. Chapter 40 of that document calls on governments to come up with indicators of sustainable development so they can assess the impacts of development programs while at the same time respecting and preserving the environment. These indicators were to be developed in a manner consistent with the general principles set out during the Rio Summit, in particular, regarding their relevance for and their appropriation by all the key stakeholders. Many groups, such as the International Union for the Conservation of Nature (IUCN), had already explored the development of such indicators, and Agenda 21 gave a further boost to these efforts.[68] In reality, indicators of sustainable development and indicators of ecosystem health may often be the same.

How do sustainable-development indicators relate to the indicators of ecosystem health? Costanza and his colleagues[69] suggest that an ecosystem's sustainability must be measured in terms of its capacity to preserve both its structure and its function (in other words, its degree of organization and its vigor) in the face of external shocks over the course of time (its elasticity). The very notion of sustainability introduces, by definition, a time component. A sustainable ecosystem is a system that will survive over some normal, intrinsic period of life expectancy. This temporal dimension to ecosystem sustainability allows for successional changes inherent to ecosystems.

There are two important factors to consider in assessing the sustainability of an ecosystem: the magnitude of the external threats from which it can recover naturally, and the length of time that such recovery will take.[69] An ecosystem incapable of recovering from a given threat is suffering from "distress syndrome,"[70] or an irreversible process of collapse that will lead to its premature disappearance. The symptoms of this distress syndrome can be measured by indicators such as the reduction in biodiversity, the loss of nutrients, and changes in its biotic composition.

According to Rapport,[11] we may consider that an ecosystem that shows none of the signs normally associated with distress syndrome is in good health. Unfortunately, the results of all these measures will reveal that an ecosystem is under stress only at a point when damage or significant alteration has already occurred. By then, it is generally too late to turn things around. Distress-syndrome indicators are thus not very suitable for detecting ecosystem health problems at their outset, when it would still be possible to do something about them. Rapport suggests that early-warning indicators could be identified based on differences over time in the behaviors of organisms and changes in key species of the ecosystem, as well as biochemical changes among certain organisms that are sensitive to toxic stress.

On this last point, recent studies have shown the great potential of measuring chemical pollution in water with the use of simple biologic methods that are within the reach of human communities inhabiting the ecosystem.[71] This tool could be an important element in establishing a diagnosis of the quality of an ecosystem's health. It does not allow us, however, to identify the causes of damage to the environment or to measure directly the impact on human health. To this end, further study is required. However, information gathered early at the community level could serve to initiate broader studies in collaboration with the authorities and with scientific experts.

If we are to conclude that an ecosystem is healthy, we must look at it on two levels. First, we must take into consideration the context in which it exists, and its complexity. Second, we must examine the various components of the ecosystem, because these will probably serve as indicators of its health. This is the basis of Whitford's[72] two classes of indicators of ecosystem health. One class is used to measure the properties of an ecosystem, and the other measures the processes inherent to it. In the latter case, the focus is on measuring criteria relating to primary production, the energy cycle, and the rate of nutrient utilization. As one may imagine, these measurements can be complex, time-consuming, and costly. For our purpose, they also have the disadvantage that, alone, they cannot provide very many points of reference for measuring human health, although they may be essential to understanding the ecosystem structure and functions.

Measuring the properties of an ecosystem is much more attractive for our purposes. These indicators are often associated with what some call ecosystem services.[73] These are processes inherent to ecosystems that, while they do not depend on human intervention (except perhaps on minimal intervention), are essential to the very life of human beings. These services include the transformation of solar energy, the decomposition of organic wastes, the regeneration of the air we breathe, and the storage and purification of water. In fact, several ecosystem properties have attributes that can be directly linked to human health. Any attack on an ecosystem that destroys these ecosystem services has the potential to affect human health. To assess the severity of this influence, we make use of risk analysis.

Risk analysis requires first of all that we estimate the probability that the threat will produce a consequence. If

that probability is significant, we can then assess the severity of a given consequence for the ecosystem and for human beings. Clearly, the accuracy and precision of this risk analysis will depend on the quality of the information used for quantifying the probability and the severity of the possible consequences. In other words, a risk evaluation relies on a variety of data and must be interdisciplinary in its approach. We must first identify the element of risk, then define the potential effects on the various components of the ecosystem (including human beings), measure the parameters of exposure to this risk element, and, finally, use this information to characterize the risk.

As Cairns notes,[73] an approach to ecosystem health based on risk analysis relies, by definition, on a context of societal objectives. While determining the probability of a certain consequence's appearance is relatively objective and is based on the sum of existing scientific knowledge, estimating its severity is much more subjective. In fact, it is based on the concessions that communities are prepared to make relative to a given level of development. We can see immediately that estimates of the severity of consequences can vary considerably depending on the aspirations, the culture, or the needs of the people concerned,[74] but they will also depend on the time scale over which the effects of the threat are felt.

ECOSYSTEMS, HUMAN HEALTH, AND SOCIETY

As we saw earlier, some national authorities in the United States and Canada have adopted the metaphor of healthy ecosystems in their approach to natural resource management. The philosophy behind this management approach implies working out objectives for the health of ecosystems in consultation with the community itself. In this context, it is essential to design indicators of ecosystem health. According to Gaudet et al.,[75] we can design an indicator as an element that, when measured, provides an index of the quality of the ecosystem, or at least indicates a trend towards an improvement in that quality—given that it is measured over time.

If we are to speak knowledgeably of the health of an ecosystem, we must rely on indicators of its state of health, including the health of human beings. In medicine, we already have a large number of human health "indicators," for example: a reduction in serum cholinesterase in cases of organophosphate pesticide poisoning, a reduced clearance of endogenous creatinine in cases of glomerular insufficiency, or lower G-6-PD activity in cases of medication-induced hemolytic anemia. Using these measures of physiologic parameters together with the symptoms that the patient presents, a doctor can prepare a clinical diagnosis or assess the patient's state of health. In public health, we also have indicators such as life expectancy, mortality rates, DALYs, infant mortality, malnutrition, etc. These indicators, despite their inherent oversimplification, provide policymakers and public officials with the information they need to manage health services and other components of health policy.

As we pointed out in the introduction, human health must be viewed not only as the absence of disease, but also in terms of an individual's well-being. The WHO has developed a tool for measuring improvements in the quality of life with respect to health care, the WHO Quality of Life—WHOQOL—index.[76] The WHO defines quality of life in terms of individuals' perceptions of their positions in life, in the context of the prevailing cultural and value system and their own goals, expectations, standards, and concerns. Quality of life is an inclusive concept that makes itself felt in complex ways in individuals' physical health, their psychological states, their personal beliefs, their social relationships, and their links to components of the environment. This kind of instrument is likely to be used increasingly to go beyond the classic view of assessing illness (sick/healthy) and to embrace a broader view of the factors that interact with health and constitute well-being.

The development of human health indicators in relation to environmental and ecosystem factors had its origin in indicators of changes in the environment. In the late 1970s, Rapport and Friend[77] proposed an innovative statistical method for tracking the cycle of environmental changes. They started by looking at the pressures imposed on the environment. They then examined the changes that appeared in the structure and functions of the ecosystem, resulting in a modification of ecologic services. The model also accounted for associated policy shifts. This system, known by the acronyms SRESS ("Stress Response Environmental Statistical System"), was the forerunner of the system now used by the OECD, the "Pressure–State–Response Framework." This later led the WHO[30] to develop health indicators in relation to the environment, known as DPSEEA (Driving Force–Pressure–State–Exposure–Effect–Action).

The latter is a flexible approach that is relevant to our topic. For each stage of this scheme, we can design indicators to measure the impact of our interventions at each level. The advantage of this approach is that it allows us to concentrate our analysis of an ecosystem's health at a level appropriate to a given situation. For example, it is quite possible to concentrate on the Effect (diarrhea, for example) and move up to indicators of Exposure (waterborne coliforms, microbiologic contamination of food), the State of the ecosystem (polluted water sources, lack of latrines, contamination-prone food preservation or canning processes), Pressures (lack of health education, lack of proper water distribution and sanitary facilities, degradation of natural resources), and Causes (poverty, inappropriate supply and hygiene practices, misguided public health policies, etc.). All of these indicators are measurable, and they point to places where we can intervene with measurable results. We might also decide to

address the situation at quite another level of the scheme, but it is clear that in research terms it is often more intuitive to begin with the effect identified by the community as a priority problem, and one that at the same time can be confirmed by the scientific community and ecosystem managers.

Yassi et al.[78] illustrated this approach compellingly in a study they conducted in an urban ecosystem in a poor district of Havana, Cuba. Their ecosystem health indicators take account of elements directly linked to human diseases, but also indirect causes that in turn modulate the impacts of these elements on human health. This approach leaves a large part of the decision making to the communities themselves, but provides for quality control and validation through proper scientific procedure.

THE ECOSYSTEM APPROACH TO HUMAN HEALTH

Human management of the ecosystem is anthropocentric and does not necessarily seek to maintain the balance of the ecosystem as it existed before the arrival of human beings, unless this initial equilibrium is considered advantageous to humans. Human management of the ecosystem typically creates a new equilibrium that aims to be more conducive to the social and economic aspirations of the people who live in it or use it, and have the power to control it. However, ecosystem management has the potential to damage the economic and social environment and it can also have unexpected and even disastrous consequences for human health.

The ecosystem approach to human health explores the relationships between the various components of an ecosystem in order to define and evaluate the priority determinants of human health and the sustainability of that ecosystem. To do this, we focus on developing solutions based on an alternative form of ecosystem management, rather than on conventional health sector interventions. Over the course of recent decades, several examples of improvements made to human health through measures to manage ecosystem resources have been reported. Before presenting these examples, we should first look at how imbalances among the elements of an ecosystem can influence the quality of life and health of people living in it.

Five years after the Rio conference, WHO[30] concluded in its report on the state of health and the environment that the poor quality of the environment (and of ecosystems) was directly responsible for 25% of all diseases that could be classed as preventable (acute respiratory infections, malaria, diarrhea, and occupational illnesses). This burden falls most heavily upon children, who are one of the groups most vulnerable to the impact of harmful environmental conditions and who account, according to WHO estimates, for 66% of the victims of environment-induced illnesses.

