World Health Organization

Ecosystems and Human Well-being

Health Synthesis

MILLENNIUM ECOSYSTEM ASSESSMENT

Millennium Ecosystem Assessment Panel

Harold A. Mooney *(co-chair),* Stanford University, United States of America

Angela Cropper *(co-chair),* The Cropper Foundation, Trinidad and Tobago

Doris Capistrano, Center for International Forestry Research, Indonesia

Stephen R. Carpenter, University of Wisconsin-Madison, United States of America

Kanchan Chopra, Institute of Economic Growth, India

Partha Dasgupta, University of Cambridge, United Kingdom of Great Britain and Northern Ireland

Rashid Hassan, University of Pretoria, South Africa

Rik Leemans, Wageningen University, the Netherlands

Robert M. May, University of Oxford, United Kingdom of Great Britain and Northern Ireland

Prabhu Pingali, Food and Agriculture Organization of the United Nations, Italy

Cristian Samper, Smithsonian National Museum of Natural History, United States of America

Robert Scholes, Council for Scientific and Industrial Research, South Africa

Robert T. Watson, World Bank, United States of America *(ex officio)*

A. H. Zakri, United Nations University, Japan *(ex officio)*

Zhao Shidong, Chinese Academy of Sciences, China

Editorial Board Chairs

José Sarukhán, Universidad Nacional AutÛnoma de MÈxico, Mexico

Anne Whyte, Mestor Associates Ltd., Canada

MA Director

Walter V. Reid, Millennium Ecosystem Assessment, Malaysia and United States of America

Millennium Ecosystem Assessment Board

The MA Board represents the users of the findings of the MA process.

Co-chairs

Robert T. Watson, *Chief Scientist,* World Bank

A.H. Zakri, *Director,* Institute of Advanced Studies, United Nations University

Institutional Representatives

Salvatore Arico, *Programme Officer,* Division of Ecological and Earth Sciences, United Nations Educational, Scientific and Cultural Organization

Peter Bridgewater, *Secretary General,* Ramsar Convention on Wetlands

Hama Arba Diallo, *Executive Secretary,* United Nations Convention to Combat Desertification

Adel El-Beltagy, *Director General,* International Center for Agricultural Research in Dry Areas, Consultative Group on International Agricultural Research

Max Finlayson, *Chair,* Scientific and Technical Review Panel, Ramsar Convention on Wetlands

Colin Galbraith, *Chair, Scientific Council,* Convention on Migratory Species

Erika Harms, *Senior Program Officer for Biodiversity*, United Nations Foundation

Robert Hepworth, *Executive Secretary,* Convention on Migratory Species

Olav Kjørven, *Director,* Energy and Environment Group, United Nations Development Programme

Kerstin Leitner, *Assistant Director-General,* Sustainable Development and Healthy Environments, World Health Organization

Alfred Oteng-Yeboah, *Chair,* Subsidiary Body on Scientific, Technical and Technological Advice, Convention on Biological Diversity

Christian Prip, *Chair,* Subsidiary Body on Scientific, Technical and Technological Advice, Convention on Biological Diversity

Mario A. Ramos, *Biodiversity Program Manager,* Global Environment Facility

Thomas Rosswall, *Executive Director,* International Council for Science - ICSU

Achim Steiner, *Director General,* IUCN - The World Conservation Union

Halldor Thorgeirsson, *Coordinator,* United Nations Framework Convention on Climate Change

Klaus Töpfer, *Executive Director,* United Nations Environment Programme

Jeff Tschirley, *Chief,* Environmental and Natural Resources Service, Research, Extension and Training Division, Food and Agriculture Organization of the United Nations

Riccardo Valentini, *Chair,* Committee on Science and Technology, United Nations Convention to Combat Desertification

Hamdallah Zedan, *Executive Secretary,* Convention on Biological Diversity, United Nations Convention on Biological Diversity

At-large Members

Fernando Almeida, *Executive President,* Business Council for Sustainable Development-Brazil

Phoebe Barnard, *Global Invasive Species Programme,* South Africa

Gordana Beltram, *Undersecretary,* Ministry of the Environment and Spatial Planning, Slovenia

Delmar Blasco, *former Secretary General,* Ramsar Convention on Wetlands, Spain

Antony Burgmans, *Chairman,* Unilever N.V., the Netherlands

Esther Camac-Ramirez, *Asociación Ixä Ca Vaá de Desarrollo e Información Indígena (Association Ixacavaa for Indigenous Development and Information),* Costa Rica

Angela Cropper *President (ex officio),* The Cropper Foundation, Trinidad and Tobago

Partha Dasgupta, *Professor,* Faculty of Economics and Politics, University of Cambridge, United Kingdom of Great Britain and Northern Ireland

José María Figueres, *Fundación Costa Rica para el Desarrollo Sostenible,* Costa Rica

Fred Fortier, *Indigenous Peoples' Biodiversity Information Network,* Canada

Mohamed H.A. Hassan, *Executive Director,* The Academy of Sciences for the Developing World, Italy

Jonathan Lash, *President,* World Resources Institute, United States of America

Wangari Maathai, *Assistant Minister for Environment and Natural Resources,* Kenya

Paul Maro, *Professor,* Department of Geography, University of Dar es Salaam, Tanzania

Harold A. Mooney *(ex officio), Professor,* Department of Biological Sciences, Stanford University, United States of America

Marina Motovilova, *Faculty of Geography,* Laboratory of Moscow Region, Russian Federation

M.K. Prasad, *Environment Centre of the Kerala Sastra Sahitya Parishad,* India

Walter V. Reid, *Director,* Millennium Ecosystem Assessment, Malaysia and United States of America

Henry Schacht, *past Chairman of the Board,* Lucent Technologies, United States of America

Peter Johan Schei, *Director,* The Fridtjof Nansen Institute, Norway

Ismail Serageldin, *Director,* Bibliotheca Alexandrina, Egypt

David Suzuki, *Chair,* David Suzuki Foundation, Canada

M.S. Swaminathan, *Chairman,* MS Swaminathan Research Foundation, India

José Galízia Tundisi, *President,* International Institute of Ecology, Brazil

Axel Wenblad, *Vice President of Environmental Affairs,* Skanska AB, Sweden

Xu Guanhua, *Minister,* Ministry of Science and Technology, China

Muhammad Yunus, *Managing Director,* Grameen Bank, Bangladesh

Ecosystems and Human Well-being

Health Synthesis

A Report of the Millennium Ecosystem Assessment

Core Writing Team
Carlos Corvalan, Simon Hales, Anthony McMichael

Extended Writing Team
Colin Butler, Diarmid Campbell-Lendrum, Ulisses Confalonieri, Kerstin Leitner, Nancy Lewis, Jonathan Patz, Karen Polson, Joel Scheraga, Alistair Woodward, Maged Younes and many MA authors.

Review Editors
José Sarukhán and Anne Whyte (co-chairs); Philip Weinstein and other members of the MA Board of Review Editors.

WHO Library Cataloguing-in-Publication Data

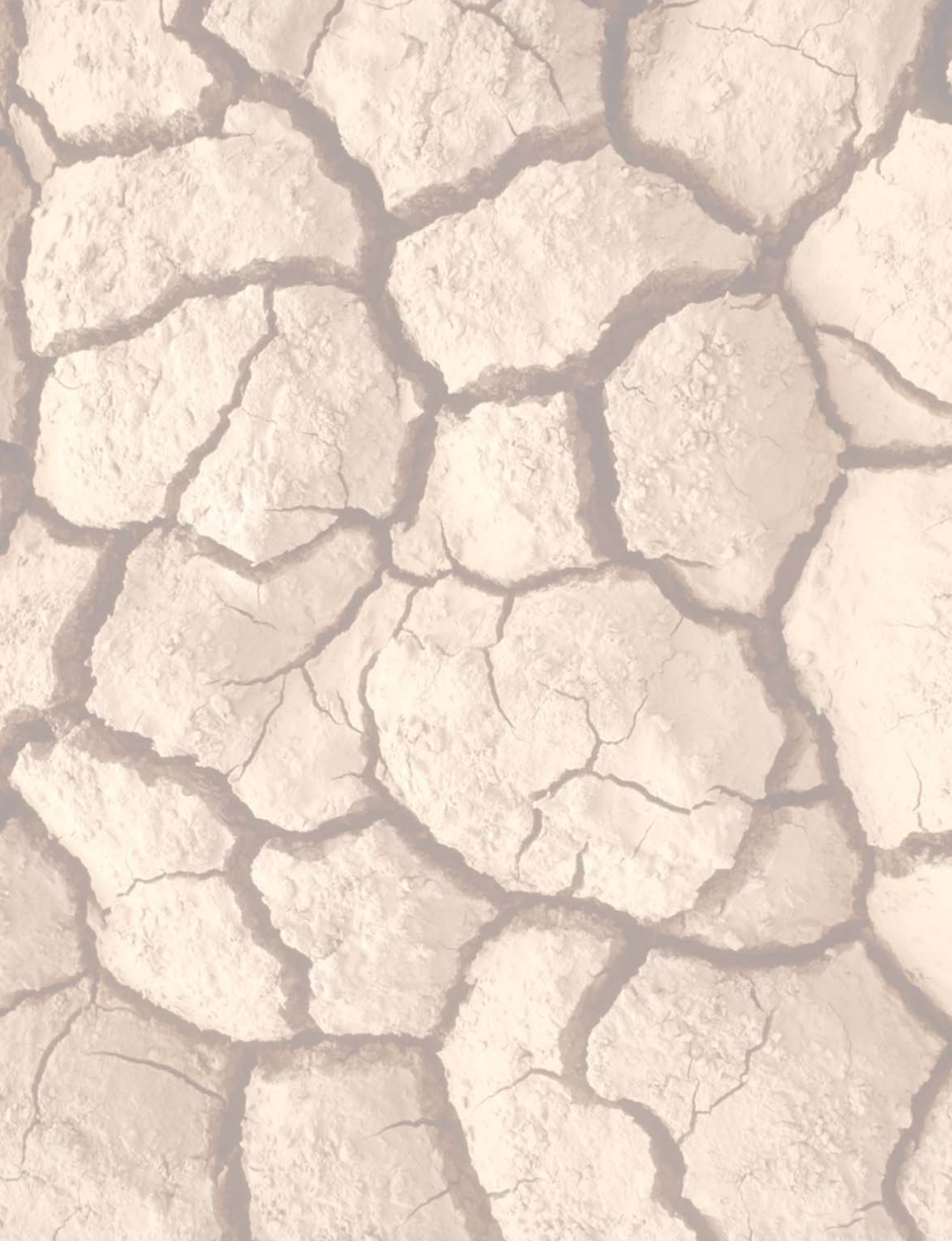
Ecosystems and human well-being : health synthesis : a report of the Millennium Ecosystem Assessment / Core writing team: Carlos Corvalan, Simon Hales, Anthony McMichael ; extended writing team: Colin Butler ... [et al.] ; review editors: José Sarukhán ... [et al.].

1. Ecosystem 2. Environmental health 3. Health status 4. Development 5. Goals 6. Risk assessment I. Corvalán, Carlos F. II. Hales, Simon. III. McMichael, Anthony J. IV. Butler, Colin. V. Sarukhán, José.

ISBN 92 4 156309 5 (NLM classification: WA 30)

Printed in France.

Contents



Foreword

It is becoming increasingly clear that population growth and economic development are leading to rapid changes in our global ecosystems. In recognition of this, the United Nations' Secretary-General Kofi Annan, in a 2000 report to the General Assembly entitled: "*We the Peoples: The Role of the United Nations in the 21st Century,*" called for the Millennium Ecosystem Assessment to be undertaken. Since 2001, the Millennium Ecosystem Assessment has worked to assess the consequences of ecosystem change for human well-being, and establish the scientific basis for actions needed to enhance the conservation and sustainable use of those systems, so that they can continue to supply the services that underpin all aspects of human life.

The assessment exercise has involved more than 1 300 experts worldwide. The findings provide the strongest evidence so far of the impact of our actions on the natural world. They show, for example, that over the past 50 years, humans have changed natural ecosystems more rapidly and extensively than in any comparable period in human history. This transformation of the planet has contributed to substantial net gains in human well-being and economic development. But not all regions and groups of people have benefited from this process, and many have been harmed. Moreover, the full costs associated with these gains are only now becoming apparent. Approximately 60% of the ecosystem "services" examined, from regulation of air quality to purification of water, are being degraded or used unsustainably.

Nature's goods and services are the ultimate foundations of life and health, even though in modern societies this fundamental dependency may be indirect, displaced in space and time, and therefore poorly recognized. These more distant and complex links mean that we now need to look at environmental health through a broader lens. Health risks are no longer merely a result of localized exposures to "traditional" forms of pollution – although these still certainly exist. They are also a result of broader pressures on ecosystems, from depletion and degradation of freshwater resources, to the impacts of global climate change on natural disasters and agricultural production. Like more traditional risks, the harmful effects of the degradation of ecosystem services are being borne disproportionately by the poor. However, unlike these more traditional hazards, the potential for unpleasant surprises, such as emergence and spread of new infectious diseases, is much greater.

This report represents a call to the health sector, not only to cure the diseases that result from environmental degradation, but also to ensure that the benefits that the natural environment provides to human health and well-being are preserved for future generations.

LEE Jong-wook
Director-General
World Health Organization

Reader's Guide

This report synthesizes the findings from the Millennium Ecosystem Assessment's (MA) global and sub-global assessments of how ecosystem changes do, or could, affect human health and well-being. All the MA authors and review editors have contributed to this report through their contributions to the underlying assessment chapters on which this text is based.

Five additional MA synthesis reports were prepared to facilitate access to information by other audiences: general overview; UNCCD (desertification); CBD (biological diversity); Ramsar Convention (wetlands); and business. Each MA sub-global assessment also will produce additional reports to meet the needs of its own audience. The full technical assessment reports of the four MA working groups will be published in mid-2005 by Island Press.

All of the assessment's printed materials, together with core data and a glossary of terminology used in the technical reports, will be available on the Internet at www.maweb.org. Appendix A lists the acronyms and abbreviations used in this report. References for the underlying chapters in the full technical assessment reports of each working group appear in parentheses in the body of this synthesis report. A list of the assessment report chapters is provided in Appendix B.

The following set of words has been used, where appropriate, to indicate estimated levels of certainty about the observations or conclusions: very certain (98% or greater probability), high certainty (85-98% probability), medium certainty (65-85% probability), low certainty (52-65% probability) and very uncertain (50-52% probability). These estimates are based on the collective judgment of the authors, using the observational evidence, modelling results and relevant theory. Elsewhere the following qualitative scale is used to gauge the level of scientific understanding: well-established, established but incomplete, competing explanations and speculative. These terms appear in italics.

Throughout this report, dollars ($) indicate U.S. dollars, and tonne means metric tonne. The term billion is used in accordance with the WHO definition – of one thousand millions.