In fact, the persistence of malaria around the world and its progression in certain regions would seem to be invariably associated with environmental disturbances, often linked to improper use of ecosystems. Some experts suggest that as much as 90% of this global scourge can be traced to environmental factors such as intensified farming practices, mining, irrigation, or hydroelectric development.[30] Ghebreyesus and his colleagues,[79] for example, reported that in northern Ethiopia the incidence of malaria attacks over the course of a year was seven times higher among children living in villages located less than 3 km from new micro-dams than among a control group living 8–10 km from such facilities.

A second famous example illustrating this link between ecosystem degradation and human health problems is that of the Aswan high dam in Egypt. In an effort to control flooding on the Nile during the 1960s, Egypt built a dam upriver in the Aswan region. A number of major ecologic changes were observed, such as changes in the river's rate of flow, flood control, and species changes, following this major undertaking. One of the most spectacular effects from the creation of this dam was the collapse of fishing on the Nile River downstream from Aswan, where the commercial fishery catch declined by nearly two thirds.[80] In addition to these environmental and economic impacts, the building of the Aswan dam also created a serious human health problem linked to the parasitic disease schistosomiasis (Box 1).

As Daily and Ehrlich pointed out,[81] the development of human society has been so successful that mankind is now a factor rivalling the forces of nature in changing the climate, modifying the landscape, and so on. Consequently, we are now experiencing a process of change on a global scale. We have already examined the health risks inherent in the ecosystems of developing countries. As we have seen, some of these risks have their origins in the changes brought about by new technologies imported from the industrial world. But the biosphere is also changing at a dramatic pace. Most of these changes flow from worldwide economic activity, and for this reason they have the power to affect all parts of the planet and its inhabitants. Costanza et al.[82] point out just how much the world has changed; in 12,000 years we have moved from a relatively uninhabited world to one full of people and their artifacts. During most of human history, people have had the power to alter their immediate environments. Thanks to industrialization, they are now able not only to affect their immediate environments but also to have an impact on entire regions, and even on the biosphere itself, including such key variables as the climate and temperatures.

There are several studies dealing with the various processes implied by these changes at the global level, and what they may mean for our health. The reader is invited to consult these studies, the scope of which goes far beyond that of this report.[43,58,81,83-85] We limit ourselves here to mentioning three broad themes illustrating the need for an ecosystem approach to human health.

Box 1

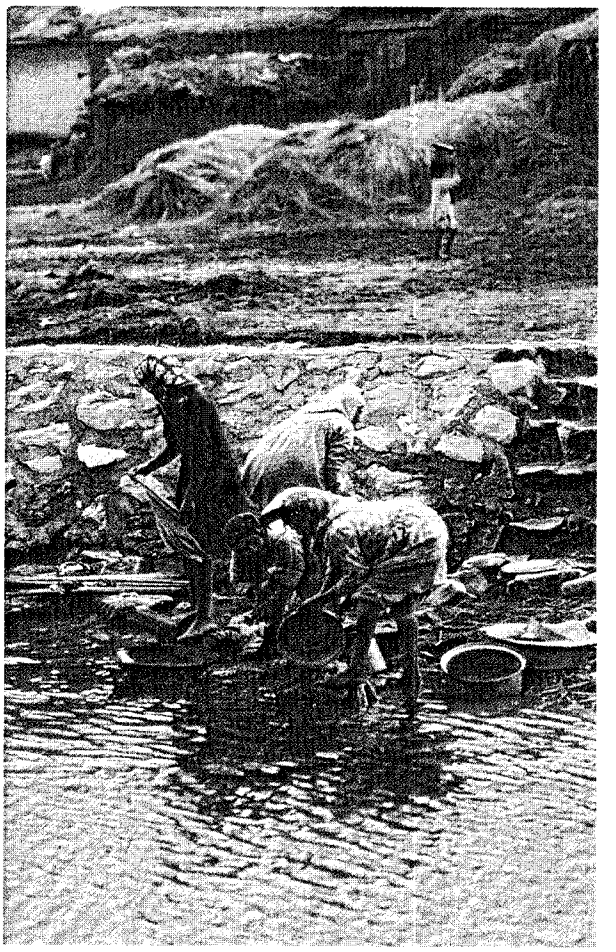
The Aswan High Dam and Bilharziosis

Following construction of the Aswan dam, water backing up behind it created Lake Nasser. Environmental conditions within the lake promoted the astronomic growth of the aquatic snail, *Biomphalaria sp*,[121,122] an intermediate host of the parasitic fluke *Schistosoma mansoni* (a flatworm of the trematode family). This fluke, which causes bilharziosis in human beings, was originally responsible for a modest, endemic level of this parasitic liver disease in Egypt. The infection is via the skin through contact with the parasite at the larval stage, the miracidium, and occurs wherever the snails live, particularly in irrigation canals that draw their water from the Nile, downstream from Aswan to the Delta.

The Aswan dam has modified the characteristics of the ecosystem considerably. One of the consequences for public health is that the prevalence of bilharziosis reached 73% in the area in 1979, while in 1935 it had been only 3.2%.[123] This shows just how readily the vector multiplied thanks to the population explosion of the *Biomphalaria sp* snail following the building of the dam. Van der Schalie[124] reports that the incidence of bilharziosis, which had been 5% before the dam was built, rose to 35% soon thereafter.

While this story may seem straightforward, it is more complicated than it appears. In fact, at the time the dam was being built, Egypt was also an endemic zone for another form of bilharziosis, this one caused by another fluke, *Schistosoma haematobium*, which is a parasite of the urinary tract. The prevalence of infection from *S. haematobium* before construction of the dam was 74%, but by 1979 it had dropped to 2.2%. We may conclude that the building of the Aswan dam and the ecologic changes that so favored the *Biomphalaria* snail (the intermediate host of hepatic bilharziosis) were disastrous for the *Bulinus* snail, the intermediate host for transmission of urinary-tract bilharziosis.

Bilharziosis of the liver (*S. mansoni*) is now well on the way to replacing the urinary tract form (*S. haematobium*) in Egypt. The health impact of the substantial decline in urinary-tract bilharziosis, which had been common before the dam was built, may be regarded as a beneficial effect of changes to the ecosystem. Yet from a broader viewpoint, the picture is less clear, because the morbidity associated with the new, liver-attacking form of bilharziosis, now prevalent among the population, is much more severe.



Women washing clothes in a canal. The damming of the Nile in Egypt has brought about significant changes in the ecology of the region, and increased the risk of schistosomiasis in Egypt wherever contact with surface water is frequent. (Photograph: Neil McKee, IDRC)

Global warming, as a result of emissions of greenhouse gases such as carbon dioxide, would now seem to be an undeniable reality. While experts do not always agree on the exact causes of global warming, we can point to a number of events that could well be related to such a phenomenon. For example, for several years now malaria has been invading regions at higher altitudes,[86] where the cooler climate used to discourage the establishment of the mosquito vector. It has not been demonstrated that there is necessarily a direct cause-and-effect

relationship between the warming of the earth's atmosphere and the progress of malaria into areas previously free of the disease. As we have seen, ecosystems are characterized by their complexity, and straightforward relationships are rarely clear. Nevertheless, even if global warming is not the only cause of spreading malaria, it is likely that it is one of the significant factors. Along the same line of thinking, and with the same caveats, we may well suppose that the warming of the world's temperate regions could also herald the appearance of tropical diseases such as malaria, yellow fever, and dengue in industrialized countries. Global warming could have more pernicious effects, as well: changing the nature of the vegetation cover, and sparking more frequent and more severe natural disasters such as floods and tornadoes. At the same time, there may be less rainfall in some parts of the world, with disastrous effects on agricultural output and on the state of nutrition in those areas.[87]

Another global change that has been demonstrated conclusively is the destruction and depletion of the stratospheric ozone layer, due primarily to emissions of chlorofluorocarbons and their atmospheric reactivity.[88] This decline in the ozone layer is causing a rise in ultraviolet radiation reaching the surface of the earth.[89] The effects of solar radiation on animals and human beings are well known: skin cancer, cataracts, sunstroke, and reduced efficiency of the immune system. Other, less well-documented, effects include a decline in the productive potential of crops and of marine phytoplankton, as a result of altered photosynthesis. These could have dramatic consequences for world food production and the structure of aquatic food chains.[87] McKenzie et al.[90] recently reported a substantial increase of ultraviolet radiation in New Zealand, and more specifically of the UV-B wavelengths that are responsible for sunstroke, DNA-molecule changes, and damage to vegetation.

Soil degradation due to the overgrazing of pastures and the use of farmland for intensive cultivation and the destruction of forests for farming purposes are phenomena that can be observed especially in the tropical zones of the world. They lead to soil erosion and infertility. The resulting decline in agricultural output and the drying up of water sources are direct causes of rural migration towards urban centers, and the ills associated with such movements. Deforestation can reduce the capacity of the biosphere to recapture carbon dioxide and thus contributes to the greenhouse effect and to global warming. The loss of biodiversity caused by deforestation and the overexploitation of land further weakens the equilibrium and durability of ecosystems.

One of the most obvious global changes is the demographic explosion. In developing countries, overpopulation is responsible for exacerbating the incidence of infectious diseases, especially in the slums and shantytowns. More than most other global changes, it is the demographic explosion that has the potential to overload the recovery capacity of ecosystems.

The population explosion has direct implications for human living patterns. For example, it leads to greater concentrations of people, generally organized in the form of urban centers. While cities are artificial phenomena compared with natural ecosystems, they are nonetheless entities that have a significant impact on ecosystem health. We believe that the "artificiality" of cities is often overemphasized. Agro-ecosystems are also artificial phenomena when compared with virgin ecosystems; they require many inputs to maintain their homeostasis and impressive human efforts must be mobilized to manage them.

Urban agglomerations have a significant impact on ecosystem health that goes well beyond the geographic spaces occupied by the cities themselves. In fact, meeting the needs of city dwellers requires ever more intense exploitation of agro–ecosystems to feed and clothe people, mining operations to supply metals and other minerals, and so forth. In most cases, the ecosystems called upon to make such contributions are not necessarily located in the immediate surroundings of the city, but may be fact be just about anywhere in the world.[91] It is well known that industrialized countries "harvest" much more from the ecosystems of developing countries than the latter receive from the ecosystems of industrialized countries. Yet it is not only the "output" of ecosystems that is being taken. Human beings produce vast quantities of wastes that must be assimilated by the biosphere. Because of their heavy concentrations of people, cities produce a large proportion of such wastes. Carbon dioxide is one of the wastes most frequently used as an indicator of this assimilation demand, and forest ecosystems are usually the ones enlisted for this purpose.[92]

Over the past decade, experts have developed the concept of the ecologic footprint, particularly as it applies to cities.[92] This approach involves a kind of accounting that allows us to measure the ecosystem services needed to maintain and support human establishments.[93] It is thus a measure of the inherent carrying capacity of the earth with respect to the communities of organisms living upon it. An ecologic-footprint evaluation allows us to measure both the productive lands necessary to produce the resources consumed by its inhabitants and the urban processes and ecosystem services necessary to assimilate their wastes. For example, the ecologic footprint of Canadians has been calculated at 4.3 hectares of productive land. Of these 4.3 hectares, 2.3 hectares are needed to assimilate the carbon dioxide generated by their activities.[92] If we apply these data to an urban population, we can assign the ecologic footprint of their city. In other words, we can evaluate the amount of productive land needed to meet the consumption needs of the city's inhabitants and to assimilate their wastes.

This tool is not as simple as it at first appears. In fact, the flow of energy is not a one-way street. We need only think of the urban output of farm machinery, chemical inputs, mining equipment, pharmaceutical products, and all the other articles for managing and exploiting non-

urban ecosystems and promoting the well-being of the people living in them. Perhaps the ecologic footprint notion should be used with somewhat greater rigor than it currently is in order to analyze the real deficit between the urban needs that are assumed by non-urban, often remote ecosystems and what the cities return to those ecosystems. That said, it would seem that this tool, with the desired modifications, is still a very useful one for illustrating the impact of urban centers on ecosystem health. It holds added advantages of taking into account issues of consumption, equity, and social capital.

IMPROVING HUMAN HEALTH THROUGH BETTER MANAGEMENT OF ECOSYSTEM RESOURCES

As we have seen, human intervention can damage the health of ecosystems and undermine their durability, and at the same time harm the health of the human beings who live in them. It would appear obvious, then, that wise management of the ecosystem should minimize the negative impacts human intervention can have on the health of the ecosystem and on the health of the people who are part of it. Yet the ecosystem approach to human health goes further than this. In fact, here we propose not only to preserve the state of health of a region's inhabitants by better management of the ecosystem, but actually to improve the local state of health through certain judicious interventions. Moreover, it is quite feasible for such intervention to improve the state of health at less cost than certain initiatives in the area of primary health or medical care.

Esrey and his collaborators[94] conducted a meta-analysis of research projects in Asia, Africa, and America that examined the impacts of improving public hygiene conditions and the availability of safe drinking water in relation to diarrhea and to the growth rates of children. The analysis shows clearly that there is a significant correlation between the level of public hygiene and the incidence of diarrhea. The effect is even more significant if it is accompanied by access to safe drinking water. These interventions were also associated with stronger growth rates in children.

According to the World Bank,[95] better management of the ecosystem could significantly reduce the burdens now represented by various diseases, particularly in developing countries. In its report "Investing in Health," the Bank argued that better management of the home environment could reduce morbidity from diarrhea-related diseases by 40%, through the use of already-established interventions such as supplying safe drinking water and environmental hygiene. A similar reduction in infections by intestinal parasites could be achieved through the same interventions in the ecosystem. Diseases such as trachoma, schistosomiasis, and Chagas' disease can be reduced by 30% by improving environmental hygiene, trash removal, and the safety of drinking water, and by eliminating the breeding sites of vectors in the vicinity of dwellings. It was also predicted that respiratory illnesses could be cut by 15% by improving the quality of air inside homes and by taking action to reduce overcrowding.

Two recent examples illustrate these notions. Konradsen[96] recently surveyed the costs and effectiveness of various types of interventions in the anti-malaria campaign in Sri Lanka. The authors divided these interventions according to whether they were preventive or curative. The least costly option in terms of prevention is to forestall the development of the *Anopheles* larva, the adult of which is the vector for malaria. Larvae are destroyed through the flooding of breeding sites during the mosquito breeding season, by periodically opening the sluice gates of dams upstream along the watercourse involved. This approach to "ecosystem management," targeted specifically at improving human health, has been shown to be three and a half times more economical than using personal mosquito netting to protect sleepers against insect bites, and nearly ten times less expensive than treating homes with a persistent insecticide. This approach also has the advantage that it does not depend on inputs such as pesticides that could have negative effects on other aquatic and terrestrial organisms dependent on the watercourse being treated. In fact, this "pure" method of ecosystem management was shown to be twice as economical as controlling larvae by spraying watercourses with a larvacide such as Temephos.[96]

That said, sound ecosystem management does not necessarily mean the "natural" manipulation of the environment, such as regulating the flow of a watercourse. It may sometimes be found that the use of inputs, when applied judiciously, is preferable and more effective as an ecosystem-management tool for improving public health. Rojas de Arias et al.[97] examined several environmental interventions to control Chagas' disease in Paraguay. This disease, endemic to the Americas, is caused by a blood parasite, *Trypanosoma cruzi*, the vector of which is the triatoma (an insect of the Reduviidae family). The illness is transmitted to human beings by nocturnal bites from the triatoma, which hides during the day in the cracks of walls and the thatch of roofs. One intervention performed by the researchers was to improve and repair dwellings. By eliminating cracks through which triatomas invades houses, the risk of contracting the disease should be reduced. In this way, one element of the ecosystem was managed by minimizing contact between humans and the disease vector. This intervention was shown to be very effective: improving dwellings alone reduced infestation by triatomas by 96.4%, and the rate of reinfestation during the following 18 months was less than 10%.

These results are comparable to those obtained from treating houses with a pyrethroid pesticide. However, the cost of repairs for an individual home was placed at US$700, compared with that of applying this persistent pesticide, which was US$29. A combination of the two

interventions in a third locality reduced the infestation of triatomas by 100%, with a reinfestation rate also below 10%. It is noteworthy that, in the last two cases, the presence of the insecticide was enough to kill the triatomas that attempted to re-colonize treated dwellings, and this showed up in a seroconversion rate (indicator of infections) of 0, compared with a rate of 1.3% in the case where homes were repaired without also using the insecticide.

At first glance, it would seem clear that given the costs of the two interventions, the most cost-effective approach is the application of a persistent pesticide. It is likely that the public health authorities would opt for this cheaper solution in order to protect the greatest number of individuals at risk as economically as possible. In most developing countries, there isn't the budgetary leeway to opt for such expensive solutions as rebuilding homes. In fact, if we look at economies of scale, the health authorities in industrial countries would have been no more likely to select the more costly option. It is unfortunate that the gap between the costs of these two types of intervention is so great (a factor of 24), because it is now very unlikely that "clean" interventions not requiring pesticides will be used. Yet if an ecosystem approach to human health had been taken, the authorities would also have paid attention to other factors, such as how upgrading the dwellings of rural people would have improved their living standards and encouraged the local management of interventions. For example, it might have been possible to investigate lower-cost ways of refurbishing dwellings, to bring such work within the reach of the residents concerned.

Recently, Wood et al.[98] reported the use of rags soaked with beta-cypermethrine in dwellings in Argentina to control Chagas' disease. Field results show such an approach to be highly effective in eradicating triatomas from houses over the course of a year, and one that is readily accepted by the residents. This kind of intervention may turn out to be an affordable means of controlling Chagas' disease over the medium term.

RESEARCH: AN ESSENTIAL TOOL FOR THE ECOSYSTEM APPROACH TO HUMAN HEALTH

As we have seen in several cases, it is difficult to dissociate the state of health of the ecosystem from that of human beings. Research can help us characterize the links between environmental degradation and impacts on human health. However, if we are going to propose interventions that will not only halt the degradation of ecosystems but also give them new vitality, we will need to look beyond the simple fact that environmental factors are associated with health effects.

An action–research strategy using an iterative process such as the one proposed by the Canadian Council of Ministers of the Environment[42] or by Forget[99] is perhaps most appropriate in an ecosystem approach to human health. With a view to improving health, it involves a continuous process of research that first attempts to identify and evaluate the importances of the various determinants of the health of an ecosystem and of the human

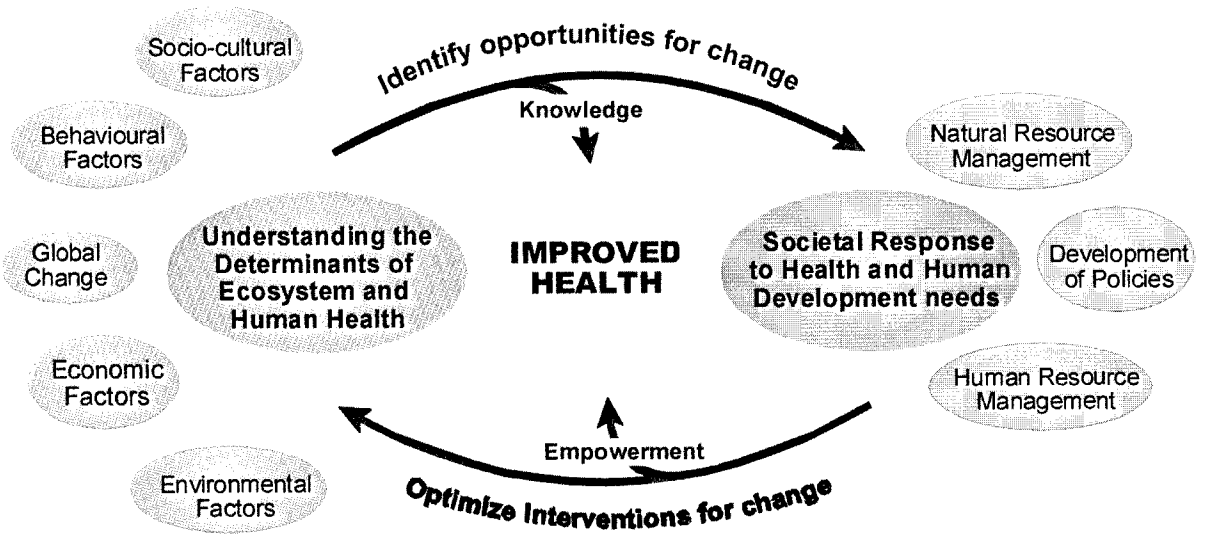


Figure 4—An iterative research strategy for improving human health. The research into health improvement proposed under the ecosystem approach to human health considers two principal aspects: a better understanding of the determinants of health (whether these are environmental, social, economic, etc.) and a better appreciation of the social responses to these determinants (development of sound policies, human natural resource management). In fact, in international development terms, this line of research is intended both to identify opportunities for change and to develop and test interventions likely to optimize the changes. Community participation in the research project creates an empowering body of community knowledge whereby the community can take charge of the process of change.

beings who live in it. This new knowledge can then be used to develop an appropriate social response and to measure the effectiveness of interventions (Figure 4). The most important feature of this strategy is that it is a continuous process—one that allows interventions to be refined and adapted as necessary to changing conditions in the ecosystem or to shifting social values.