Summary for Decision-makers

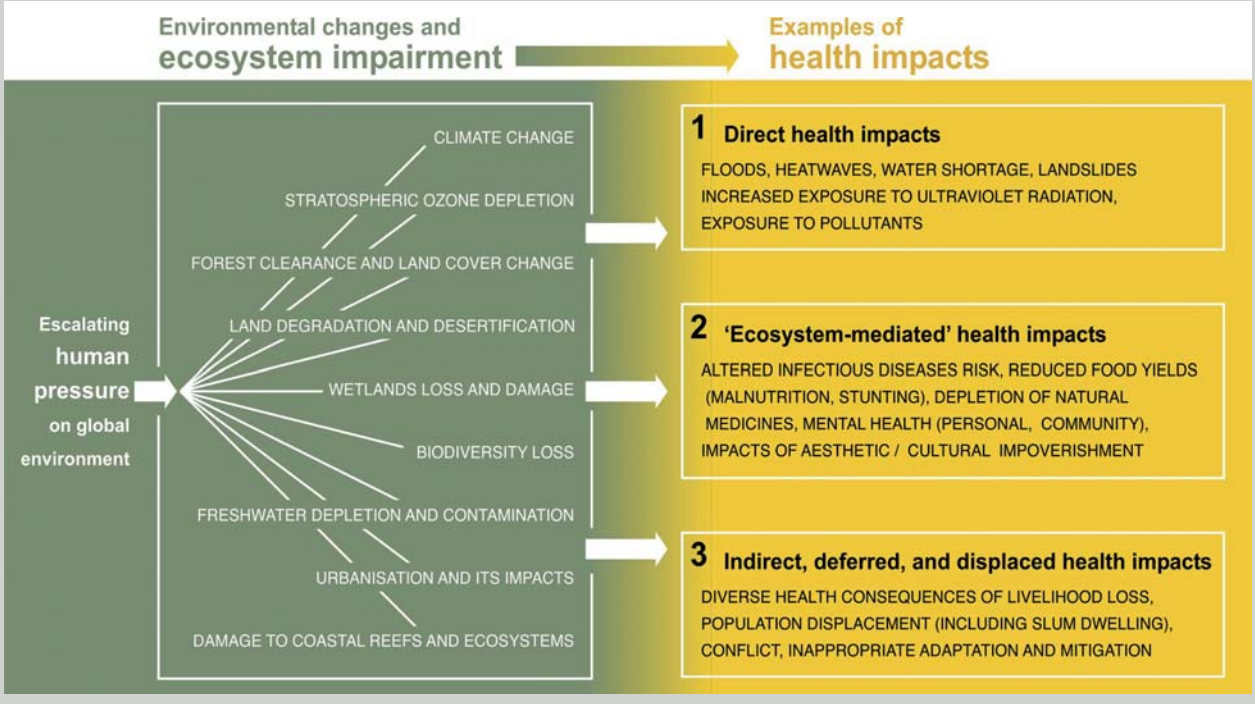
SeaWiFS / NASA / Goddard Space Flight Center and ORBIMAGE/ http://visibleearth.nasa.gov

The health impacts of ecosystem change are global as well as local; here dust from north Africa is distributed widely across the continent, with potential impacts on health. Degradation of drylands, as well as biomass burning, exacerbates problems associated with dust storms.

Why do ecosystems matter to human health?

Ecosystems are the planet's life-support systems - for the human species and all other forms of life. Human biology has a fundamental need for food, water, clean air, shelter and relative climatic constancy. Other health benefits include those derived from having a full complement of species, intact watersheds, climate regulation and genetic diversity. Stresses on freshwater sources, food-producing systems and climate regulation could cause major adverse health impacts *(high certainty)* (see Figure SDM1).

Figure SDM1. Harmful effects of ecosystem change on human health



This figure describes the causal pathway from escalating human pressures on the environment through to ecosystem changes resulting in diverse health consequences. Not all ecosystem changes are included. Some changes can have positive effects (e.g. food production).

Ecosystem services are indispensable to the well-being and health of people everywhere. In addition to providing life's basic (above-mentioned) needs, changes in their flow affect livelihoods, income, local migration and, on occasion, political conflict. The resultant impacts on economic and physical security, freedom, choice and social relations have wide-ranging impacts on well-being and health.

The causal links between environmental change and human health are complex because often they are indirect, displaced in space and time, and dependent on a number of modifying forces. For example, climate changes can place stresses on agricultural production or the integrity of coral reefs and coastal fisheries. This can lead to malnutrition, stunted childhood growth, susceptibility to infectious diseases and other ailments. Deforestation may alter infectious disease patterns, for example by affecting vector (e.g. mosquito) distributions over time. The MA identified key ecosystem services and their links to human health. These are described in more detail below.

CDC / Jim Gathany

Anopheles stephensi *mosquito, a known malaria vector, with a distribution from Egypt to China, obtaining a blood meal from a human host. In the wild, mosquito larvae are found in sites such as stream pools and margins, puddles, irrigation channels and springs. In urban areas the larvae are found in a wide variety of artificial containers including cisterns, wells, tubs and fountains.*

Ecosystem services and human health

Fresh water

Many aspects of the world's hydrological (water) cycle are regulated by the natural functions of ecosystems and associated geophysical processes (such as evaporation and the functioning of the climate system). Human interventions in watersheds, lakes and river systems take many forms - deforestation, farming, irrigation, river damming and extractions from subterranean aquifers. Wetlands play a crucial role in the filtering of fresh water, including the removal of various chemicals and potentially toxic elements (e.g. heavy metals such as cadmium and lead).

Fresh water is essential for human health. It is used for growing food, drinking, personal hygiene, washing, cooking and the dilution and recycling of wastes. Water scarcity jeopardizes food production, human health, economic development and geopolitical stability. Globally, the availability of water per person has declined markedly in recent decades. One third of the world's population now lives in countries experiencing moderate to high water stress. This fraction will continue to increase as both population size and per capita water demand grow - reflecting the escalating use of fresh water for irrigated agriculture, livestock production, industry and the requirements of wealthier urban residents.
Over 1 billion people lack access to safe water supplies; 2.6 billion people lack adequate sanitation. This has led to widespread microbial contamination of drinking water. Water-associated infectious diseases claim up to 3.2 million lives each year, approximately 6% of all deaths globally. The burden of disease from inadequate water, sanitation and hygiene totals 1.7 million deaths and the loss of more than 54 million healthy life years. Investments in safe drinking-water and improved sanitation show a close correspondence with improvements in human health and economic productivity. Every day each person needs 20-50 litres of water free from harmful chemical and microbial contaminants, for drinking, cooking and hygiene. The growing challenge of providing this basic service to large segments of the human population is highlighted by one of the United Nations Millennium Development Goals, MDG-7, which calls for halving by 2015 the proportion of people without sustainable access to safe drinking-water and basic sanitation.

Food

Productive terrestrial and marine ecosystems, both wild and managed, are the source of our food - a prerequisite for health and life. Global aggregate food production currently is sufficient to meet the needs of all. However, of the present world population of 6.5 billion, over 800 million - nearly all of them in low-income countries - do not obtain enough protein and calories for energy. Worldwide, a similar (increasing) number are now overfed. Several billion people experience deficiences of one or more micronutrients (especially vitamin A, zinc and iodine).

In poor countries, especially in rural areas, the health of human communities often is directly dependent on locally productive ecosystems providing sources of basic nutrition. Local food production is critical in preventing

hunger and promoting rural development in areas where the poor do not have the capacity to purchase food from elsewhere. Wild foods are important locally in many developing countries, often bridging the hunger gap created by stresses such as droughts and civil unrest. In richer urban communities, human dependence on ecosystems for food is less apparent but no less fundamental.

Cooking and heating using solid fuels in poorly verticlated houses results in very high levels of exposure to indoor air pollution, especially among women and children. WHO estimates that this causes over 1.6 million deaths per year.

Worldwide, undernutrition accounts for nearly 10% of the global burden of disease. Almost all of this occurs in poor countries where food production has not kept up with population increases, particularly in sub-Saharan Africa. Furthermore, undernutrition is related strongly to poverty in developing countries with high mortality rates; between one-sixth and one-quarter of the burden of disease is related to childhood and maternal undernutrition. In developed countries with low mortality rates, diet-related risks (mainly overnutrition, often in combination with physical inactivity) account for between one-tenth and one-third of the burden of disease. The nutritional disparity between rich and poor primarily is caused by social and economic factors as well as the uneven impacts of world food trade. In the future, however, adverse changes in food-producing ecosystems are likely to play an increasingly important role in nutritional disparities *(medium certainty).*

Timber, fibre and fuel

Many processes and resources in nature provide power that can be harnessed by human communities, especially wind, water and biomass combustion. Different geographical regions and countries at varying stages of development use varied methods of generating power. This has many health impacts and the availability of power, especially electricity, has important applications in health care.

Over half of the world's population continues to rely upon solid fuels for cooking and heating. These fuels - including wood, crop stubble and animal dung - are a direct product of ecosystems. Indoor air pollution produced by the combustion of biomass fuels as well as coal in poorly ventilated heating and cooking environments, causes significant mortality and morbidity from respiratory diseases, particularly among children.

In areas where the demand for wood has surpassed local supply and people cannot afford other forms of power, there is increased vulnerability to illness and malnutrition from consuming (unboiled) microbiologically contaminated water and improperly cooked food, as well as from exposure to cold. Poor women and children in rural communities often are those most affected by a scarcity of fuel wood. Many must walk long distances searching for fuel and firewood (as well as water) and hauling it home. These time-consuming tasks reduce the time and energy available for tending crops, cooking meals or attending school. Therefore, provision of adequate and sustainable energy supplies is fundamental not only to economic development, but also to health and well-being.

Outdoor air pollution is caused predominantly by the combustion of non-renewable fossil fuels for electricity generation, transport and industry. Globally, urban air pollution is responsible for significant mortality every year, mostly as a result of heart and lung diseases. In addition, the accompanying release of a major greenhouse gas (CO_2) and its consequent contribution to global warming have further, mostly adverse, impacts on human health. Air pollution due to forest fires and burning practices in agriculture also can have serious local and regional health consequences. This was highlighted by the public health experiences in south-east Asia in 1998, following widespread (drought-associated) forest fires in Sumatra and Kalimantan, Indonesia in the latter part of 1997 and early 1998.

Timber exploitation has contributed to species' loss and ecosystem degradation in many regions of the developing world, affecting traditional livelihoods, microbial ecology and causing other health-related risks. In particular the destruction and fragmentation of habitats, accompanied by new patterns of human-microbe contacts, has introduced new infectious diseases into human populations – e.g. the Nipah virus in Malaysia and various viral haemorrhagic fevers in South America. Deforestation also endangers health by intensifying the effects of natural disasters such as floods and landslides (see Box 1.1).

Bark of white willow (Salix alba) *was recommended as a pain reliever by the Ancient Greek physician, Hippocrates. Salicin, the active ingredient in willow bark – similarly found in the spirea or meadowsweet plant* (Filipendula ulmaria/Spiraea ulmaria) *– was discovered in the early 1800s. Aspirin® was introduced to the public in 1899, following synthesis of the salicin derivative: acetylsalicylic acid.*

Biological products

Millions of people around the world depend partly or fully on natural products collected from ecosystems for medicinal purposes. Although synthetic medicines (over half of which originated from natural precursors) are available for many purposes, the global need and demand for natural products persists. Some of the better-known mainstream pharmaceuticals from natural sources include aspirin, digitalis and quinine.

Nutrient and waste management, processing and detoxification

Ecosystems play a critical role in the recycling and redistribution of nutrients. This fundamental service underpins the health of plant and animal species everywhere. Disruption of nutrient cycling can impair soil fertility, resulting in reduced crop yields. This impairs the nutritional status of households *(medium certainty)* and diet deficiencies (both macro-and micro-nutrients) harm children's physical and mental development. In turn, this can impair the livelihoods of farmers and limit the options open to their children.

Human health can be harmed by exposure to certain toxins produced by algal blooms. These can occur as a result of eutrophication of waterways excessively loaded with nitrates and phosphates infiltrating from run-off water discharged in agricultural, industrial and domestic processes.

Humans are also at risk from inorganic chemicals and persistent organic chemical pollutants in food and water. Such exposures can occur when attempts to improve water access lead to contamination from natural sources (as occurred recently with arsenic contamination of tube wells in Bangladesh), and when human actions release toxic chemicals into the environment (for example, through pesticide use). Toxic chemicals in water and food can have adverse effects on various organ systems. Exposure to low concentrations of some chemicals (such as PCBs, dioxins and DDT) may cause endocrine disruption, interfering with normal human hormone-mediated physiology and impairing reproduction.

Regulation of infectious disease

Infectious diseases are caused by viruses, bacteria and other types of microbes or parasites. Only a few infectious agents cause actual disease in plants, animals and humans; usually these are constrained geographically and seasonally by ecosystems and ecological relationships in nature. Patterns of microbe entry into the human species (sometimes as new mutants) are sensitive to climatic and micro-environmental conditions. These factors may impact upon the spread of microbes between humans; their more distant dissemination; and the activity of vector organisms (e.g. mosquitoes) involved in their transmission. Often human-induced changes in ecosystems and in physical environmental conditions alter these natural influences on infectious agent range and activity.

The pattern and extent of change in incidence of a particular infectious disease depends on the particular ecosystems affected, type of land-use change, disease-specific transmission dynamics, sociocultural changes and the susceptibility of human populations. Infectious disease risks are affected particularly by destruction of, or encroachment into, wildlife habitat (particularly through logging and road

building); changes in the distribution and availability of surface waters, e.g. through dam construction, irrigation and stream diversion; agricultural land-use changes, including proliferation of both livestock and crops; uncontrolled urbanization or urban sprawl; resistance to pesticide chemicals used to control certain disease vectors; climate variability and change; migration and international travel and trade; and the accidental or intentional human introduction of pathogens.

Recently, there has been an upturn in the rate of emergence or re-emergence of infectious diseases. Factors contributing substantially to this trend include: intensified human encroachment on natural environments; reductions in biodiversity (including natural predators of vector organisms); particular livestock and poultry production methods; and increased long-distance trade in wild animal species (including as food). Further contributors include: habitat alterations that lead to changes in the number of vector breeding sites or in reservoir host distribution; niche invasions or interspecies host transfers; human-induced genetic changes of disease vectors or pathogens (such as mosquito resistance to pesticides or emergence of antibiotic-resistant bacteria); and environmental contamination by infectious disease agents.

Human health is likely to be affected indirectly by climate-induced changes in the distribution of productive ecosystems. This photo shows rice cultivation in south-east Asia.