In action–research, it is essential to involve the stakeholders in identifying the causes, documenting the effects, and developing interventions that will have a positive influence on their health by improving the quality of the ecosystem. To be successful, the strategy must develop and implement interventions that are culturally acceptable and economically viable for the communities concerned. This acceptance by the community is more likely to make the strategy effective.

The ecosystem approach also calls for a strategy that differs from conventional research methods emphasizing biology or anthropology, where research is conducted by a single researcher, sometimes with the help of assistants, working at a single site.[47] As we have stated, the ecosystem concept demands a "systemic" approach to understanding problems and their solutions. The research must be conducted through a process of true collaboration between researchers from different, complementary fields. The body of knowledge generated during the course of such a project will go well beyond a simple tally of the data collected. It also makes research and the adoption of solutions one integrated process.

We must always bear in mind that society is not a homogeneous body. The most evident dichotomy, but one that has been largely ignored by researchers, is that of gender. This distinction is very important if one wishes to apply an ecosystem approach to human health. In developing countries, for example, the distribution of roles and responsibilities is generally differentiated according to an individual's sex. It is highly probable, therefore, that changes to ecosystem properties will result from activities normally associated with one sex rather than the other. This is not to say that both sexes may not take different but complementary actions for both ecosystem and human health improvement.

We must also recognize that some marginalized groups may have greater impacts on the ecosystem then does the predominant society or group. It is important to understand that marginalized people are often sidelined by more economically powerful groups. Marginalized people often experience the loss of resources and degraded ecosystems because of externalities and oppression generated by the more powerful. Thus any subsequent ecosystem degradation is often the result of marginalized people's need to survive on a reduced resource base. A research project that does not take account of these factors is almost certain to fail.

The ecosystem approach to human health is knowledge-intensive. The real issue is generating *and* sharing existing knowledge to increase stakeholders' understanding of all components of the ecosystem so that they can make intelligent and effective choices about future actions and interventions. Research is the tool for increasing understanding and not the end in itself.

THE NEED FOR A TRANSDISCIPLINARY APPROACH

The ecosystem approach to human health requires a global view enriched by contributions from many disciplines, working in an integrated manner. It is easy to grasp the concept of multidisciplinary research as the opposite of an activity that involves only one single scientific discipline (unidisciplinary). However, the concepts of interdisciplinary research and of transdisciplinary research, on which the ecosystem approach to human health is based, are rather less intuitive. Let us examine some definitions proposed by Havel.[100]

Unidisciplinary research is generally much more appropriate to basic experimental or theoretical research. In this kind of activity, it is normally possible for a single individual with appropriate scientific training in a given specialty to achieve significant success. Yet it is generally less well suited to environmental and development research, where several components may be present, and where a great number of variables need to be taken into account. This is difficult to resolve using the scientific tools of any single discipline and by applying a strictly reductionist method.

Multidisciplinary research requires collaboration among many scientific disciplines. In theory, however, such research can achieve its objectives in the absence of concerted interaction among the different disciplines concerned. It might be enough, for example, to have specialists in each field who are aware of the presence of other researchers, their activities, and their results, and who can use these as inputs in their own research.

Interdisciplinary research focuses instead on a subject matter that stands at the frontier between two disciplines or at the point where two disciplines intersect. It is generally accepted that interdisciplinary research requires the researcher to have training in both fields of interest, which are generally related. In fact, interdisciplinary research often leads to the creation of new disciplines covering both of the old ones, although they do not necessarily lose their intrinsic value.

Transdisciplinary research is based on collaboration among several disciplines, not only in terms of developing research protocols but also in terms of conducting field work and interpreting the integrated results. This approach often sparks new theories, new ideas, and original concepts, thanks to the synergy created among the different disciplines involved in the project. Research always depends, of course, on the scientific expertise of the different specialists on the team, but it is the overall management of activities and the compre-

hensive interpretation of results that will assure the success of this approach. Another potent example of transdisciplinary research is the integration of different knowledge systems.

In Box 2, the example of mercury pollution in the Amazon ecosystem is used to illustrate how, over time and in the absence of a transdisciplinary framework, researchers came to believe that small-scale gold mining was the only cause of this contamination. We now know that the reality is quite different and that there are complex mechanisms in play, associated with the natural peculiarities of the region and with certain agricultural practices.[101] This example also shows how a team composed of specialists from various fields (fisheries, agriculture, forestry, health care, and social sciences) shed new light on the neurotoxic effects of human exposure to a pollutant that originates from different sources. Finally, interventions to reduce the impact of mercury exposure, now under way or planned, emphasize community participation.

PARTICIPATORY RESEARCH AND COMMUNITY PARTICIPATION

The ecosystem approach to human health is an iterative one that calls for participation by local communities in the quest for knowledge and the development of solutions. Participatory research implies that local communities take an active part in the research process carried out in their midst. This participation is based on the premise that community involvement is essential to the success of a research project if it is to take due regard of local concerns, needs, and knowledge. Researchers must integrate these elements in a systematic way into their research proposals, so that participants are no longer mere "guinea pigs" but actors and engines of change. The ultimate goal of the research process is ensuring that actions and interventions will improve the overall living conditions of the community. Given the intimate links between individuals' well-being and their health, there should be a great potential for participatory research as a means of promoting human health by helping people to understand and reduce the risks arising from the ecosystem. Participatory research must go beyond simply verifying hypotheses. It must include action; once the results are generated, the community will be expected to make the appropriate decisions. In fact, communities often take action before results are available, blurring the distinction between research and the adoption of results.

Several methodologic approaches for integrating community participation into the research process have been discussed recently. Labonté[102] presents an interesting description of a partnership effort between external experts and a local community for promoting community development. Selener[103] provides an exhaustive review of action–research undertakings of the participatory kind aimed at promoting social change in the field of agriculture. Narayan[104] gives a simple and understandable description of participatory research by highlighting the characteristics, the advantages, and the drawbacks of this approach, as well as the roles and characteristics of the researchers who conduct work of this type.

Rather than go into the specifics of these methods, Box 3 describes an example of a research project in the Ivory Coast, where a team of researchers performed an initial diagnosis of the state of the environment in a region subject to numerous environmental stresses. Based on their results and their discussions with local community members, the research team decided to take greater account of local knowledge and concerns in pursuit of their work. The process of consulting communities and including them in the research led the researchers and the communities to develop common objectives for the work, whereas originally they had had diverging concerns. This example illustrates how research strategies involving community participation can make a significant contribution to development.

In this respect, donor agencies are increasingly emphasizing the importance of encouraging beneficiaries to participate in aid programs.[105] The WHO now recognizes the importance of taking into account the views and needs of the target population just as the scientific opinions of health experts would be taken into account when assigning research priorities.[106]

Implementing participatory research practices into human health studies is not without its difficulties, however. Akukwe[107] lists several constraints that make it difficult to apply this approach in developing countries. First, he notes that local communities are not always able to articulate the nature of their health problems in a way that is readily understood by public health experts, because of the influences of their local customs and traditional practices. This difficulty can be overcome by involving a local health worker such as a midwife or health-post personnel. Moreover, it is often the case that communities in developing countries do not have the material means to address their health problems, and they are often highly dependent on health services from outside sources. This became clear in several projects where the state of health had already deteriorated to the point where a curative approach was required. Akukwe goes on to say that international agencies responsible for financing such health services often have goals and objectives that are different from those of the communities they are serving. It is important, then, to ensure that the donors clearly explain their goals and objectives to the communities and researchers with whom they are working. The people involved will then be in a better position to decide whether they should pursue the research or give it up.

It is clear that a participatory research strategy calls for close collaboration between the local community and the research team. It must incorporate both the knowl-

Box 2

Origins and Effects of Mercury on Riparian Populations of the Brazilian Amazon

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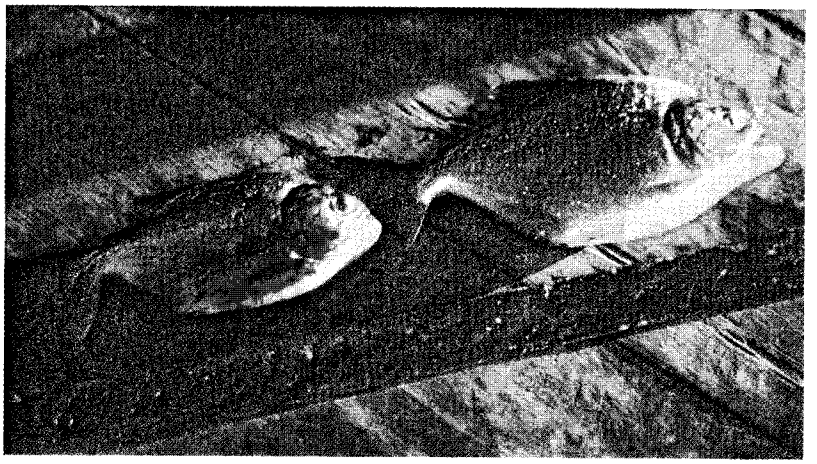

The piscivorous piranha is one of the fish that contained the highest concentration of methylmercury originating from the biotransformation in water of the mercury leached from the soils after slash-and-burn agricultural practices. In the Amazon, fish are a very important component of the diet. Through their fish consumption, humans are exposed to methylmercury at levels that are creating visual and motor impairments. (Photograph: Marc Roulet, UQAM)

Research into the issue of mercury and its effects on human and environmental health in the Amazon basin was sparked, after considerable delay, by the gold rush of the 1970s. In the 1960s, development plans for the Brazilian Amazon conceived by the military governments called for opening up a vast network of roads along which traditional farming colonies could be established. Such projects were intended to provide both immediate employment opportunities (construction work) and permanent settlement alternatives to absorb the surplus population in the country's Northeast. People were abandoning the Northeast for the industrial cities of the South under the twin impact of spreading *latifundios* and drought-induced famine. For the most part, the roads were built at great cost only to degenerate into tracks or mere traces of roads through lack of maintenance. Colonization projects eventually collapsed, undermined by malaria and doomed to failure by unsustainable farming practices and by the huge distance from consumer markets.

The sharp jump in the price of gold in the late 1970s was thus a windfall for a vast and depressed contingent of humanity, virtually abandoned to its fate. The regions where gold mining was already practiced on a small scale, in the states of Para and Maranhao, underwent a boom, and new mining fronts (*garimpos*) sprang up throughout the Amazon basin.

The technique for extracting gold contained in soils and sediments, namely amalgamation with mercury, is attractive because it is very simple, is effective, and requires little investment. It can be practiced on dry land or on river barges and can be performed manually by a single individual or by a team of several people equipped with pumps and mechanical grinders.

During the 1980s, between 2 and 4 million people lived directly or indirectly on the proceeds from frontier gold mining in Brazil. In a society of great inequality, gold mining offered better incomes than agriculture and held the possibility of upward social mobility. The public authorities were unhappy with the success of this parallel society. Incapable of controlling the mushrooming gold mining frontiers, the government banned the use of mercury for gold mining, but this had no apparent practical impact. Here and there, the Army and the Federal Police pursued the itinerant gold miners or *garimpeiros. Garimpo* was made a crime and was viewed as a problem of public order amounting almost to insurgence.

continued on next page

Box 2 (continued)

The effects of *garimpo* activity on the environment and on health were much better reported in the media than was the socioeconomic impact, positive or negative. Deforestation, the buildup of sludge in rivers, and mercury emissions were seen as an environmental catastrophe that threatened to become a "tropical Minamata." Ironically, the first impact on public health was due not to toxic substances, but rather to a resurgence of malaria, carried back from the gold mining regions by the *garimpeiros* who returned to their home villages during the rainy season.

The first studies of *garimpo* gold mining targeted the extraction techniques used, measuring the flow and emission sources of mercury and the effects on occupational health. High concentrations of mercury were found downstream in carnivorous fish and in the hair of the riparian people who ate them, and this was attributed to gold mining activity. Mercury is emitted from these operations either in the form of vapor or in the liquid state. Nothing was yet known about the bioavailability of metallic mercury in sediments, or the conditions and factors that convert inorganic mercury to methyl mercury (MeHg) , which is much more toxic and is the form predominantly found in fish. This is also the mercury compound responsible for the Minamata symptoms found in Japan. The biologic and geochemical diversity of the catchment areas makes comparisons difficult, and this is compounded by the great mobility of the *garimpo* industry.

Several research projects were launched, some supported by other countries such as Japan, Germany, Sweden, and the United States. There was virtually no coordination of these efforts. Some villages were visited several times by different teams, each of which would take samples of blood and hair. These teams attempted to address the problem from its biologic, geochemical or medical aspects. A few individual researchers focussed on socioeconomic aspects. None of these projects embraced more than two of the above-mentioned aspects. Generally speaking, these efforts lacked continuity, little time was devoted to field work, and there was scant communication with the communities concerned. Thus, while a great deal of evidence was compiled with respect to mercury and, later, methyl mercury in fish, sediments, soils, and hair, there was little progress in understanding the mercury cycle and its effects on local people's health. The link between the presence of mercury in the environment and activity of the *garimpeiros* was finally thrown into question when high concentrations of mercury were found in the basin of the Rio Negro, where gold mining activity was almost nonexistent, and when the monitoring of mercury levels in fish of the Rio Tapajós and the Rio Madeira showed virtually no change even several years after mining activity had sharply dropped. By the end of the 1980s, gold mining activity in Brazil had shrunk by a factor of 3, or even 10, from its earlier peak.

In 1994, a team from the University of Québec at Montreal (UQAM) and two Brazilian universities (Federal University of Para and Federal University of Rio de Janeiro) put together a strong multidisciplinary group to conduct a study of mercury in the Tapajós basin that integrated geochemical, ecologic, and public health aspects. A laboratory was set up at Santarém to measure mercury residues by means of atomic fluorescence, students were trained, and sampling campaigns were conducted for a period of two years covering a stretch of some 300 kilometers along the middle and lower reaches of the river.

To their surprise, the researchers found that mercury residues in water (dissolved and particulate) are low and virtually constant throughout the sector, which covers some 300 kilometers downstream from the gold mining regions. They also found that soils throughout the region had a high mercury content, and that this was associated with the mineral fraction of the soil, in particular oxides of iron and aluminum. Moreover, this association was also established in suspended particles along the river and in the sediment of lakes within its flood plain. A recent increase in mercury concentrations was confirmed by analyzing sediment core samples, but this was apparently due to leaching and erosion of the fine soil fraction, which is richer in natural mercury deposited by atmospheric transport over the course of many centuries. The leaching of mercury from the soil as a result of lateral transport was documented in core samples taken from various slopes, either wooded or cleared. Soil erosion is sharply accelerated by the slash-and-burn approach to farming that is prevalent in the region, and locally by gold mining sites. The progressive degradation of soils in the catchment basin of the Tapajós has significantly changed the appearance of its waters, which were once famed for their clarity.

The fine particles released from the soils are carried in suspension by the river and are deposited in the flood plain, where they help to restore fertility. On the other hand, it is in the same environments that mercury is most apt to become biomethylated, in particular on the roots of plants that form the "floating prairies" and at the surface of soils in the flooded forest. This was revealed by a combination of measurements of natural methyl mercury and methylation tests using Hg-203 as a radioactive tracer.

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Box 2 (continued)

The lake shores, covered with floating prairies, and the flooded forest are highly productive environments that are typical of, and virtually exclusive to, the tropics. They are essential breeding and feeding sites in the life cycle of fish, which are consumed by the local populace or exported to other markets, and which spend several months in these waters during the flood season.

Fish consumption is heavy in all villages along the Tapajós, and it represents the principal manner of ingesting mercury in the form of MeHg. Neurophysiologic tests adapted to local conditions showed perceptible effects of mercury on vision and motor function, at levels lower than those that produce clinical symptoms (50 μg/g of mercury in the hair) among riparian people. A detailed socioeconomic study that included monitoring mercury-exposure patterns throughout the year revealed a relationship between this exposure and the consumption of certain species of predator fish. The correlation between the sizes of the fish and their mercury contents, which is clear in temperate or cold climates, is rarely found in the Amazon. A study of this relationship has therefore been undertaken in more than 30 species of fish, so that local people can manage their fish consumption in terms of the species and sizes consumed. This first project is intended to reduce the consumption of predatory species and to develop eating habits based on herbivorous species that contain only low levels of mercury. Over the medium term, the project hopes to reduce mercury exposure without having to ban consumption of what is the most important source of protein for local people. It is interesting that the women in the villages asked the researchers to produce and distribute posters illustrating the fishes commonly consumed, with a color code for distinguishing those species that have high (red), medium (yellow), or low (green) levels of mercury.

To get to the source of the problem, scientists are working in close cooperation with local people to assess the impact of new farming practices that might stabilize riverbanks and thus limit the lateral transport of mercury from the soil into the aquatic environment. These measures, together with improved management of gold mining activities, are for the moment the only hope for gradually reducing the overall level of contamination over time.

The main elements of success with this project were the use of better analytic and sampling skills and a profound knowledge of the social and natural setting, acquired after a lengthy stay in the region and through intensive contact with local communities. The fact that scientists from each country learned the language of the other was also proof of mutual dedication, and assured a deeper degree of reciprocal understanding and communication.

Finally, there is no doubt that this project, which went beyond the inter- and multidisciplinary approach, has done much more than simply measure the impact of mercury on the environment and on health, and has produced new knowledge that can be used for comprehensive solutions, without which the problem of mercury in the Amazon will never be resolved.

edge and intuitions of the scientific experts and the traditional know-how and local awareness of the community. This will help to ensure that research results are appropriated by the community and that they will foster solutions that meet local needs and have a lasting impact. We must not forget, however, that communities are not homogeneous. They are demonstrably not idyllic entities of human harmony. Practitioners of an ecosystem approach to human health must take into account all such internal tensions and inequities in designing their participatory strategy.

DISAGGREGATED ANALYSIS OF SOCIAL VARIABLES, INCLUDING GENDER

The ecosystem approach must ensure that strategies for gathering and analyzing data allow social variables to be differentiated. Many societies include highly stratified social groups that are often isolated from one another; castes, ethnic groups, and social classes will all have impacts on resource access and management and on the state of health. The roles of men and women are also often differentiated, and the two sexes have different responsibilities and sometimes unequal says in decision making. It is essential to perform a disaggregated analysis of data relating to the different groups, particularly men and women, if we are to fully understand the impacts environmental factors can have on those groups. This enables researchers to identify groups that are more vulnerable than others to certain changes in the ecosystem, and to take these factors into consideration in preparing interventions.