Cultural, spiritual and recreational services

People and communities obtain many non-material benefits from ecosystems. Ecosystems provide sites and opportunities for tourism, recreation, aesthetic appreciation, inspiration and education. Such services can improve mental health; enhance a subjective sense of culture or place; and also enrich objective knowledge of natural and social sciences, e.g. botany, biology, history and archaeology. Health benefits of these services may be materially less tangible than those captured by conventional health indicators or standard economic valuation measures. Nonetheless, such services are highly valued by people in all societies. Various traditional practices linked to ecosystem services, including seasonal cycles of thanks and celebration, play an important role in developing social capital and enhancing social well-being.

Climate regulation

Regional climatic conditions are influenced by changes in ecosystems and landscapes, especially deforestation and desertification. On a larger scale, the ongoing human-induced alteration of atmospheric composition (the greenhouse effect) also affects climatic conditions.

Each of the ecosystem services described above is sensitive to climatic conditions and therefore will be affected by human-induced climate change. In turn, these ecosystem changes will affect the well-being and health of human populations. Meanwhile, climate change itself does, and will, affect human health.

Although climate change will have some beneficial effects on human health, most are expected to be negative. Direct effects, such as increased mortality from heatwaves, are most readily predicted but indirect effects are likely to have greater overall impact. Human health is likely to be affected indirectly by climate-induced changes in the distribution of productive ecosystems and in the availability of food, water and energy supplies. These changes will affect the distribution of infectious diseases, nutritional status and patterns of human settlement.

Extreme weather events (including heatwaves, floods, storms and droughts) and sea-level rise are anticipated to increase as a result of climate change. These events have local and sometimes regional effects: directly through deaths and injuries and indirectly through economic disruption, infrastructure damage and population displacement. In turn, this may lead to increased incidence of certain communicable diseases as a result of overcrowding; lack of clean water and shelter; poor nutritional status; and adverse impacts on mental health.

Extreme weather events, including heatwaves, floods, storms and droughts, are anticipated to increase as a result of climate change. This is a true colour image of Hurricane Frances as it passed over the Bahamas with sustained winds of 185 kph, 3 September 2004.

Globally, the annual absolute number of people killed, injured or made homeless by natural disasters is increasing. An important factor is the growth in human settlements in geographically sensitive locations, such as coastal zones and flood plains, exposed to extreme events. Case-studies have shown that environmental degradation has reduced the capacity of ecosystems to act as a buffer against climate extremes. For example, degraded coral reefs and mangrove forests may lose their capacity to stabilize coastlines and protect against some of the damaging effects of storm surges. Heavy rain falling on deforested slopes may be more likely to trigger landslides. In many cases, the only lands available to poor households and communities for settlement may also be highly vulnerable to impacts from weather extremes, e.g. flooding, as well as to natural disasters.

How have ecosystems changed and what are the health implications?

As a result of human actions, the structure and functioning of the world's ecosystems changed more rapidly in the second half of the twentieth century than at any other time in human history. The magnitude of these changes is growing as both population size and intensity of economic activity increase. One consequence is that the diversity of life on Earth is being depleted at an accelerating rate. The loss of plant and animal species is irreversible. So, too, is the unravelling or elimination of whole ecosystems.

Human societies also achieve benefits for well-being and health by restructuring and managing various ecosystems. In most countries and regions, the changes made to food-producing ecosystems in recent decades have provided substantial gains in production. Many of the most significant human-induced changes to ecosystems have been essential to meet growing needs for food and water. These changes have helped to reduce the proportion of malnourished people and improve human health.

However, these gains have been achieved at increasing cost: degradation of 60% of ecosystem services; exacerbation of poverty for some; and growing inequities and disparities across groups of people. The intensification of food production methods, expanded use of irrigation, forest-clearing and the intensive exploitation of capture fisheries (e.g. fishing in open marine or inland waters), all have entailed losses in natural resources and changes in ecosystems' functions. The loss from nature of potential medicinal compounds is one consequence. Further, these changes to ecosystems have occurred unevenly, often exacerbating the inequalities in access to ecosystem services and contributing further to poverty. Both within and between countries, poverty is a consistent underlying determinant of undernutrition; lack of access to safe water and sanitation; and lack of access to other public services important to health and well-being, e.g. health services, garbage disposal, etc. These adverse factors have staggering human health implications, costing millions of lives each year.

By dint of much higher per-person consumption levels, the world's richer populations exert disproportionate pressure on global ecosystems - yet are less vulnerable to the adverse consequences. These populations exhibit less vulnerability to the effects of ecosystem degradation, largely as a result of their ability to import resources from, and displace health risks to, other geographical locations.

Poverty and hunger have tended to force rural people onto marginal drought-prone lands with poor soil fertility, and others to urban slums. About 1 billion people are affected by land degradation such as that caused by soil erosion, waterlogging or salinity of irrigated land. Erosion has caused substantially reduced crop yields in Africa.

Diminished human health and well-being tends to increase the immediate dependence on ecosystem services. The resultant additional pressure can (further) damage the ecosystems' capacity to deliver services *(medium certainty)*. As well-being declines, people's options for regulating their use of natural resources at sustainable levels are reduced. Immediate needs inevitably take priority, increasing the pressure on ecosystem services, and can create a downward spiral of increasing poverty and further degradation of ecosystem services.

How might ecosystems change and what would be the health implications?

Continuation of the dual trends of growing exploitation of ecosystem services and the generally declining condition of most ecosystems is unsustainable and likely to lead to irreversible changes. When changes to an ecosystem cross a threshold, recovery is generally slow and costly, even impossible. Thresholds may become lower as anthropogenic impacts simplify these natural systems and reduce their intrinsic resilience to change.

Many of the people and places affected adversely by ecosystem changes and declining ecosystem services are highly vulnerable and ill-equipped to cope with further loss of ecosystem services. Highly vulnerable groups include those whose needs for ecosystem services already exceed supply. This includes people who lack adequate safe water supplies as well as those living in areas with declining agricultural yields and therefore at risk of malnutrition and impaired child development. In tropical and semitropical regions much of the ongoing deforestation alters the dynamics of infectious disease transmission, especially by changing the conditions for mosquito, tick and rodent populations. This may increase outbreaks of diseases such as malaria and dengue fever.

The regions facing the greatest challenges in achieving the MDGs overlap largely with those facing the greatest problems related to the sustainable supply of ecosystem services. Many of these regions include large areas of drylands, in which the combination of population growth and land degradation is increasing human vulnerability to both economic and environmental change and, consequently, impairing well-being and health.

Ecosystem changes may occur on such a large scale as to have a catastrophic effect on human health. There is an increasing risk of non-linear changes in ecosystems, including accelerating, abrupt and potentially irreversible changes *(established but incomplete evidence)*. The increased likelihood of these non-linear changes stems from the loss of biodiversity and growing pressures from multiple direct drivers of ecosystem change. Similar non-linearities are anticipated in social-economic-political contexts. For example, widespread food insecurity resulting from severe climate change, institutional failure and increasingly damaged soils could worsen inequality and lead to widespread conflict. Meanwhile, a great many individually less dramatic losses in ecosystem services are likely to influence human health adversely.


UNEP/C Jo Kan Sara/TopFoto.co.uk

The MA Scenarios Working Group developed four scenarios to explore possible future trends and developments until 2050, and the consequences for ecosystem services and human well-being. Scenarios are plausible, proactive and relevant stories about how the future might unfold. They are not forecasts, projections, predictions or recommendations. Rather, they are implications of specific policy outcomes based on current knowledge of underlying socioecological processes. The MA scenarios are used to explore a range of contexts under which sustainable development could be pursued, and approaches supporting sustainable development. The scenarios are: (i) *Global Orchestration*: globally-driven economic development emphasising social responsibility, equity, and social public goods, and with a reactive approach to ecosystems; (ii) *Order from Strength*: regionalized development with an emphasis on security and economic growth and a reactive approach to ecosystems; (iii) *Adapting Mosaic*: regionalized development emphasising proactive management of ecosystems, local adaptation and flexible governance; and (iv) *TechnoGarden*: globalized development using technology to achieve environmental outcomes, with a proactive approach to ecosystems (see Box 3.2).

Under all four MA scenarios, the projected changes in the underlying driving forces result in significant growth in consumption of ecosystem services, continued loss of biodiversity and further degradation of some ecosystem services.

- During the next 50 years, demand for food is projected to grow by 70-80% and demand for water by 30-85%. Water withdrawals in developing countries are projected to increase significantly.
- Food security is not achieved under any of the MA scenarios by 2050. Child malnutrition will be difficult to eliminate, despite an increasing food supply and more diversified diets.
- A severe deterioration of the services provided by freshwater resources (such as aquatic habitat; fish production; water for households, industry and agriculture) is found in the scenarios that are reactive to environmental problems. Less severe but still important declines are expected in the scenarios that are more proactive about environmental problems.
- Habitat loss and other ecosystem changes are projected to lead to a decline in local diversity of native species by 2050.

In the scenarios with more promising health prospects, the number of undernourished children is reduced and the burden of epidemic diseases such as malaria and tuberculosis also falls. Improved vaccine development and distribution could allow populations to cope relatively well with the next influenza pandemic, while the impact of other new infectious diseases should also be limited if well-coordinated public health measures are in place. Under a less optimistic scenario, the number of malnourished children increases. The health and social conditions for rich and poor countries diverge and a negative spiral of poverty, declining health and degraded ecosystems could develop.

What actions would address the health consequences of ecosystem change?

There are two strategies for avoiding disease and injury caused by ecosystem disruption. One - preferable in principle - is to prevent, limit or manage the environmental damage. The other is to make adaptive changes that will protect individuals and populations from the adverse consequences of ecosystem change. These should not be viewed as alternatives; both strategies are useful.
Two aspects need to be considered to understand the potential negative health impacts of ecosystem change: the current (and likely future) intrinsic vulnerability (e.g. nutritional status) of populations and their likely future capacity for adaptation. These are closely related. In many cases the forces that place populations at risk (such as poverty and high burdens of disease) also impair their capacity to prepare for the future.

Improving water and sanitation infrastructure in Viet Nam.

As part of a strategy for achieving the MDGs, improved ecosystem management would need to address a complex set of underlying causes of environmental change. This entails cross-sectoral policies, institutions and investments on local, national, regional and global scales. Achievement of the MDGs, enhanced human well-being and improved human health status requires particular attention to improving ecosystem management and the capacity for policy-making at national and local levels. Meanwhile, there is the need to address global challenges including long-term climate change, the depletion of international fisheries and the spread of exotic species.

How can priorities be established for actions to address the health consequences of ecosystem change?

There is a need for a more systematic inventory, by region and country, of current and likely population health impacts of ecosystem change. Clearly, information is a crucial resource. An appropriate metric - for instance disability-adjusted life years (DALYs) gained or lost - should be used to make at least approximate estimates of these impacts. This will require an unusual level of inter-disciplinary analysis and synthesis in which the population health sciences are central, especially epidemiology. Burden-of-disease evaluations within the context of ecosystem change are appropriate for aggregating health impacts through a range of mechanisms and, potentially, can aid priority-setting and decision-making to address ecosystem change. However, they must be considered as only one component of evidence; they cannot account fully for complex causal pathways, long timescales and potential irreversibility. These important properties need to be included in the final considerations about any response to ecological change.

Priority-setting of actions to address the health consequences of ecosystem change also should reflect the priorities and values of all those affected by the proposed actions. Therefore the final decisions about priorities should be taken either by individuals or by their legitimate political representatives, with reference to the prevailing stakeholder/community values.

Monitoring nutritional status in Zambia: an officer from the Central Statistical Office collects data on food and water availability and prices of important food items in a village.

It is important to consider which sections of the population are most affected by ecological changes, including the distribution of disease impacts by age, gender, social status, ethnicity and geographical region. Global estimates for the year 2000 indicated that in poor countries with high mortality rates, between one-sixth and one-quarter of the total disease burden was attributable to childhood and maternal undernutrition. Children and pregnant women are at much greater risk for morbidity and mortality from malaria, particularly if malnourished; morbidity and mortality due to heatwaves is highest among the elderly. Many other such differences in vulnerability to disease have been documented. For example, in many poor countries the risk of child diarrhoeal disease is related strongly to poverty and the risk of malnutrition among the poor is greater among girls than among boys.

The responses to ecosystem changes include mitigation and adaptation. Mitigation implies reducing or reversing the change process. Adaptation aims to increase the resilience of both social systems and ecosystems to the impacts of ecosystem change in order to reduce the current and future health risks – and to take advantage of beneficial consequences of ecosystem changes. Decisions on priority actions should consider the best evidence available on the likely effectiveness of any intervention in either class. Mitigation and adaptation response options can be legal, economic, financial, institutional, social, behavioural, technological or cognitive. They encompass spontaneous responses to ecosystem change and planned (anticipatory) interventions by affected individuals and institutions such as governments. In order to protect human health, responses very often must involve actions outside of the health sector – particularly in agriculture, industry, education, coastal zone management and urban planning.

What are the policy implications of ecosystem change's threats to health?

Measures to ensure ecological sustainability would safeguard ecosystem services and thereby benefit health in the long term. A good and equitable health status within a population confers a range of social, economic and political benefits. Society is more cohesive, more productive and more stable. For a population weighed down by disease related to poverty and by inequities in access to food and other resources, equitable provision of these resources would have major health benefits *(high certainty).* Where ill-health is caused, directly or indirectly, by excessive consumption of ecosystem services (such as food and energy), substantial reductions in consumption would have major health benefits and simultaneously reduce pressure on life-support systems *(high certainty).*

Increasing populations and growing economies result in higher total consumption. In addition to the pressure on ecosystems this situation directly increases certain health risks - such as those from over-nutrition and physical inactivity. A reduction in consumption of animal products and refined carbohydrates (simple sugars) in rich countries would have benefits for both human health and ecosystems. The rise of obesity in urban populations around the world is essentially a 'human ecological' problem due to the societal-level imbalance between energy ingested and energy expended - it is a modern way-of-living problem. The implementation of better transport practices and systems could lead to fewer injuries, decreases in obesity and cardiovascular disease through more physical activity in sedentary populations, and reductions in local air pollution and greenhouse gas emissions.

Integration of national agricultural and food security policies with the economic, social and environmental goals of sustainable development could be achieved, in part, by ensuring that the environmental and social costs of production and consumption are reflected more fully in the market price of food and water.

Cross-sectoral policies that promote ecologically sustainable development and address underlying driving forces also will be essential. Agenda 21, the international action plan adopted in 1992 at the United Nations Conference on Environment and Development (Earth Summit), and the World Summit on Sustainable Development Plan of Implementation, adopted in Johannesburg in 2002, both describe a comprehensive approach to ecologically sustainable development incorporating cross-sectoral policies. Within these two frameworks, the following strategies have specific relevance to health.