The insistence on a gender-sensitive approach is not merely a question of equity but one of ensuring the scientific validity of the research. For example, when we examine data broken down by sex, age, and social class, we often find a complex web of social ties and negotiations explaining the relationships among these groups. The processes of negotiation are extremely important to an ecosystem approach because they allow us, among other things, to identify the efforts that each group must

Box 3

Ecosystems and Human Health in Africa: Experience and Perspectives from a Research Project in the Buyo Region of Southwestern Ivory Coast

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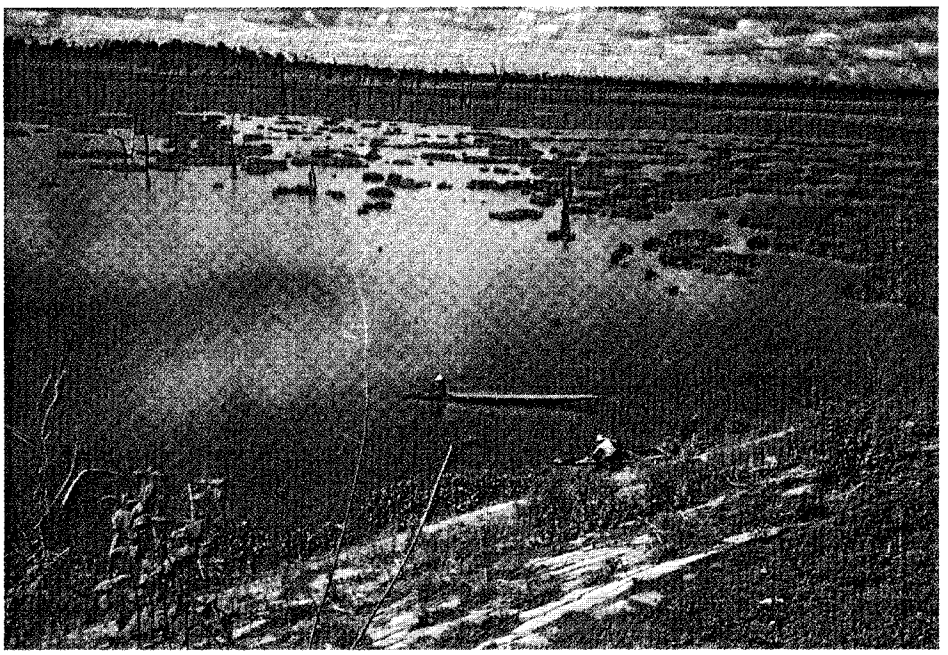

The lake created by the hydroelectric dam at Guessabo, Ivory Coast. The eutrophication of the lake from runoff and erosion has caused noticeable proliferation of aquatic plants. (Photograph: Pascal V. Houenou)

In 1960, the Buyo region of the Ivory Coast boasted a number of natural assets: thick, humid forest vegetation, substantial rainfall (between 1,600 and 2,800 mm), a dense hydrographic network that was part of the Sassandra River, and soils suitable for agriculture. The region covers an area of some 11,000 square kilometers and, since 1968, has been the target of an ambitious land-use planning program. In 1980, one of the country's largest hydroelectric dams was built in Buyo, producing 610 GWh of power. In the space of the single decade, from 1980 to 1990, the Buyo region became a top producer of coffee and cacao, and a fishing industry was developed almost from scratch. With the rapid development came a number of environmental and social problems linked to particular ecosystems.

Between 1996 and 1998, a research project called the "Integration of Agriculture into the Environment of Buyo (Southwestern Ivory Coast)" was undertaken to diagnose the physical state and health of the environment. This research involved specialists from several disciplines, including chemistry, ecotoxicology, geography, environmental history, pedology, sociology, statistics, ichthyology, and community health. They described the region's physical features and studied soil and water pollutants as well as the economic and social dynamics of the area.

This research produced five significant findings:

1. The Buyo region suffers from a lack of integrated land management at the village level, manifested by a mushrooming population, degradation of the natural resource base, ambiguity in the forms of access to land, conflicts over landholding, and a lack of social cohesion.

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Box 3 (continued)

2. The Buyo region has an export economy and a significant degree of poverty among inhabitants who have not embraced fishing as a livelihood activity.

3. The situation is aggravated by the inadequacy of community facilities and economic infrastructure. Communication routes, schools, and health centers are lacking or they are of poor quality.

4. In addition, the uncontrolled sale and use of prohibited agrochemical products, such as lindane and heptachlor, and the presence of heavy metals such as cadmium and mercury in the soil and water, as well as in fish and maternal milk, constitute potential health threats to the populace.

5. There has been a resurgence or persistence of water-borne diseases, primarily malaria. This is likely due to water pollution (lakes, wells), certain forms of social behavior, and the impounding of water behind the dam. *Eichhornia crassipes* or water hyacinth, an invasive aquatic plant, is now a problem, largely a result of eutrophication, a byproduct of water polluted with nitrates and phosphates.

On the basis of meetings, interviews, and questionnaires given to heads of households, community leaders, and health personnel, it became clear that community perceptions and concerns differ to some extent from the research findings listed above. The members of the community ranked their concerns as follows:

1. Lack of electrification. Despite the existence of the dam only a very small number of localities had been hooked to the grid.

2. Lack of proper roads. As noted above, this poses an obstacle to moving products and makes it difficult to reach the few available health centers.

3. Inadequacy of the supply of drinking water. People had to rely on traditional wells or draw their water directly from rivers or the lake. They used the latter sources, for two reasons: authorities had not drilled enough modern public wells, and pumps were often not maintained and were, therefore, frequently out of service. Safe drinking water was also in short supply in urban centers. In the towns of Buyo and Guiglo, only 116 and 980 households, respectively, were connected to the public water distribution system, representing one person serviced for every 214 inhabitants in Buyo and one person for every 48 inhabitants of Guiglo. Water quality analyses in several cases revealed the presence of pathogenic germs (fecal coliforms and *streptococcus* as well as *Escherichia coli, Pseudomonas cepacia, Providencia alcalifaciens*). These are ideal conditions for the transmission of water-borne diseases.

4. Deficiencies of sanitation facilities: only 24 of the 125 villages surveyed (19%) had latrines, numbering 84 in total. Showers were for the most part poorly maintained and the stagnant water left behind was an ideal breeding site for mosquitoes. Finally, given the shortage of sewers and septic tanks, the handling of human wastes was a problem in both urban and rural areas.

In terms of specific diagnoses, the principal problems in these areas, for the public as well as medical personnel, are malaria, diarrhea-related diseases, and malnutrition (proteino-caloric deficiencies). Health care coverage in general is weak and care is uncertain in many places.

These findings were presented to the public and to the local authorities during a feedback seminar at which people were able to express their urgent concerns and discuss areas for further work or exploration. These meetings also allowed the researchers to inform people of problems that, until then, had been ignored, for example, the presence of toxic agrochemical products in concentrations well above those permitted by public health standards. This first experience also served to highlight the limitations of the research that had been carried out. It had failed to take sufficient advantage of transdisciplinarity. Specialists had not disseminated their findings beyond their own areas of interest, making it difficult to generate a pool of knowledge sufficient for proposing comprehensive interventions. Community participation was also inadequate. It was limited to a few key players, and the gender aspects were not specifically integrated. All these components are essential in an action–research approach.

After considerable thought and reflection and with the support of the IDRC, the research team from UFR-SGE in June 1999 organized a workshop to develop an in-depth research protocol that focused squarely on a systemic approach to human health. This seminar brought together researchers, public authorities, nongovernmental organizations, and community representatives from Buyo (village chiefs, women, young people) to work together to define local priorities. They decided that what was needed was a research project to enhance the quality of human health and that of the ecosystem in Buyo, based on the following hypotheses:

1. The composition and structure of local ecosystems, including their human dimension, are not sufficiently understood to establish a link of cause-and-effect

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Box 3 (continued)

between the dysfunctional dynamics of the natural and man-made environments and the state of human health.

2. The contamination of ecosystems by chemical pollutants and the bioconcentrations of these pollutants in aquatic and terrestrial ecosystems could be having a toxic impact on human health.

3. The prevalence of poverty reflects the absence or inadequacy of strategies for exploiting agricultural and fishery resources based on sound ecosystem management.

4. The resurgence of water-borne diseases is linked to certain behavioral factors that cause ecosystem degradation.

5. The dissemination of integrated management strategies for drinking water would do much to improve human health.

In due course, this research will lead to alternative strategies for restoring polluted environments, for combating disease vectors, and for ensuring better health, not only in terms of the absence of disease, but also as a state of complete well-being.

Although it was part of the report submitted to the local authorities, the need for more suitable housing was not included in the strategy, on the grounds that it was not a research problem but rather one of public administration. It is interesting that during this workshop, people were able to express this need directly to the responsible local authorities. Moreover, they were able to discuss the expected results of the research with the researchers themselves. Thus, from the outset of the research process, it was understood that research alone would not solve all of the environmental and health-related problems. In the end, the priorities of the communities and those of the researchers converged on the need for a project that would be of use to all stakeholders. Not only will these results help expand our understanding, but the new knowledge produced can be used by the community to actively participate in interventions to improve the health of the ecosystem and those living in it.

While this second study has not yet begun, improvements in the design of the second phase of research show how, through an ecosystem approach to human health, we can better meet the expectations of communities for resolving environmental and health-related problems. Given its integrated and holistic nature, this approach goes beyond simply identifying problems: it integrates local knowledge into the pursuit of research and the resulting interventions.

Such a strategy presupposes a research team adept at social communication and mobilization techniques (something that was lacking from the first study) in order to facilitate exchanges within the team and with the local inhabitants. It is the latter who should design the research, based on their own ecologic, social, cultural, economic, and health data and behaviors. This will make it easier to validate the results and will broaden the impact of the research. The research team, with all the relevant skills, will involve itself only to the extent of mobilizing local people and providing the scientific information needed to resolve the problems identified.

This is not an easy undertaking, because the research team itself is likely to suffer from certain internal conflicts and also from a tendency to favor multidisciplinarity. In such a context, it is important that everyone's role be recognized and that the team members be able to reconcile private and common interests. Community diagnosis is an excellent research tool. It should be the first step in any planning exercise. When local people are involved in research, they will have a real desire to resolve the problems in question, and the researchers must continue to support this enthusiasm once their research work is completed. In the specific case of Buyo, the negative effects of pesticides, heavy metals, and nitrate residues on the ecosystems, along with ethnic tensions and socioeconomic, cultural, and health problems, are solid grounds for concern about the quality of the environment. Yet such risks are not always noticed by the local populace, most of whom are concerned with meeting their own most elementary needs.

The ecosystem approach not only should offer appropriate solutions for developing the Buyo region but also will endow the research team from the University of Abobo-Adjamé with a degree of expertise in a promising area of research that is still not well understood. The efforts undertaken at Buyo, in sharp contrast to conventional research, are meant to translate the old Kashmiri proverb—"we do not inherit the earth from our ancestors, we borrow it from our children"—into action. This, then, is the challenge: to foster and preserve an essential and beneficial balance between humans and nature.

make to gain access to resources and to participate in decision making. Kettel[108] notes that in all human communities, men and women tend to occupy, use, and manage their surroundings in ways typical of their own genders. Therefore, it is essential to understand how this differential utilization of environmental resources exposes men and women to risks in different ways.