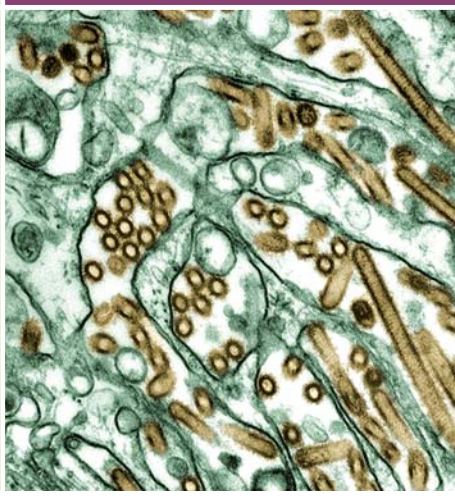
- Mitigation strategies that reduce the underlying causes of ecosystem change, while simultaneously improving human health.
- Adaptation strategies to reduce the effect of ecosystem disruption on health (addressing direct, mediated and long-term health impacts).
- Integrated action for health, such as a health impact assessment of major development projects, policies and programmes and indicators for health and sustainable development.
- Inclusion of health in sustainable development planning efforts such as Agenda 21, in multilateral trade and environmental agreements and poverty reduction strategies.
- Improvement of intersectoral collaboration between different tiers of government, government departments and NGOs.
- International capacity-building initiatives that assess health and environment linkages, using the knowledge gained to create more effective national and regional policy responses to environmental threats.
- Dissemination of knowledge and good practice on health gains from intersectoral policy.

The ongoing degradation of ecosystem services is a significant barrier to achieving the MDGs. Ecologically unsustainable use of ecosystem services raises the potential for serious and irreversible ecological change. This may occur on such a large scale as to have a catastrophic effect on the economic, social and political processes on which social stability, human well-being and good health depend. The MDGs give prominence to achieving reductions in malnutrition, infectious diseases, maternal mortality, exposure to unsafe drinking-water and, most importantly, poverty. All these goals are seriously jeopardized by continuing decline in the world's ecosystems.

This indicates strongly that a precautionary approach to environmental protection is the most effective way to protect and enhance health. Unavoidable uncertainties about aspects of the risks to well-being and health from environmental changes should not be an excuse for delaying policy decisions.

Key Questions in the Millennium Ecosystem Assessment

CDC/C. Goldsmith



Electron micrograph of avian influenza A (H5N1) viruses (seen in gold) grown in MDCK – canine kidney – cells (seen in green). Changes in poultry and livestock production have contributed to the emergence of avian influenza as a global public health concern (see Box 1.1).

1. *Why do ecosystems matter to human health?*

1.1 Introduction

In a fundamental sense, ecosystems are the planet's life-support systems - for the human species and all other forms of life (see Figure 1.1). The needs of the human organism for food, water, clean air, shelter and relative climatic constancy are basic and unalterable. That is, ecosystems are essential to human well-being and especially to human health – defined by the World Health Organization as a state of complete physical, mental and social well-being. Those who live in materially comfortable, urban environments commonly take for granted ecosystem services to health. They assume that good health derives from prudent consumer choices and behaviours, with access to good health care services. But this ignores the role of the natural environment: of the array of ecosystems that allow people to enjoy good health, social organization, economic activity, a built environment and life itself.

Historically, overexploitation of ecosystem services has led to the collapse of some societies (SG3). There is an observable tendency for powerful and wealthy societies eventually to overexploit, damage and even destroy their natural environmental support base. The agricultural-based civilizations of Mesopotamia, the Indus Valley, the Mayans, and (on a micro-scale) Easter Island all provide well-documented examples. Industrial societies, although in many cases more distant from the source of the ecosystem services on which they depend, may reach similar limits.

Resource consumption in one location can lead to degradation of ecosystem services and associated health effects in other parts of the world (SG3). At its most fundamental level of analysis, the pressure on ecosystems can be conceptualized as a function of population, technology and lifestyle. In turn, these factors depend on many social and cultural elements. For example, fertilizer use in agricultural production increasingly is dependent on resources extracted from other regions and has led to eutrophication of rivers, lakes and coastal ecosystems.

Notwithstanding ecosystems' fundamental role as determinants of human health, sociocultural factors play a similarly important role. These include infrastructural assets; income and wealth distribution; technologies used; and level of knowledge. In many industrialized countries, changes in these social factors over the last few centuries have both enhanced some ecosystem services (through more productive agriculture, for instance) and improved health services and education, contributing to increases in life expectancy. The complex multifactorial causation of states of health and disease complicates the attribution of human health impacts to ecosystem changes. A precautionary approach to ecosystem management is appropriate.

In many respects human health is a bottom-line (or integrating) component of well-being, since changes in economic, social, political, residential, psychological and behavioural circumstances all have health consequences. Basic determinants of human well-being may be defined in terms of: security; an adequate supply of basic materials for livelihood (e.g. food, shelter, clothing, energy, etc.); personal freedoms; good social relations; and physical health. By influencing patterns of livelihoods, income, local migration and political conflict, ecosystem services impact the determinants of human well-being. The ways in which health status may both reflect and influence human well-being are illustrated in Figure 1.2.

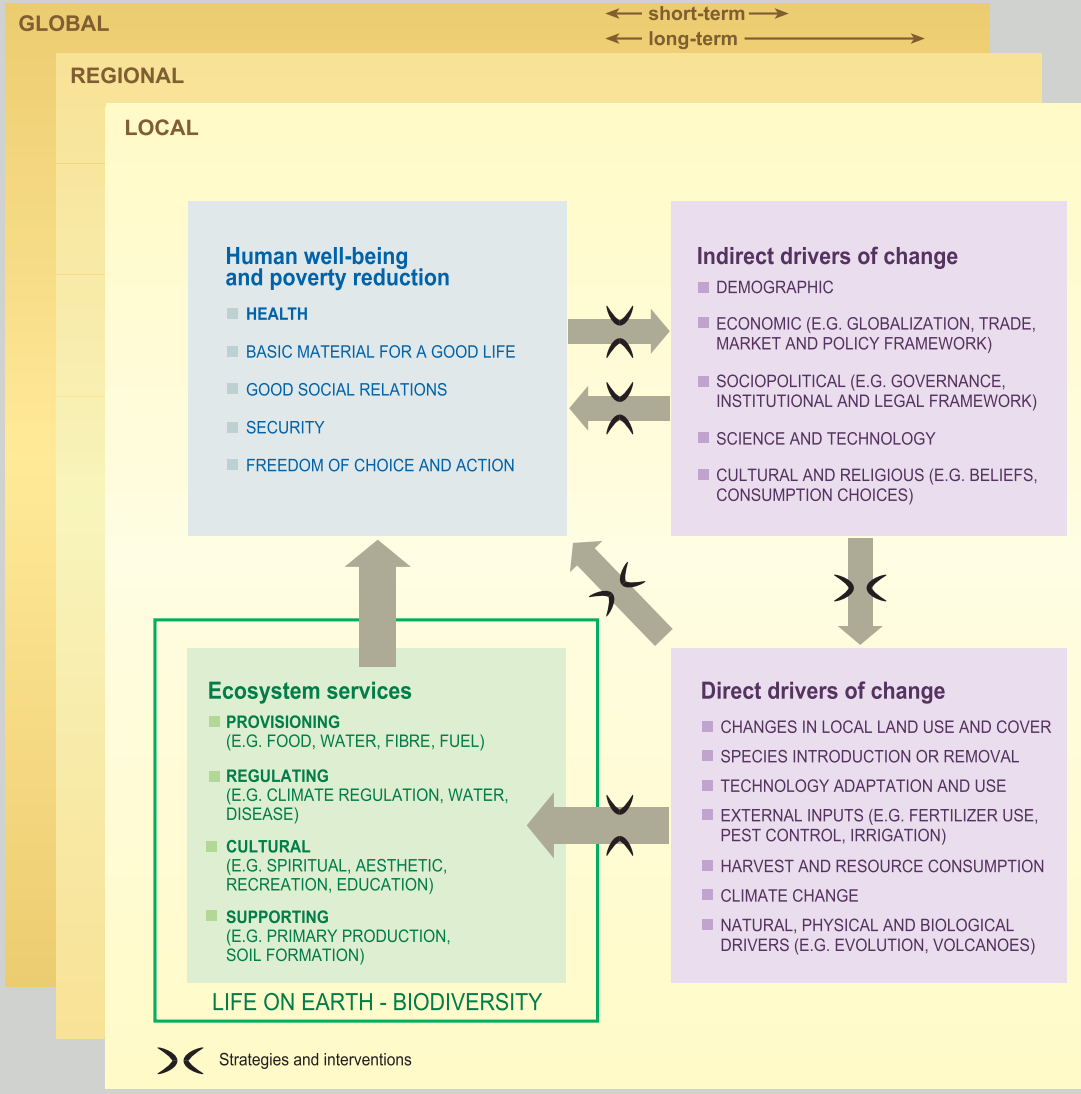
1.2 Current state of ecosystems and associated human health status

Ecosystem services are indispensable to the well-being of people throughout the world (SG3). The benefits obtained from ecosystems include: food; natural fibres; a steady supply of clean water; regulation of some pests and diseases; medicinal substances; recreation; and protection from natural hazards such as storms and floods. The MA categorizes ecosystem services as follows: provisioning services, regulating services, supporting services and cultural services – each of which has several sub-categories (see Figure 1.3). The state of the environment and ecosystems are modified by patterns of demographic growth, development and consumption, all of which may reduce or increase (if only temporarily) the supply of ecosystem services.

The causal links between environmental change and human health are complex because often they are indirect, displaced in space and time and dependent on a number of modifying forces. For example, climate changes can place stresses on agricultural production or the integrity of coral reefs and coastal fisheries. This can

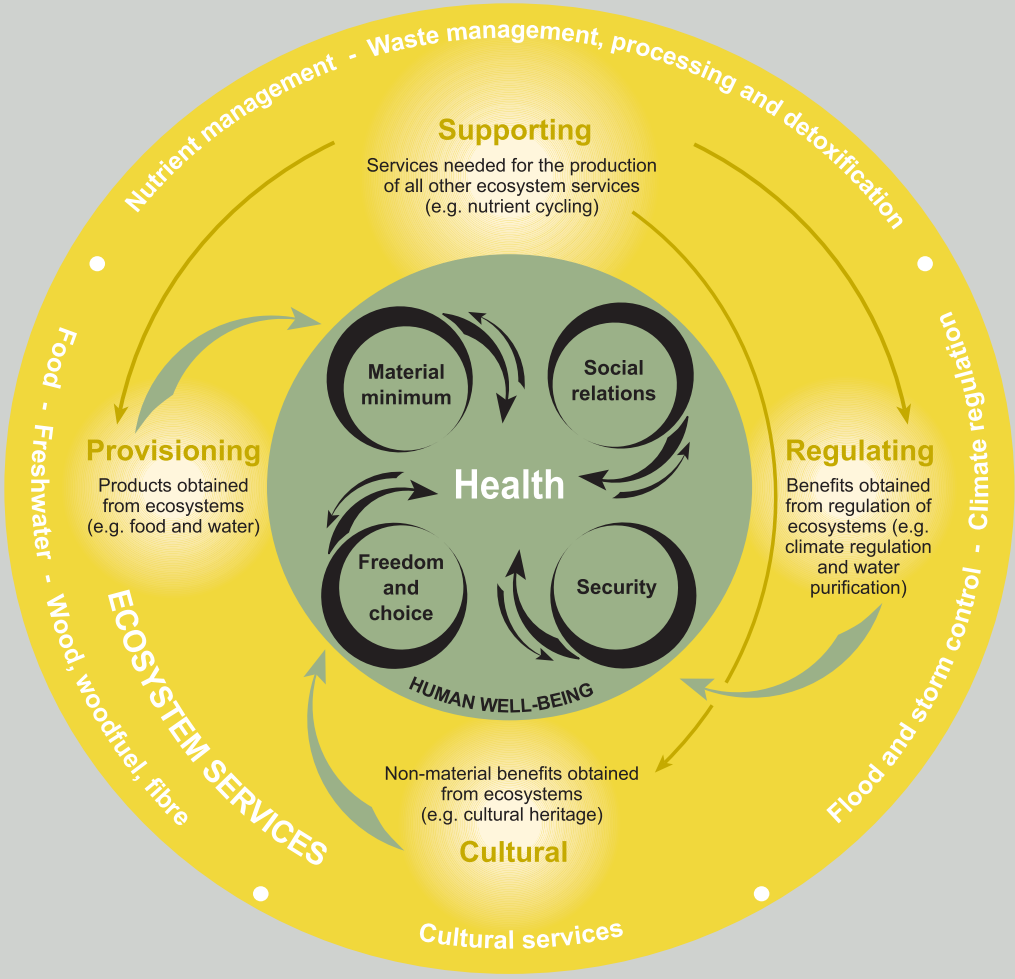
lead to malnutrition and related ailments. Deforestation may alter disease patterns as well as local and regional climates, potentially affecting disease vector distributions over time. Processes stemming from disruption of ecosystems may lead to the emergence or resurgence of disease, while local factors such as poverty, poor prevention and treatment and heightened susceptibility may lead to local establishment of transmission. When these events combine with human activities related to globalization (such as international trade and travel) global pandemics can arise, as illustrated already by the development and spread of HIV/AIDS and, potentially, by the appearance in human populations of other new infectious disease strains, e.g. avian influenza.

Figure 1.1 MA: CONCEPTUAL FRAMEWORK



Changes in drivers that indirectly affect ecosystems, such as population, technology and lifestyle (upper right corner of Figure 1.1) can lead to changes in drivers that directly affect ecosystems, such as fisheries' catches or fertilizer applications to increase food production (lower right corner). The resulting changes in the ecosystem (lower left corner) cause ecosystem services to change and thereby affect human well-being. These interactions can take place at more than one scale and can cross scales. For example, a global timber market may lead to regional loss of forest cover, increasing flood magnitude along a local stretch of river. Similarly, interactions can take place across different timescales. Actions to respond to negative changes or to enhance positive changes can be taken at almost all points in this framework (cross bars).

Figure 1.2 Associations between health, other aspects of human well-being and ecosystem services (R 16 Figure 16.1)



The MA identifies five main aspects of human well-being. This diagram makes health the central aspect. Human health is affected directly and indirectly by changes in ecosystems but also is affected by changes to other aspects of well-being. Lack of aspects of human well-being (i.e. material minimum, good social relations, security, freedom and choice) all can have health impacts. Health also can influence these other aspects of human well-being.

1.2.1 *Fresh water*

Over 1 billion people lack access to safe water supplies; 2.6 billion people lack adequate sanitation. This has led to widespread microbial contamination of drinking-water (see Figure 1.4). Water-associated infectious diseases claim 3.2 million lives each year, approximately 6% of all deaths globally. The burden of disease from inadequate water, sanitation and hygiene totals 1.7 million deaths and the loss of more than 54 million healthy life years. Investments in safe drinking-water and improved sanitation show a close correspondence with improvements in human health and economic productivity. Every day each person requires 20-50 litres of water free of harmful chemical and microbial contaminants for drinking, cooking and hygiene. There remain substantial challenges to providing this basic service to large segments of the human population (C7).

Fresh water is a key resource for human health. It is used for growing food, drinking, washing, cooking and the dilution and recycling of wastes. Globally, the amount of fresh water available per person decreased from 16 800 m^3 in 1950 to 6800 m^3 in 2000, as a result of population growth.

Figure 1.3 CATEGORIES OF ECOSYSTEM SERVICE

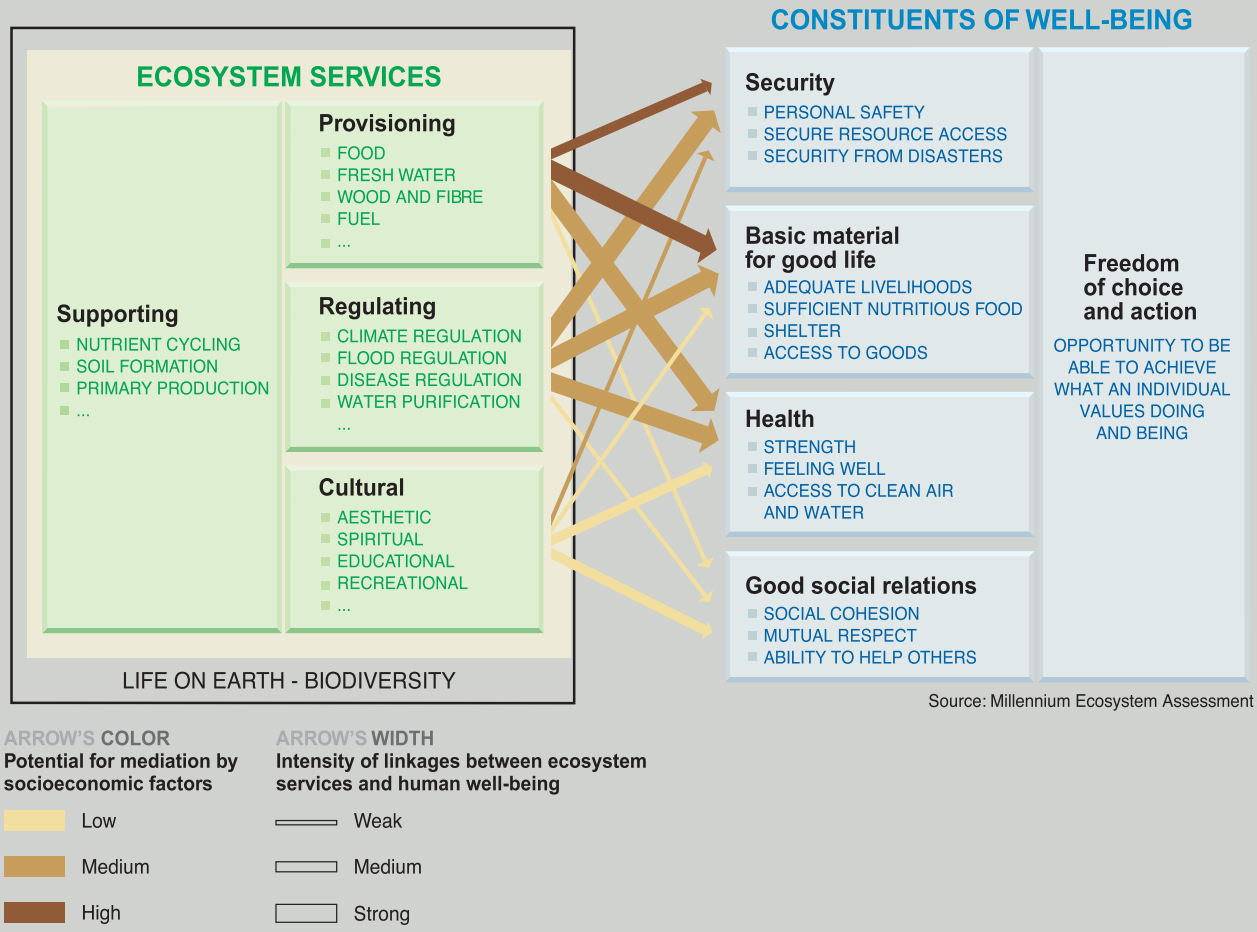


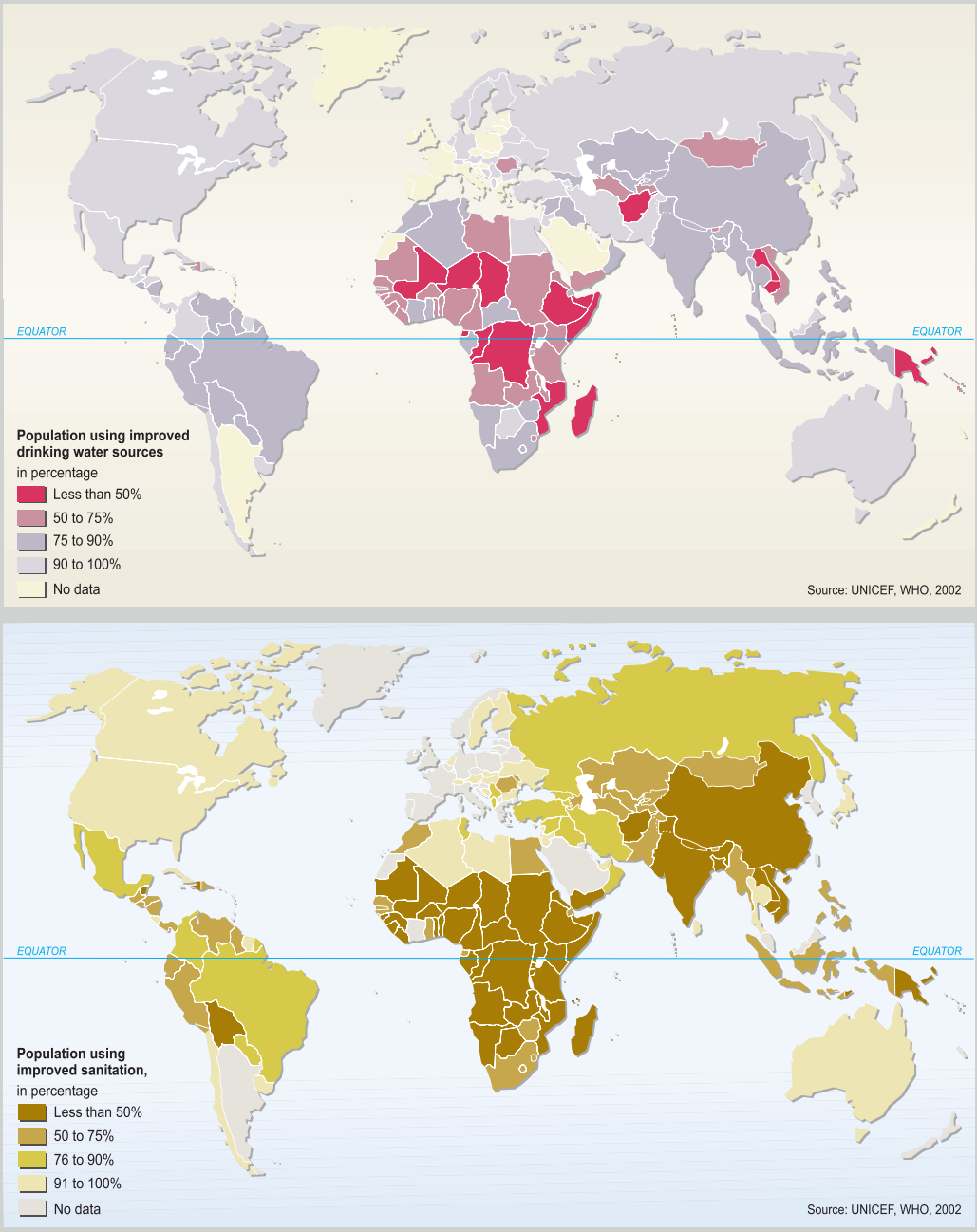
Figure 1.3 depicts the strength of linkages between commonly-encountered categories of ecosystem services and components of human well-being, and includes indications of the extent to which it is possible for socioeconomic factors to mediate the linkage. For example, the ability to purchase a substitute for a degraded ecosystem service offers a high potential for mediation. The strength of the linkages and the potential for mediation differ in different ecosystems and regions. In addition to the influence of ecosystem services on human well-being depicted here, other factors influence human well-being including other environmental factors as well as economic, social, technological and cultural factors. In turn ecosystems are affected by changes in human well-being.

One third of the world lives in countries experiencing moderate to high water stress, a fraction that is increasing as population and per capita water demand grow.

Water scarcity is a globally significant and accelerating condition for 1-2 billion people worldwide, leading to problems with food production, human health and economic development. A high degree of uncertainty surrounds these estimates and they merit substantial further analysis in order to support sound water policy formulation and management. Rates of increase in a key water scarcity measure (water use relative to accessible supply) from 1960 to the present averaged nearly 20% per decade globally, with values of 15% to more than 30% per decade for individual continents (C7).

The supply of fresh water safe for human use and consumption has been reduced further by severe pollution from anthropogenic sources. Over the past half-century there has been an accelerated release of artificial chemicals into the environment, many of which

Figure 1.4 Access to improved water and sanitation facilities globally



The top map shows the percentage of population using improved drinking-water sources. The lower map shows the percentage of population using improved sanitation. In regions of the world where a significant proportion of the population has no access to improved sanitation, the natural water filtration and purification services provided by ecosystems may be quickly overwhelmed by improperly disposed human waste. If this service is not replaced by a reliable engineered filtration system or water supply, the result is likely to be high levels of diarrhoea and other water-borne diseases Altogether, unsafe water, sanitation and hygiene were estimated to be responsible for approximately 1.7 million deaths in the year 2000.

are long-lived and transformed into by-products whose behaviours, synergies and impacts are not well-known. Inorganic nitrogen pollution of inland waterways, for example, has more than doubled globally since 1960 and increased by a factor of over 10 for many industrialized parts of the world. Pollution impairs the ability of ecosystems to provide clean and reliable sources of water. Deterioration of fresh water quality is magnified in cultivated and urban systems (high use, high pollution sources) and in dryland systems (high demand for flow regulation, absence of dilution potential) (C7).

From 5% to possibly 25% of global fresh water use exceeds long-term accessible supplies and is now met either through engineered water transfers or overdraft of groundwater supplies *(low to medium certainty).* Much of this water is used for irrigation, with irretrievable losses in water-scarce regions. All continents record such withdrawals. In the relatively dry region of North Africa and the Middle East up to 30% of all water use is unsustainable (C7).

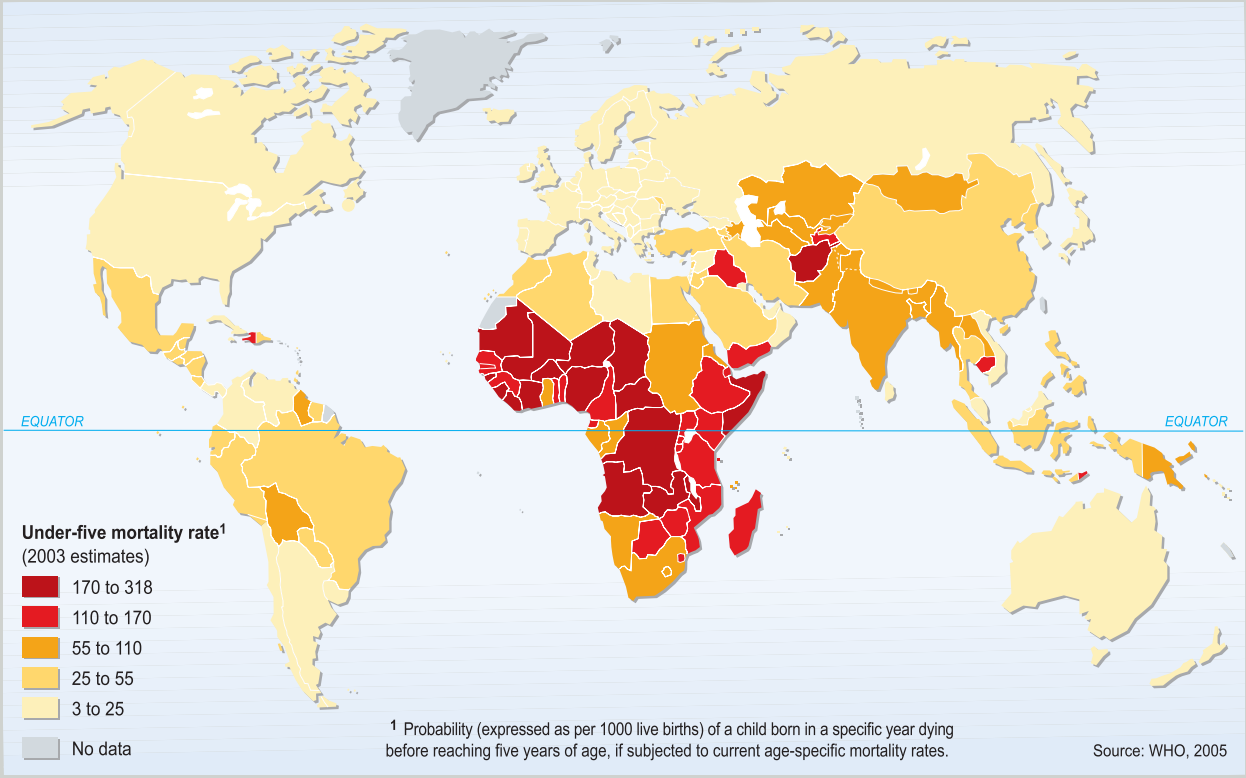
The effects of climate change on water resources are difficult to forecast because of the many factors that influence rainfall, runoff and evapotranspiration (R16). Temperature increases may worsen water quality by increasing the growth of microorganisms and decreasing dissolved oxygen. Water-related disasters, such as droughts and floods, also have important health impacts. The frequency of heavy rainfall events is likely to increase, leading to an increase in flood magnitude and frequency. Heavy rainfall tends to affect water quality adversely by increasing the quantities of chemical and biological pollutants that are suddenly flushed into rivers and by overloading sewers and waste storage facilities. In some parts of the world, climate change also may raise requirements for irrigation water because of increased evaporation. Climate change will affect the distribution and length of transmission seasons for vector-borne diseases.

1.2.2 *Food*

For maximum well-being, people must have access to and consume not only sufficient calories but also a diverse diet with sufficient protein, oils and fats, micronutrients and other dietary factors (C8). Average daily energy intake has declined recently in the poorest countries. Inadequate energy intake is exacerbated by the generally low-quality diets of poor people. The world's poorest populations generally rely on starchy staples for energy, leading to significant protein, vitamin and mineral deficiencies. Nutritional status and children's growth rates improve with consumption of greater food diversity, particularly of fruits and vegetables.