Let us look at a few aspects of gender with respect to risk exposure. In most societies, there are divisions of labor by sex and by social group. The tasks of men and women are often quite different, and what is even more important, they are not valued using the same yardstick. Moreover, even if the work is similar—farm work for example—tasks will often be quantitatively or qualitatively differentiated by sex,[109-111] and hence the health risks to which a man and a woman are exposed will be different. Because of their inferior status within the community, women and marginal groups often do not enjoy equal access to resources. And even if they do have access, it is rare that women will be able to exercise any control over resources. In fact, the social position of women within a society has a direct influence on their capacity to negotiate access to resources, and even more influence on their ability to control those resources. This precarious access to resources can pose additional risks for women or marginal groups. Often, the control that women can exercise is circumscribed by the immediate imperative of ensuring the family's survival: gaining access to drinking water, nutrition, health care, firewood for cooking food, etc. This distribution of roles can be seen as an additional element of risk to women's health.

As described in Box 4, only an approach attentive to the specific elements of gender behaviors and to the ages of individuals allowed the research team to understand how the plague was being transmitted through communities in the Lushoto district of Tanzania. Without such attention, the researchers would not have completely understood the etiology of the disease, and it would have been difficult or impossible to design any kind of effective and permanent intervention. In fact, it is not enough to take into account the genders of individuals when the research protocol is designed or when data are analyzed. Interventions seeking to overcome health problems related to ecosystem management will not prosper if they fail to redress inequalities between men and women, or between marginalized groups and society at large.

As a general rule, gender risk is related in one way or another to an individual's work. Men and women are generally exposed to risks as a function of their roles in production or in reproduction. For example, searching for water may involve walking great distances, carrying heavy loads, and being exposed to the elements, preparing food exposes women to the toxic fumes of burning wood and to fatigue from repetitive tasks, pregnancy and childbirth have all the risks of giving birth, often with minimal care. These examples are daily occupations that women must perform in addition to their other, so-called productive roles such as field work, vending, handicrafts, and paid work. They pose additional health risks, even though they are often not identified as work. In any case, women's work is seldom valued in the same way as men's, which is usually rewarded in cash.

Why does this make a difference to the kind of research we are talking about? One widely used practice in epidemiology—adjusting data to control for the effect of independent variables—can easily bias the results by canceling out the impact of gender on health. Mergler[112] shows that, although standard in epidemiology, this practice should not be applied to gender in the same way as it is applied, quite justifiably, to age or smoking. It is for this reason that differential gender analysis cannot rely exclusively on raw statistics, but requires a qualitative analysis of the results. As shown in Box 4, this technique is also a very powerful one, and often leads to conclusions that are more valid than those that would flow from a simple analysis of statistics adjusted for gender. While the examples given here relate to situations in developing countries, the situation is not that different in industrialized countries.

A CONCEPTUAL RESEARCH FRAMEWORK FOR AN ECOSYSTEM APPROACH TO HUMAN HEALTH

The objective of the ecosystem approach to human health is to enhance the health of communities by instituting ecosystem-management methods that will foster the sustainability of the ecosystem itself and the health of the human beings who are part of it. The proposals for research projects that are submitted to us as a donor agency, as part of the Ecosystem Approaches to Human Health Program Initiative of the International Development Research Centre, generally focus on one of two principal frameworks for understanding the links between human health and environmental conditions.

The first framework reflects the desire of researchers to understand a situation of environmental degradation where a negative impact on health is suspected. These research projects typically have relatively clear and well-delineated definitions of the area to be studied (a dam, a farming region or practice, a mining region, a village, a city, etc.) and of the nature of the environmental problem (or the natural resource-management problem) associated with it (pesticides, heavy metals, soil degradation, water quality, housing). But they contain few elements for assessing human health. Projects of this type are normally undertaken by specialists in the pure and applied sciences who have some knowledge of health.

The second framework is typical of situations where there is a suspected association between observed cases of declining health, such as high incidences of malaria, and environmental degradation. This situation is more difficult to pin down within a clearly defined space. Researchers often start with their observation of a situa-

Box 4

Social and Environmental Determinants of Plague in Tanzania

The traditional role of women in food storage and handling in Tanzania, allied to the differences in sleeping arrangements for men, women, and children in the homes, may impart differential risk factors for contracting plague among these groups. (Photograph: Luc Mougeot, IDRC)

The district of Lushoto in Tanzania is an area where plague is endemic. Years of research had failed to discover the reasons why conventional methods for controlling this disease were unable to prevent its transmission among the affected populations. The Muhumbili University College of Health Sciences at Dar es-Salaam tackled this problem, with financial support from the International Development Research Centre (IDRC), under the direction of Prof. B. S. Kilonzo.

Using quick evaluation methods and a holistic approach, a multidisciplinary team consisting of experts in medicine, entomology, rodent biology, rural development, quantitative anthropology, and qualitative anthropology succeeded in identifying the principal components of this ecosystem as they relate to the plague and to risks of transmission.

First, the researchers discovered that people have a fairly accurate idea of the disease and of its association with rats and fleas. They know the distinction between the bubonic plague and pneumonic plague and the septicemic form of the disease, and they have confidence in Western medicine for treating it. But they also recognize a form that is caused by casting an evil curse, specifically by breaking earthen pots for revenge. Local lore sees no value in modern medicine for dealing with such cases, and families are more inclined to turn to traditional dealers. This behavior, based on traditional beliefs, explains in part why the human reservoir of infection has persisted.

How do cultural constraints and gender-related practices of individuals influence the risk of disease in these communities? During the first phase of this study, rural development experts found that, in contrast to agrarian communities in West Africa, where grain is stored in granaries separate from people's homes, the farmers in Lushoto build their grain lofts over their houses. Epidemiologists, using a method that discriminates personal data by gender, were able to confirm that women and children were at greater risk of contracting the disease. Anthropologists and social scientists then looked at prevailing domestic habits and at the specific behaviors of the women, children, and men. They discovered that it was generally the women and children who went up to the lofts to get corn for preparing meals. These lofts are a favorite hiding place

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Box 3 (continued)

for rats infested with fleas, which in turn are infected by the plague bacillus, *Yersinia pestis*. Women and children are therefore more susceptible to being bitten by the fleas. Their risk of catching the plague is thus greater, because of the distribution of domestic chores that are traditionally allocated according to an individual's gender or age.

A further discovery about gender-dependent roles and prerogatives is that in large families, the women and children sleep on the ground on mats, where they are at much greater risk of coming into contact with fleas. During the night, infested rodents explore the house while the family members are asleep. Local custom dictates that men and nursing women have first claim to a bed. Therefore, they are less likely to come into contact with fleas during their sleep, and hence become infected. These characteristics of the plague in the Lushoto area would apparently have gone unnoticed had it not been for a method that includes the differential analysis of specific cultural practices related to people's gender or age.

In cooperation with the residents of Lushoto, a second phase of this project is exploring how to make use of this new knowledge about the mode of transmission of the plague in this area of East Africa. Interventions will be designed in consultation with the local inhabitants and will take account of the social and cultural information and behavioral data identified during the first phase.

tion concerning the health of the local population rather than the biophysical makeup of that group's environment. In contrast to the previous approach, projects of this kind contain solid documentation for evaluating human health. But these projects pay little attention to the elements needed to improve the health of the ecosystem. They are usually undertaken by environmental health specialists with only limited knowledge of environmental management.

These two frameworks illustrate how difficult it is to cover the entire spectrum of the ecosystem approach to human health within a single project, in particular where there is no regular evaluation of socioeconomic questions. Based on the IDRC's experience over the last few years, the principal shortcoming of the approach is that it is difficult to conduct a research project covering such a broad spectrum. We also note that researchers are often reluctant to use this approach because they fear that it will complicate their projects and make it difficult for them to proceed. To deal with these difficulties, we have articulated one strategy for operations and another for consolidation, the goal of which is to ensure the long-term development of the ecosystem approach to human health.

Our experience shows that from the outset a project will frequently require a research team with a broader range of expertise than originally envisioned by the proponents. Discussions that bring together knowledge and expertise related to health, the environment, natural resource management, and the social sciences often reveal that the problem under study is much broader than originally thought. This recognition makes it possible to look beyond specific disciplinary boundaries in considering the resources required and the new knowledge that must be generated to better understand and resolve a complex problem. Broadening the scope of expertise is also neccssary for defining the spatial and temporal scale of the problem to be documented and resolved.

It is also important, from the outset of a research project, to consult and enlist key players associated with the problem, such as the local community, the government, and nongovernmental agencies, to name a few. This produces a dynamic exchange of knowledge and understanding concerning the "ins and outs" of the project. Holding a project development workshop at the study site can be an extremely effective way to integrate the concerns and know-how of the local community. Such a workshop helps to refine the research objectives while taking account of the concerns of both the scientists and the local stakeholders. Moreover, in bringing together scientists and community members, the broad lines of the research protocols can be established by drawing upon different areas of expertise while taking account of local realities, logistic constraints, and financial resources.

With this process, the researchers can decide, in a very pragmatic way, what is essential versus what can be dispensed with while still ensuring that the research activities meet their needs and those of the community. With joint development of the project, the researchers can achieve considerable savings from a more judicious selection of the samples to be collected, the analyses to be conducted, the evaluations to be made, the personnel to be hired, etc. It should also be noted that many projects include graduate students and thus draw upon high-quality, low-cost local expertise. This approach also helps to develop a permanent scientific foundation for meeting the country's future needs.

Furthermore, launching a research project with a preparatory workshop is one way of building mutual confidence between the researchers and the local populace. This confidence can be further reinforced if the researchers feed their research results back into the com-

munity, in an accessible form. This involves the researchers in a dynamic process where it is much more difficult to escape responsibility for efforts to improve local living conditions. It goes without saying that it will be easier to sustain these bonds of confidence if the community perceives that its concerns have been respected as interventions are implemented.