A global epidemic of diet-related obesity and noncommunicable disease is emerging as increasingly urbanized populations adopt diets that are higher in energy and lower in diversity of fruits and vegetables than those consumed traditionally (C8). Many poor countries now face a double burden of diet-related disease: the simultaneous challenges of significant incidence of communicable diseases in poor and undernourished communities and an increasing incidence of chronic diseases associated with the overweight and obese, especially in richer and less physically active subsections of the populations, often in urban areas. The pathway from traditional rural diets to those of increasingly urban and affluent societies and the attendant implications for nutrition and health has been dubbed the nutrition transition or the diet transition.

Figure 1.5 Map of child mortality



The poorest countries have the highest rates of child deaths, particularly from environmental hazards.

In poor countries, especially in rural areas, people's health is highly dependent on the services of local productive ecosystems for food (R16). Aggregate food production currently is sufficient to meet the needs of all, yet of the present world population of over 6 billion, over 800 million consume insufficient protein or calories to meet daily minimum requirements. Similar numbers are overfed, often with diets that are high in energy but lacking in diversity. Several billion people experience micronutrient deficiency. In richer urban communities, human dependence on ecosystems for nourishment is less apparent but no less fundamental.

The nutritional imbalance between rich and poor has been driven primarily by social factors, though ecological factors may play an increasingly important role in the future (R16). Undernutrition is related strongly to poverty; in the poorest countries with the highest mortality rates, between one-sixth and one-quarter of the burden of disease is related to childhood and maternal undernutrition (see Figure 1.5). Worldwide, undernutrition accounts for nearly 10% of the burden of disease. In developed countries with low mortality rates, diet-related risks (mainly overnutrition, in combination with physical inactivity) account for between one-tenth and one-third of the burden of disease, mainly through conditions such as hypertension, coronary heart disease and diabetes. Population health considerations have important implications for agricultural policy.

Local food production is critical for eliminating hunger and promoting rural development in areas where the poor do not have the capacity to purchase food from elsewhere (C8). In regions such as sub-Saharan Africa, two thirds of the population relies on agriculture or agriculture-related activities for their livelihood. At the same time, the number of food-insecure people is growing fastest in poor countries where underdeveloped market infrastructures and low per capita income prevent food needs from being satisfied through globalized chains of food production and

Box 1.1 Pigs, poultry and people

Many important human diseases (including influenza, tuberculosis and measles) are zoonoses that long ago became established within human populations after crossing from domesticated animal species including chickens, cattle and dogs (C14). Modern, intensive farming practices in association with trade, travel and ecological change, are implicated in the emergence of diseases including BSE, foot-and-mouth disease and Nipah virus. Probably the zoonosis of greatest contemporary concern for public health is avian influenza, which has been reported recently in Asia. This virus has the capacity to swap or reassort genes with coinfecting/coexistent influenza viruses circulating in human populations, and among wild birds or domesticated ducks and pigs, leading to new, highly virulent strains. The size and crowding of flocks found in many poultry farms - an ecosystem which could never exist in nature - creates many reservoirs of potential infection. Despite vaccination and the periodic culling of infected flocks, this risk of human infection is almost impossible to eradicate, given current poultry production patterns and the close cohabitation of pigs, poultry and people in poor rural areas.

In recent years, outbreaks of Nipah virus have been reported in Malaysia, Singapore, Bangladesh and India. In the Malaysian outbreak, which killed more than 100 people, the causal web included an expanding human population, poor governance, climate change, illegal land clearing, forest fires and intensive animal husbandry. The path of contagion has been traced back to migrations of bats from Indonesia to neighbouring Malaysia, beginning around 1998. This followed an intense El Niño dry spell, which coincided with the illegal burning by farmers of large sections of Indonesian forest, particularly in the Sumatra and Kalimantan regions, in 1997 and 1998, to clear land for plantations. The intense smoke and haze, which persisted for months, forced the migration of flocks of bats, infected with a previously unknown virus, to neighbouring Malaysia. Here they came into contact with intensively-farmed pigs. The pigs developed a respiratory illness, transmitted directly to other pigs and humans. Many pigs were culled in order to limit the spread of the virus. No human-to-human transmission was proven. More recently, an outbreak of Nipah virus occurred in Bangladesh. The causal pathway there is less well-investigated and understood, but may involve direct human exposure to bat droppings.

An epidemic of Japanese encephalitis in Sri Lanka has been attributed, in part, to the promotion of smallholder pig husbandry in an attempt to generate supplementary income among rice farmers in an irrigated ecosystem that increased the habitat for vectors. Diseases affecting flocks and herds also can impose a high human cost, both economic and psychological, upon animal husbandry workers who depend on the infected animals for their livelihoods. This is the case especially when animals are uninsured or when large numbers of animals are culled.

supply. In these areas, local food production is critical for eliminating hunger and providing insurance against rising food prices. When household food surpluses are marketed locally, such production may be a generator of employment and economic benefits. Subsistence agriculture thus can provide a nutritional baseline and social safety net for rural families – alongside income-oriented agricultural production (cash crops) – and enhance health.

The accelerating demand for livestock products increasingly is being met by intensive (industrial or landless) production systems, particularly for chickens and pigs, and especially in Asia (C8). These highly modified systems have contributed to large increases in production but pose a range of risks to ecosystems and human health. These include the generation of high levels of waste, increased pressure on cultivated systems to provide feed inputs with consequent increased demand for water and nitrogen fertilizer, as well as the risk of outbreaks of infectious disease such as BSE, SARS and avian flu (see Box 1.1).

In poor countries (excluding China), per capita fish consumption declined between 1985 and 1997 (C18). Pressure on marine ecosystems is increasing to the point where wild fisheries are near or exceeding their maximum sustainable levels of exploitation. World fish catches have

been declining since the early 1990s due to overexploitation. Inland water fisheries, which are particularly important in providing high-quality diets for poor people, also have declined due to habitat modification and water abstraction.

Wild foods are locally important in many developing countries, often bridging the hunger gap created by stresses such as droughts and civil unrest (C8). In addition to fish, wild plants and animals are important sources of nutrition in some diets and have significant value, although this is not captured by conventional economic measures. The capacity of ecosystems to provide wild food sources generally is declining, as natural habitats worldwide are under increasing pressure, and as wild plant and animal populations are exploited for food at unsustainable levels. Agricultural intensification and the 'simplification', e.g. increased uniformity and decreased biodiversity, of agricultural landscapes, can limit the availability of, and access to, wild foods and food plants growing as weeds. These may be of nutritional importance, especially to landless poor people and vulnerable groups within households. Similarly the decline of traditional fisheries (due to commercial exploitation of coastal fisheries and damage to inland water ecosystems due to water extraction and diversion) can have severe negative nutritional and health consequences in poor countries.

1.2.3 *Timber, fibre and fuel*

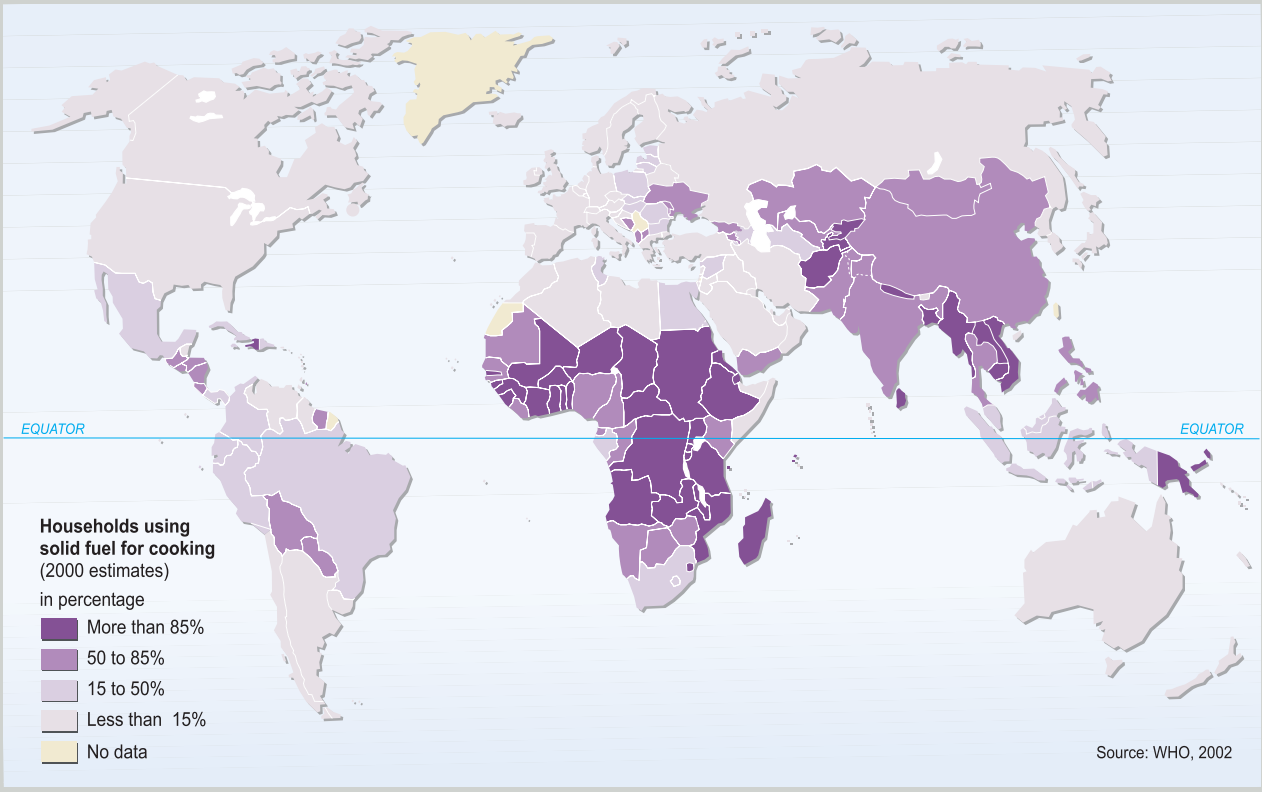
Timber exploitation has contributed to ecosystem degradation and associated health effects in many regions of the developing world (C9). Demand for timber has led to widespread deforestation in tropical rainforests. This is associated with high rates of occupational injuries and exposure to infectious diseases, such as malaria, among workers and families in the Amazon rainforest. Over the longer term, deforestation can lead to transmission cycles of vector-borne diseases transferring from the forest to the domestic environment, increasing disease burdens for women and children particularly.

Power generation has a range of health impacts (R16). Outdoor air pollution is caused predominantly by the combustion of non-renewable fossil fuels for electricity generation, transport and industry. Globally, urban air pollution is responsible for significant mortality and morbidity every year, largely as a result of heart and lung diseases. The accompanying release of a major greenhouse gas (CO_2) and its consequent contribution to global warming have further, mostly adverse, impacts on human health. Air pollution due to forest fires and burning practices in agriculture also can have serious local and regional health consequences. This was highlighted by the public health experiences in south-east Asia in 1998, following widespread drought-associated forest fires in Sumatra and Kalimantan, Indonesia (see Box 1.1). Indoor air pollution from the combustion of solid fuels, including biomass (e.g. wood, crop stubble, and animal dung) and coal, in poorly ventilated heating and cooking environments, is responsible for significant respiratory disease and deaths globally, particularly among children. Over half of the world's population relies upon solid fuels for cooking and heating (see Figure 1.6). In areas where the demand for wood has surpassed local supply and alternative energy sources are either unavailable or too expensive, the shortage of biomass fuel can lead to a variety of other health impacts, including: increased vulnerability to illness from exposure to cold, and increased vulnerability to food and water-borne diseases from improper heating of food and water. Increased incidence of food- and water-borne diseases can, in turn, contribute to malnutrition. Poor women and children in rural communities often are the most affected by fuelwood scarcity. Many must walk long distances searching for and carrying firewood (often water too) and therefore have less time and energy for tending crops, cooking meals or attending school. For these reasons, adequate energy supplies are fundamental to sustainable development.

1.2.4 *Biological products*

Millions of people around the world depend partly or fully on products collected from ecosystems for medicinal purposes (R16). Even when synthetic medicines (often originating from natural sources) are available, the need and demand for wild products persists. Some of the better-known pharmaceuticals from natural sources include aspirin, digitalis and quinine.

Figure 1.6 Percentage of households using solid fuel for cooking



Most of the world's population uses solid fuels, including both biomass and coal, to meet their basic energy needs, often cooking and heating upon open fires or rudimentary stoves. The resulting indoor smoke is responsible for significant morbidity and mortality from respiratory disease.

1.2.5 *Nutrient and waste management, processing and detoxification*

Humans are at risk from inorganic chemical compounds and persistent organic pollutants present in food and water (C7, R16). Contamination can infiltrate from natural sources (as in the case of arsenic contamination of water in tube wells in Bangladesh) and from human actions resulting in the release of toxic chemicals into the environment (for example, through pesticide use). Toxic chemicals can cause a variety of adverse health effects. Low-level exposure to some chemicals present in industrial effluent or used as pesticides, such as PCBs, dioxins and DDT, may cause endocrine disruption, undermining disease resistance and reproduction. They are also responsible for more acute health impacts, including poisonings.

The presence of pharmaceutical products or residues in the environment is a related emerging environmental issue. Pharmaceutical residues may be released through sewage and solid waste disposal and removed only partially by conventional biological treatment. As a result, they can be detected in sewage treatment plant effluents and in receiving waters, posing health risks that have not yet been quantified.

Nutrient depletion, e.g. as a result of inadequate soil conservation practices, can impair soil fertility resulting in lower crop yields, which in turn may negatively affect the nutritional status of farm households. Dietary deficiencies (in terms of both macro- and micro-nutrients) have been demonstrated to harm children's physical and mental growth. The economic and livelihood impacts on farmers may also impinge on their ability to secure adequate education and health services for themselves and their children, limiting their future options.

While ecosystems provide effective mechanisms for cleansing the environment of wastes, this service is now overtaxed in many settings, leading to local and sometimes global waste accumulation (C15). Well-functioning ecosystems absorb and remove contaminants; for example, wetlands can remove excess nutrients from sewage runoff, preventing damage to ecosystems downstream. If excessive wastes are discharged into ecosystems, waste treatment technologies are required to restore or preserve ecosystem balance, and thus reduce or eliminate the risks to human health. When recycled appropriately, human waste can be a useful resource that promotes soil fertility. However, where waste contains persistent chemicals such as organochlorines or heavy metals, recycling can lead to the accumulation of these pollutants and increased human exposures through food and water. In poor countries, nearly all sewage and most industrial wastes are dumped untreated into surface water. It is uncertain whether the waste detoxification capabilities of the planet as a whole are increasing, decreasing, or reaching a critical threshold at which such services may no longer function effectively.

Sustained increases in nitrogen and phosphorus loading of ecosystems due to land-based human activities are contributing to the deterioration of water quality over many of the globe's inhabited regions (C7). Fertilizer use is the major contributor to this problem. Excessive fertilizer runoff into lakes and streams can upset the balance of nutrients in lakes and rivers, facilitating the growth of certain algal plants, including some that are toxic to humans. Eutrophication, the process whereby excessive plant growth depletes oxygen in the water, can negatively impact other forms of aquatic life, e.g. fish, and thus food sources, creating risks to human health and well-being.

1.2.6 *Regulation of infectious disease*

The magnitude and direction of altered infectious disease incidence due to ecosystem changes depend on the characteristics of the particular ecosystems; type of land-use change; disease-specific transmission dynamics; and the susceptibility of human populations (C14). Infectious disease risks are affected particularly by destruction of, or encroachment into, wildlife habitat, particularly through logging and road building; changes in the distribution and availability of surface waters, such as through dam construction; irrigation and stream diversion; and agricultural land-use changes, including proliferation of both livestock and crops.

The reasons for the emergence or re-emergence of some diseases are unknown, but the main biological mechanisms that have altered the incidence of many infectious diseases are clear: altered habitat features leading to changes in the number of vector breeding sites or reservoir host distribution; niche invasions of new species or interspecies host transfers; changes in biodiversity, including loss of predator species and changes in host population density; human-induced genetic changes of disease vectors or pathogens (such as mosquito resistance to pesticides or emergence of antibiotic-resistant bacteria); and environmental contamination by infectious disease agents (C14). Numerous disease/ecosystem relationships illustrate these biological mechanisms.

Box 1.2 Can biodiversity regulate infectious diseases?

Many other infectious diseases have been, or are potentially, transmissible to humans from wild animals, either directly or via insect vectors. Others are transmitted between humans by vectors, e.g. malaria. Close contact with bushmeat is believed to have led to the first transmission of HIV to humans. SARS may have entered the human population via wild species, also raised domestically, and consumed as food in China. It is clear that ecosystem change, including changed biodiversity, influences the risk of transmission of many diseases to humans (C14). For example, the increased transmission of Lyme disease in recent years partly is due to increased rodent populations, the most important reservoir of the causative organism of this tick-borne disease. Other zoonotic diseases affecting humans include West Nile virus and Hendra virus.

Many ecosystem changes can alter the habitats, and hence populations, of disease-transmitting vectors. Such changes may include: forest clearance; construction of dams, or irrigation and canal networks; and deliberate or inadvertent water collection (e.g. in debris). However, the transmission of major infectious vector-borne diseases such as malaria and yellow fever can never be described as entirely ecosystem-dependent, but rather as a function of human interactions and ecosystem services. Along with improved management of ecosystem services, other actions (e.g. public education, medical and chemical interventions, and poverty alleviation), all play a role in reducing, and in some cases eliminating, disease transmission.

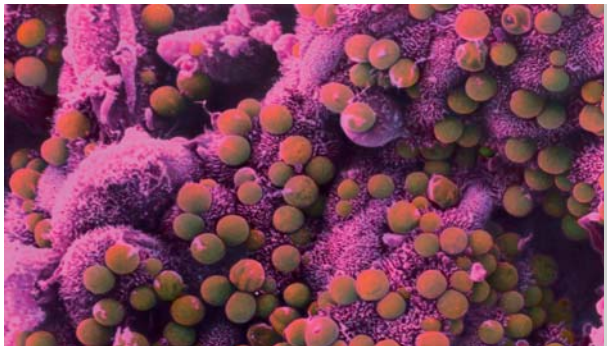
Box 1.3 Infectious diseases related to ecosystem disturbance

Disturbance or degradation of ecosystems can have biological effects that are highly relevant to infectious disease transmission (C14). The reasons for the emergence or re-emergence of some diseases are unknown, but the following mechanisms have been proposed:

- altered habitat leading to changes in the number of vector breeding sites or reservoir host distribution;
- niche invasions or transfer of interspecies hosts;
- biodiversity change (including loss of predator species and changes in host population density);
- human-induced genetic changes in disease vectors or pathogens (such as mosquito resistance to pesticides or the emergence of antibiotic-resistant bacteria); and
- environmental contamination by infectious disease agents (such as faecal contamination of source waters).

- Dams and irrigation canals provide ideal habitats for snails that serve as the intermediate reservoir host species for schistosomiasis. Irrigated rice fields increase the extent of mosquito breeding areas, leading to greater transmission of mosquito-borne malaria, lymphatic filariasis, Japanese encephalitis, and Rift Valley fever.
- Deforestation alters malaria risk, depending on the region of the world. Deforestation has increased the risk of malaria in Africa and South America, but the effect in south-east Asia is very uncertain.
- Natural systems with intact structures and characteristics generally resist the introduction of invasive human and animal pathogens brought by human migration and settlement. This seems to be the case for cholera, kala-azar and schistosomiasis, which have not become established in the Amazonian forest ecosystem.
- Uncontrolled urbanization of forest areas has been associated with mosquito-borne viruses (arboviruses) in the Amazon and lymphatic filariasis in Africa. Tropical urban areas with poor water supply systems and lack of shelter promote transmission of dengue fever.
- Zoonotic pathogens, e.g. pathogens completing their natural life-cycle in animal hosts, are a significant cause of both historical diseases (such as HIV and tuberculosis) and newly emerging infectious diseases affecting humans (such as SARS, West Nile virus and Hendra virus) (see Box 1.2.)
- Intensive livestock management practices that include routine, sub-therapeutic use of antibiotics have contributed to the emergence of antibiotic-resistant strains of *Salmonella, Campylobacter* and *Escherichia coli* bacteria. Overcrowding of livestock and the mixing of livestock breeds that may occur in intensive meat production, as well as trade in wild, undomesticated animals (bushmeat), can facilitate interspecies host transfer of disease agents. This, in turn can lead to the emergence of dangerous novel human pathogens such as SARS and new strains of influenza (see Box 1.3).

Major trade-offs may exist between infectious disease risk and certain kinds of development projects geared towards increasing food production, power generation capacity, and economic growth (C14). The infectious diseases of major public health importance that require special attention due to ecosystem changes, but also have the greatest potential for risk reduction by planned interventions include: malaria, across most ecological systems; dengue fever in tropical urban centres; schistosomiasis and filariasis in cultivated and inland water systems in the tropics; leishmaniasis in forest and dryland systems; cholera in coastal and urban systems; cryptosporidiosis in agricultural systems; Japanese encephalitis in agricultural systems; and West Nile virus and Lyme disease in urban/suburban systems of Europe and North America (see Table 1.1).



Cryptosporidium parvum

Coloured scanning electron micrograph (SEM) of the surface of the small intestine infected with Cryptosporidium parvum *parasites (red), cause of cryptosporidiosis. The parasite develops in the protrusions (microvilli) of epithelial cells that line the intestinal wall. Severe infection causes the folds of the intestinal wall to fuse and atrophy. Infection typically produces mild symptoms of diarrhoea, fever and headache. However, in the immuno-compromised, such as those with AIDS (acquired immune deficiency syndrome), infection can be fatal.*

Moredum Scientific LTD/Science Photo, Library

Table 1.1 Infectious diseases and mechanisms of potential changing incidence as related to ecosystem changes - some examples (C14)

Disease	DALYs[a] *(thousand)*	(Proximate) Emergence mechanism	(Ultimate) Emergence driver	Geographical distribution	Sensitivity to ecological change	Confidence level
Malaria	46 486	niche invasion, vector expansion	deforestation, water projects	tropical (America, Asia and Africa)	+ + + +	+ + +
Dengue fever	616	vector expansion	urbanization, poor housing	tropical	+ + +	+ +
HIV	84 458	host transfer	forest encroachment, bushmeat hunting, human behaviour	global	+	+ +
Leishmaniasis	2090	host transfer, habitat alteration	deforestation, agricultural development	tropical Americas, Europe and Middle East	+ + + +	+ + +
Lyme disease		depletion of predators, biodiversity loss, reservoir expansion	habitat fragmentation	North America Europe	+ +	+ +
Chagas disease	667	habitat alteration	deforestation, urban sprawl and encroachment	Americas	+ +	+ + +
Japanese encephalitis	709	vector expansion	irrigated rice fields	south-east Asia	+ + +	+ + +
West Nile virus and other encephalitides				Americas, Eurasia	+ +	+
Guanarito, Junin and Machupo viruses		biodiversity loss, reservoir expansion	monoculture in agriculture after deforestation	South America	+ +	+ + +
Oropouche / Mayaro viruses in Brazil		vector expansion	forest encroachment, urbanization	South America	+ + +	+ + +
Hantavirus		variations in population density of natural food sources	climate variability		+ +	+ +
Rabies		biodiversity loss, altered host selection	deforestation and mining	tropical	+ +	+ +
Schistosomiasis	1702	intermediate host expansion	dam building, irrigation	America, Africa, Asia	+ + + +	+ + + +
Leptospirosis				global (tropical)	+ +	+ + +
Cholera	[b]	sea surface temperature rising	climate variability and change	global (tropical)	++ +	+ +
Cryptosporidiosis	[b]	contamination by oocytes	poor watershed management where livestock exist	global	+ + +	+ + + +
Meningitis	6192	dust storms	desertification	Saharan Africa	+ +	+ +
Coccidioidomycosis		disturbing soils	climate variability	global	+ +	+ + +
Lymphatic filariasis	5777			tropical America and Africa	+	+ + +
Trypanosomiasis	1525			Africa		
Onchocerciasis	484			Africa, tropical America	+ +	+ + +
Rift Valley fever		heavy rains	climate variability and change	Africa		
Nipah/Hendra viruses		niche invasion	industrial food production, deforestation, climate abnormalities	Australia, south-east Asia	+ + +	+

[a] Disability-adjusted life years. [b] Both cholera and cryptosporidiosis contribute to the loss of nearly 62 million DALY's annually from diarrhoeal diseases.
Key: + = low; + + = moderate; + + + = high; + + + + = very high.

1.2.7 *Cultural, spiritual and recreational services*

Cultural services provided by ecosystems may be less tangible than material services. Nonetheless such services are highly valued by all societies (R16). People obtain diverse non-material benefits from ecosystems, including recreational opportunities and tourism, aesthetic appreciation, inspiration, a sense of place and education. Traditional practices linked to ecosystem services play an important role in developing social capital and enhancing social well-being.

There is a hypothesis that stimulating contact with the rich and varied environment of ecosystems, including gardens, may benefit physical and mental health. There is limited evidence that this may help in the prevention and treatment of depression, drug addiction and behavioural disturbances as well as convalescence from illness or surgery. Regular contact with pets seems to prolong and enhance the quality of life, especially in old age. Beneficial contact with nature need not be physical and tactile. For example, there is some evidence that certain benefits may be obtained from visual or visualized contact.

1.2.8 *Climate regulation*

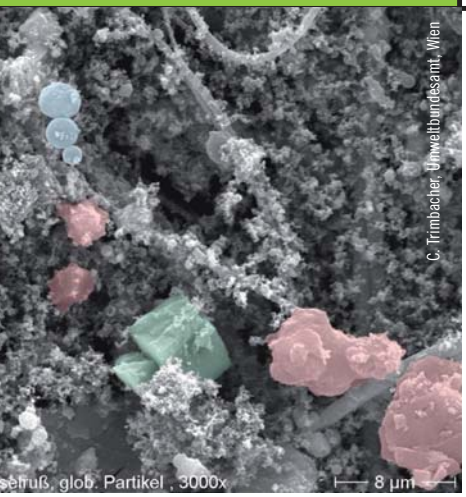
Each of the ecological services described above is sensitive to climate and will be affected by anthropogenic climate change (R16). Although climate change will have some beneficial effects on human health, most are expected to be negative. Direct effects, such as increased mortality from heatwaves, are most readily predicted but indirect effects are likely to predominate. Human health is likely to be affected indirectly by climate-induced changes in the distribution of productive ecosystems and the availability of food, water and energy supplies. In turn, these changes will affect the distribution of infectious diseases, nutritional status and patterns of human settlement. Changes in the geographical distribution, abundance and behaviour of plants and animals affect, and are affected by, biodiversity, nutrient cycling and waste processing.

Extreme weather events (including floods, storms and droughts) and sea-level rise are expected to increase as a result of climate change (R16). These have local and sometimes regional effects: directly through deaths and injuries; indirectly through economic disruption, infrastructure damage and population displacement. Changes in land cover affect flood frequency and magnitude, but the degree and extent of this impact is highly dependent on the characteristics of the local ecosystem and the nature of the land cover change. Health effects of climate extremes include: physical injuries; increases in communicable diseases resulting from crowding; lack of safe water and shelter; poor nutritional status; and adverse effects on mental health.

Globally, the annual absolute number of people killed, injured or made homeless by natural disasters is increasing (R16). An important reason for this is the growth of human settlements in coastal zones and on floodplains that are particularly exposed to extreme events. Case studies have shown that environmental degradation has reduced the capacity of certain ecosystems to serve as a buffer against climate extremes. For example, degraded or damaged coral reefs and mangroves may lose their capacity to stabilize coastlines and limit the damaging effect of storm surges. Landslides may be more likely to occur on deforested slopes following heavy rainfall. In many areas, the only land available to poor households and communities may also be highly vulnerable to impacts from weather extremes.

In recent decades, most regions of the world experienced significant human migration from rural areas to cities. More than half of the world's population now lives in high-density urban areas, many of which are poorly supplied with either ecosystem or human services. Such migration and increasing vulnerability means that even without growing numbers of extreme events, losses attributable to each event will tend to increase. There is particular concern for the sustainability of the livelihoods of the inhabitants of small island states. These locales provide an example of populations experiencing increasing climate variability, sea-level rise and loss of biodiversity, with associated impacts on health and well-being.