Our experience shows that researchers who have addressed the challenges inherent in a participatory approach have seen a clear bonus in their research results. In fact, we find that the results are extremely well received by the scientific community and by policymakers, because they offer a global shared perspective for resolving a problem. It is then much easier to mobilize key players and thereby ensure that solutions will be sustainable and meet local needs. Moreover, we find that the researchers themselves are inspired and motivated by the idea of developing scientific knowledge that will be of direct benefit to local communities.

We have found, then, that within a coordinated strategy, it is possible to develop and implement projects that take an ecosystem approach to human health. However, in order to place this approach on a solid footing and ensure coherence among research activities, we suggest three general objectives: developing the necessary tools, assessing relations between human health and the ecosystem, and, finally, developing management interventions.

Because this is such a new concept and because it is so difficult to integrate the three pillars of this approach—transdisciplinarity, community participation, and the integration of gender variables—within research activities, new methodologic tools have to be developed. These tools need to be derived from both theoretical and practical viewpoints. If this approach is to be successful, the processes involved in developing projects, conducting the field work, assessing the early signs of untoward effects on the health of humans and ecosystems, collecting and processing data, and developing and carrying out interventions all need to be better documented.

One illustration of progress in this field is the development of ecosystem health indicators that can be used for monitoring an environmental component for a community. For example, Forget and Sanchez-Bain[113] describe a battery of tests using simple, low-cost techniques for monitoring water quality. Gopalan[114] proposes a similar approach. Moreover, as part of an integrated program, communities can take steps to provide for water treatment in their homes at an affordable cost.

Using these tools, teams consisting of community members and scientific experts can explore and evaluate the cause-and-effect relationships between human health and improper management of the natural and man-made environments. Such evaluations must take account of the physical environment and the social, cultural, and economic components of the local setting. The ecosystem approach should provide a better understanding of the environmental dynamics underlying the emergence of effects that are harmful to human health. The global view must also integrate components relating to the ways communities organize themselves and function within their environments.

Finally, research teams must turn their attention to preparing solutions to the problems they have identified. It is not enough to come up with theoretically effective proposals for sounder management of the ecosystem, they must also be applied under actual field conditions. Community participation is crucial in preparing solutions and implementing them and also in ensuring their continuity once the researchers have left. In light of the IDRC's experience over the past 30 years, we can say that as a general rule interventions developed by the communities themselves are much more likely to be adopted, maintained, and perhaps improved upon over time, as the community continues its development.

Interventions developed from an ecosystem approach to human health perspective are a challenge to the developing world because they must be economically feasible in situations where poverty is prevalent. Such interventions must not only help resolve environmental crises but also be within reach of the communities. Above all, they must contribute to prosperity if they are to be sustainable.

As some see it, it is an illusion to expect that interventions can be sustained after completion of a project using an ecosystem approach to human health, because the current international system of development funding rarely looks beyond a five-year horizon, if that. We must distinguish the sustainability of a *research program* (or a research team) from that of a *development project.* The initial research stage is but one component of a development project. The very essence of the ecosystem approach is that it makes communities responsible for managing the follow-up to the research process. Furthermore, it is generally recognized that researchers themselves are not necessarily in the best position to apply their research results to the development of new policies.

That said, there can be no doubt that it is important to ensure the permanence of ecosystem resource-management interventions in order to improve human health. We are also quite ready to agree that operational research has a preponderant and necessary role in evaluating the success of management interventions. While the role of research funding agencies such as IDRC is obviously critical to the research phase, bilateral and multilateral aid agencies also have a role to play in ensuring the sustainability of the development process when it comes to follow-up of research. Better coordination between these two types of agencies can only help promote sustainable and equitable development.

CONCLUSION

Over the last 30 years, a more holistic approach to public health has appeared. The acceptance of this ecologic approach to human health has been facilitated, in

part, by similar thinking in the field of natural-resource management, and by a better appreciation of the links between the health of individuals and their physical, social, and economic environments. The metaphor of the "healthy ecosystem" is a very useful concept for visualizing the impact of human activities on the environment, and in return, the impact these environmental changes have on human beings. It also places human beings at the very center of an ecosystem, so that they are considered in the same way as all its other components.

As proposed by the IDRC, the ecosystem approach to human health flowing from this metaphor is, above all else, a systemic approach to health. It sets out the high-priority areas for integrated management of ecosystem resources: the environment, the community, and the economy. This focus allows users of the ecosystem approach to human health to explore the relationship between the different components of an ecosystem, to identify the most important determinants of human health, and to estimate the impact of human activity on the sustainability of the ecosystem. This innovative approach thus places human beings front and center among development concerns.

If this approach is to be used successfully, however, research teams must use transdisciplinary and participatory methods to examine the different roles and strategies used by men and women and other social groups to manage their ecosystem.

The ecosystem approach to human health is undoubtedly more difficult to put into practice than traditional approaches. On the one hand, it represents a paradigm shift with respect to the conventional reductionist approach of Western research. Second, from the outset of the project, it requires a good understanding of the complexity of the systems under study. On the other hand, thanks to the synergy that characterizes cooperation among experts from different disciplines, this approach promotes the birth of new theories, original concepts, and non-intuitive realities that in turn can be used to prepare more comprehensive and more sustainable health programs for communities.

While the ecosystem approach to human health pays particular attention to the environmental determinants of health, it is distinct from the environmental health discipline in that it also allows practitioners to study the effects of modulators of these determinants: the components of the sociocultural environment and the socioeconomic environment of the local community. The ecosystem approach is an iterative and dynamic process that takes account of the complexity of an ecosystem that continues to evolve. The ecosystem-management interventions suggested by research become, in themselves, new determinants of the health of the ecosystem that can be built into the process of transdisciplinary and participatory monitoring of the ecosystem.

Finally, community participation in the research process is crucial. In fact, local know-how is essential for steering research in the right direction. Moreover, the best way to ensure the success of development solutions, whether for health or for other concerns, is to involve members of the community from the outset. The IDRC and its partners in developing countries are committed to the ecosystem approach to human health. If it is to have a lasting impact, however, it must be adopted by all those who seek to promote sustainable and equitable development of the kind that, as the Brundtland Commission suggested, will ensure a rich and healthy environment for generations to come.

The authors thank Professor David Rapport (University of Guelph, Ontario), Dr. Robert Lannigan and Dr. Christopher M. Anjema (University of Western Ontario), Professor Donna Mergler, Professor Marc Lucotte, Dr. Mario Gauthier, and Dr. Marc Roulet, as well as Dr. Dominique Bérubé (Université du Québec à Montréal, UQAM) for reviewing and commenting on the various drafts of the manuscript and for agreeing to discuss the document in depth in a series of working sessions. The authors also thank their collaborators at IDRC, Julie Dolbec, Zsofia Orosz, and Andrés Sanchez, for their constructive comments and criticism. They are grateful to their colleague Dr. Don Peden, who provided the essential elements for the discussion of transdisciplinarity, and are grateful as well to the graduate students in the Ecosystems and Human Health course at UQAM (Winter 2000) for agreeing to provide a written critique of the document. The authors in particular thank Professor Marc Lucotte, Director of the Environmental Sciences Institute of UQAM, who hosted them in his institution for the final week of their work.

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Science for Humanity

IDRC supports research for international development. It was founded in 1970 based on the conviction that development starts when communities in the South are able to take responsibility for their growth, using their own ideas and initiatives. Solutions cannot be imposed from the outside; they must be fostered from within.

IDRC supports the work of scientists and researchers in developing countries. In essence, the Centre supports innovation from within the South—creative solutions to development problems that work in local conditions and that are effective over the long run. In so doing, IDRC also strengthens the overall capability of researchers and research institutions to generate policies and technologies that can help create more equitable societies.

A public corporation created and funded by the Parliament of Canada, IDRC works in partnership with other donors to increase the resources available for research and international development in the South.

HOW RESEARCH IS SUPPORTED

Program Initiatives

The driving force of the Centre's programming is its program initiatives. Each of these initiatives focuses on a specific set of development issues and is managed by a team of experts from a broad range of disciplines. For example, a biologist, an economist, and an anthropologist will all work together—examining the same issues from different angles—to help Southern researchers find a holistic approach to solving a development problem. IDRC believes this multidisciplinary approach is key to addressing the complexities of international development issues. Program initiatives are the Centre's primary programming unit to support research in developing countries.

International Secretariats

International secretariats, although housed at IDRC, involve donors from around the world. They are jointly managed and jointly funded—with IDRC providing the financial and administrative infrastructure needed to ensure continuity. The research of secretariats is guided by independent steering committees with representatives from around the world. Secretariats represent another major vehicle for supporting research in the South.

WHAT RESEARCH IS SUPPORTED

IDRC supports research projects that relate to three main areas. In addition, the Centre is supporting research on two cross-cutting issues: gender and knowledge systems. Focusing on gender ensures the full and equal participation of women and men in development and leads to improvements in women's lives. Exploring knowledge systems means discovering the ways that knowledge is created, maintained, and used. This includes examining everything from oral histories to databases on networked computers.

Social and Economic Equity

Targeting poverty and economic vulnerability by directing research toward:

Public goods:
Delivering public goods—health, education, social security—in ways that are more effective, fair, and financially sustainable, as well as that promote good governance.

The effects of globalization:
Helping developing countries deal with the results of globalization, notably the rules and codes of the World Trade Organization.

Employment:
Supporting people, particularly women and youth, in their struggle to earn a living.

Environment and Natural-resource Management

Finding ways to provide life's essentials and improve human health through better environmental practices, directing research toward:

Food and water:
Ensuring secure sources of food and water for the poor by focusing on local resource management and appropriate policy choices.

Health and ecosystems:
Improving human health and well-being by managing ecosystems better.

Biodiversity:

Protecting local management and control of biodiversity in the face of competing interests regarding genetic resources.

Information and Communication Technologies for Development

Harnessing knowledge to increase development opportunities, by directing research toward:

Access to information technology:

Ensuring equitable and sustainable access to information and to the use of information and communication technologies so that all of society benefits.

The information economy:

Understanding developments in the information economy and responding to the concerns of communities and small businesses, and exploring the local effects of global trade rules and e-commerce.

WHO IDRC FUNDS

IDRC provides funds and expert advice to researchers from developing countries who are working to find long-term, workable solutions to critical development problems. IDRC also helps them involve Canadian researchers in their activities. In addition, IDRC funds and administers a number of award programs in the field of international development, both for Canadians and for researchers from the South.

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