Natural ecosystems play an important role in regulating climate, mainly by acting as sinks for greenhouse gases (C13). Ecosystems, both natural and managed, exert a strong influence on climate and air quality as sources and sinks of pollutants, greenhouse gases and suspended dust (aerosols), due to physical properties that affect the flows of energy and rainfall. Ecosystems can affect climate in numerous ways: in terms of warming, as sources of greenhouse gases; and in terms of cooling, as sinks of greenhouse gases. Climatic heating and cooling mechanisms also are influenced by albedo, or

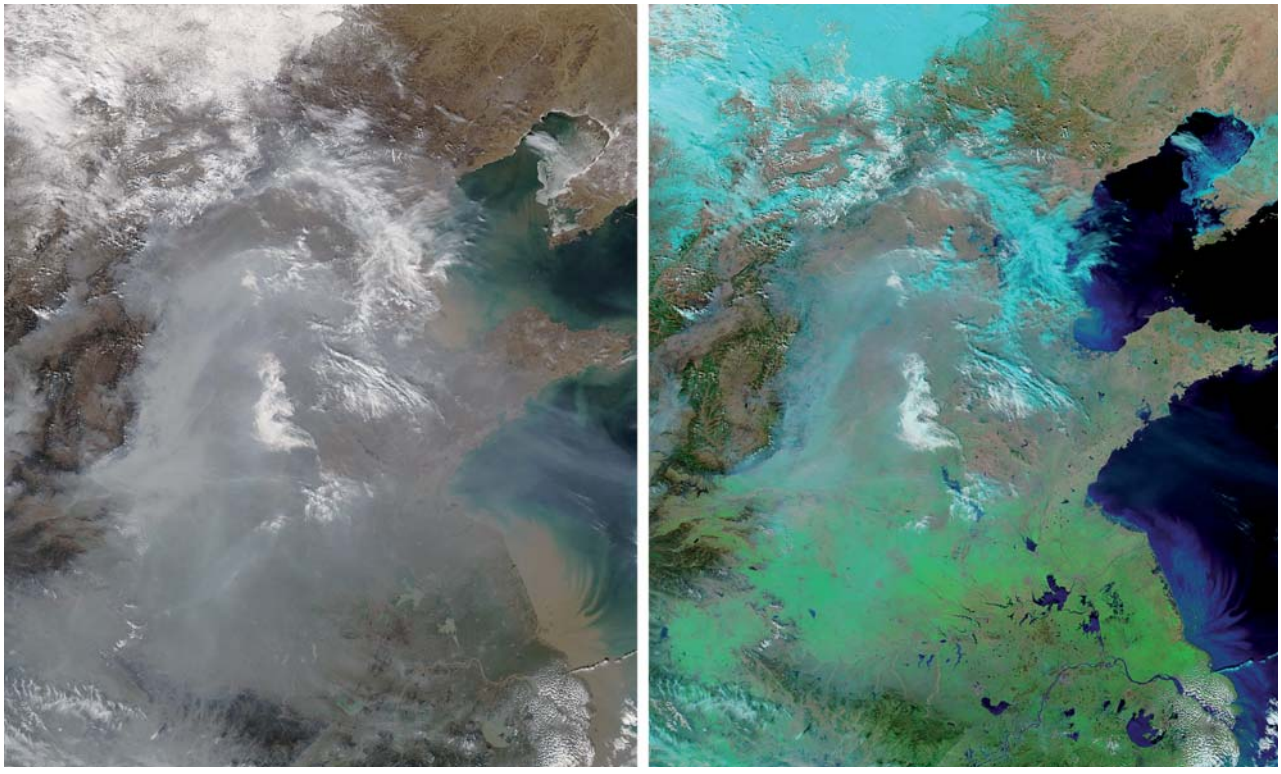


Electron micrograph of particulate matter sampled on a filter near a street; diesel soot (small grey spheres) dominates the sample. Salts and minerals are in blue and pinkish crystalline forms.

ecosystem reflectivity to solar radiation, e.g. forests absorb heat energy, and thus have lower albedo than snow, which reflects solar radiation. Natural aerosols (e.g. dust) also reflect solar radiation. Ecosystems affect climate through patterns of evapotranspiration and cloud formation, water redistribution/recycling, and regional rainfall. Ecosystems affect air quality through interactions with atmospheric cleansing processes (e.g. as sinks for air pollutants and sources of pollution such as particulates from biomass combustion); and through nutrient redistribution (e.g. fertilizing effects of nitrogen deposition, carbon dioxide and dust).

Health risks from climate change are expected to increase (C13, R16). Human activities are responsible for an annual emission of an estimated 7.9 billion tonnes of carbon dioxide to the atmosphere. Reforestation and changes in agricultural practices in temperate regions in the past few decades have enhanced global capacity to absorb this carbon, but not sufficiently to halt climate change. Reducing anthropogenic carbon emissions is critical to the mitigation of climate change. Enhancing or maintaining the capacity of ecosystems to absorb carbon is similarly important.

Ecosystem management has the potential to modify concentrations of a number of greenhouse gases, although this potential is likely to be small in comparison to the potential growth in fossil fuel emissions over the next century, as predicted in scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) *[high certainty]* (C13). In their active growth phase, forests are the terrestrial ecosystems most effective in capturing carbon dioxide, the greenhouse gas responsible for the most significant share of global warming impacts. However, such forests must be maintained intact in order to serve as effective sinks. In general, when a forest is cleared it is replaced by land uses that capture and contain less than half of the carbon that was stored by the forest.



MODIS Rapid Response Team, NASA-Goddard Space Flight Center/NASA Earth Observatory

Air pollution does not affect health alone; it can reduce farm productivity by shielding crops from sunlight. The image to the left, similar to a digital photograph, shows a natural-colour view of thick haze over the agricultural regions north of the Yangtze River in eastern China, 28 February 2005. The image to the right uses short-wave and near-infrared observations to reveal the green winter crops, mostly wheat and rice (close to the Yangtze River), underneath the haze. Water is deep blue or brighter blue when sediment levels are high.

2. *How have ecosystems changed and what are the health implications?*

The structure and functioning of the world's ecosystems changed more rapidly in the second half of the twentieth century than over any comparable period in human history. Humans are fundamentally, and to a significant extent irreversibly, changing the diversity of life on Earth and most of these changes represent a loss of biodiversity. Most changes to ecosystems have been made to meet a dramatic growth in the demand for food, water, timber, fibre and fuel.

- More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850 (C26). Cultivated systems - areas where at least 30% of the landscape is in croplands, shifting cultivation, confined livestock production or freshwater aquaculture - now cover one quarter of Earth's terrestrial surface.
- Roughly 20% of the world's coral reefs were lost and an additional 20% degraded in the last several decades of the twentieth century (C19).
- The amount of water impounded behind dams has quadrupled since 1960; reservoirs now hold three to six times as much water as natural rivers. Water withdrawals from rivers and lakes have doubled since 1960. Most water use (70% worldwide) is for agriculture.
- Since 1960, flows of reactive (biologically available) nitrogen in terrestrial ecosystems have doubled and flows of phosphorus have tripled.
- Since 1750, the atmospheric concentration of carbon dioxide has increased by about 32% (from about 280 ppm to 376 ppm in 2003).

In the aggregate, and for most countries, changes made to the world's ecosystems in recent decades have provided substantial benefits (C5). Many of the most significant changes to ecosystems have been essential to meet growing needs for food and water. These have helped to reduce the proportion of malnourished people and improve human health. However, these gains have been achieved at growing costs in the form of the degradation of many ecosystem services; increased risks of large, non-linear changes in ecosystems; exacerbation of poverty for some; and growing inequities and disparities across groups of people.

Human well-being is affected by changes in the composition, functioning and flow of ecosystem services. Management of an ecosystem to achieve a particular goal (such as food, timber production or flood control) generally results in changes to other ecosystem services. These changes are not always taken into account in planning, but they sometimes have significant impacts on human health.

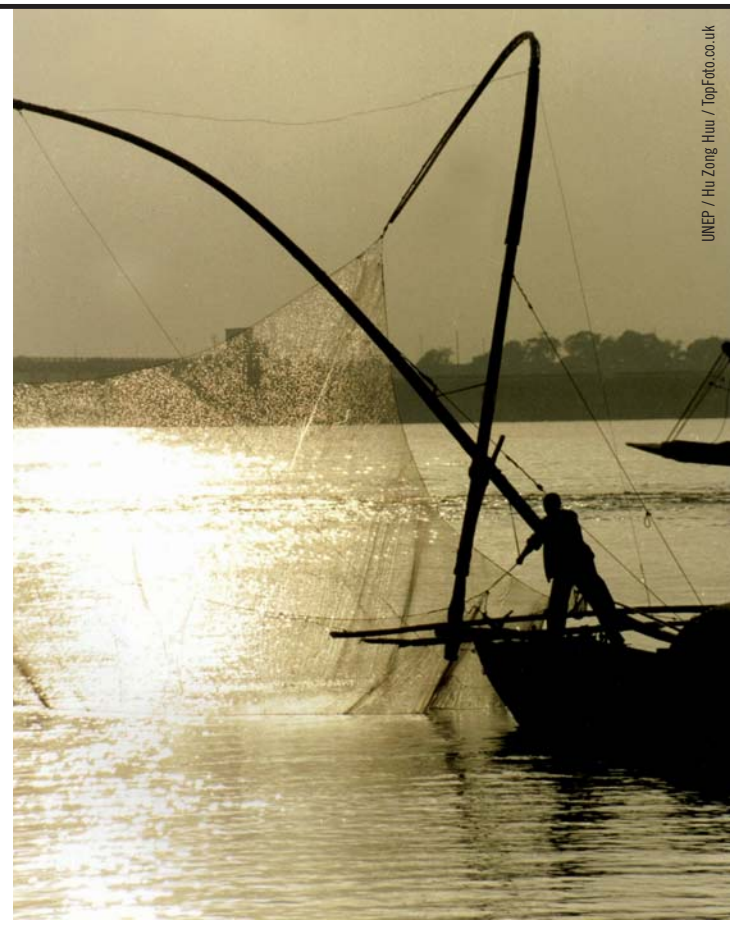
Poor populations are more vulnerable to adverse health effects from both local and global environmental changes. Richer populations exert disproportionate pressure on global ecosystems but are less vulnerable (R16). At present, major inequalities exist in access to ecosystem services. The status, or state, of these services is interlinked strongly with other components and determinants of poverty such as income, health and security. At the local level, poverty and the lack of access to clean, sustainable and efficient means for extracting ecosystem services can lead to local environmental degradation, with associated health risks. Also, poorer populations often live in environments that are more prone to infectious and other diseases, and have fewer resources for prevention and treatment. Richer populations have reduced health vulnerability to ecosystem degradation, partly because they are able to import resources from, and displace health risks to, other locations.

Many of the people and places affected adversely by ecosystem changes and declining ecosystem services are highly vulnerable and ill-equipped to cope with further losses (C6). Human alterations of ecosystems and their services shape the threats to which people and places are exposed and their vulnerability to those

threats. The same alterations of environment can have very different consequences, with reference to the differential vulnerability of the dependent social and ecological systems. For example, disease emergence and re-emergence due to altered ecosystems can occur in both rich and poor countries, and on any continent. Nonetheless, people in the tropics are more likely to be affected in the future due to their greater exposure to such diseases and the greater scarcity of resources to cope with such ecosystem alterations and disease outbreaks in such regions (R16). Highly vulnerable groups include those whose needs for ecosystem services already exceed the supply, such as people lacking adequate safe water supplies or living in areas with declining agricultural production (including a number of regions in Africa).

Vulnerability has increased as a result of the growth of populations in living ecosystems that are at greater risk from extreme weather or natural disasters, e.g. populations in low-lying coastal areas at risk of flooding, and populations in dryland ecosystems at risk of drought. Partly as a result of this, the number of natural disaster victims requiring international assistance has quadrupled over the past four decades. Finally, vulnerability is increased if either social or ecological resilience is diminished, e.g. through the loss of drought-resistant crop varieties; loss of farming expertise; or loss of institutional capacity to provide environmental management and health services that help protect local populations.

Historically, poor people disproportionately have lost access to ecosystem services as demand from wealthier populations has grown (C6, R19). Coastal habitats that primarily supported the food and livelihood needs of local populations often are converted to intensive aquaculture ponds or sites where species such as shrimp and salmon are cultured primarily for export markets. While some coastal residents may gain employment and income from these enterprises, others may lose access to cheap protein or alternative sources of livelihoods. Many areas where overfishing is a concern also are low-income, food-deficit countries. For example, many west-African countries support large distant water fleets that catch significant quantities of fish. Most of these fish are exported or shipped directly to Europe, yielding little direct benefit to the nutritional needs of local populations.



UNEP / Hu Zong Huu / TopFoto.co.uk

In poor countries (excluding China), per capita fish consumption declined between 1985 and 1997 (C18). In some areas fish prices for consumers have increased faster than the cost of living. Fish products are traded heavily (approximately 50% of fish exports are from poor countries) and exports from poor countries and the southern hemisphere presently offset much of the shortfall in European, North American and east-Asian markets.

The regions facing the greatest challenges in achieving the MDGs also tend to be the regions facing the most serious problems in the ecologically sustainable supply of ecosystem services (R19.ES). Many of these regions include large areas of drylands, in which a combination of demographic growth and land degradation is increasing human vulnerability to both economic and environmental change. In the last 20 years, these regions have experienced some of the highest rates of forest and land degradation in the world.

Over 1 billion people survive on incomes of less than US$ 1 per day, mostly in rural areas where they are highly dependent on agriculture, grazing and hunting for subsistence (R19). Although the wealthy are relatively well-buffered from changes in some ecosystem services, their mismanagement or overuse of those same services directly threatens the survival of poor people. Ecosystem conditions have a relatively direct and clear influence on human well-being in poor countries, as shown by the strong relationship between well-being indicators such as the infant mortality rate and ecosystem type in regions such as sub-Saharan Africa and Asia. In contrast, in high-income societies, for instance OECD countries, there is relatively little difference in infant mortality rates across populations living in a wide range of ecosystems (C6).

Diminished human well-being tends to increase immediate dependence on ecosystem services, and the resultant additional pressure can damage further the capacity of ecosystems to deliver essential services (SG2). As human well-being declines, there is a corresponding decline in the options available for people to regulate their use of natural resources at sustainable levels. This increases pressure on ecosystem services and can create a downward spiral of increasing poverty and further degradation of these services.

Within and between countries, poverty is a consistent underlying determinant of undernutrition and of diseases caused by lack of access to safe water, improved sanitation and other public services (R16). Over 90% of the world's undernourished population lives in poor countries (C8). South Asia and sub-Saharan Africa, the regions with the largest numbers of undernourished people, also are the regions where per capita food production has lagged the most.

Poverty and hunger have tended to force rural people onto marginal drought-prone lands with poor soil fertility; others have been forced to move to urban slums (R16). About 1 billion people are affected by land degradation caused by soil erosion, waterlogging or increased salinity of irrigated land. Erosion has caused a substantial reduction in crop yields in Africa.

In Africa, Asia and Latin America, 25–50% of the population lives in informal or illegal settlements around urban centres with few or no public services and no effective regulation of pollution or ecosystem degradation (C7). In many countries, local or regional authorities provide water and sanitation services only if proof of landownership is provided. Other problems exist in the provision of water and sanitation services to urban slums and peri-urban settlements. These include: the distance of such settlements from existing water and sewage networks; the cost of developing necessary infrastructure; rapid growth of such settlements, their irregular development; and the limited ability of many households to pay connection charges or monthly fees – unless the service is subsidized by the state.

Rapid, uncontrolled urban growth in Africa, Latin America and Asia has contributed to ecosystem degradation and increased pollution, with consequent health impacts.

3. *How might ecosystems change and what would be the health implications?*

There is a dynamic interaction, growing rapidly in scale, between people and ecosystems. Although understanding of these issues is expanding, the near to mid-term future of these linked elements is permeated by complexity, uncertainty, surprise and contest.
Against this range of variables, scenarios are nonetheless a tool useful in exploring an otherwise impenetrable future.

The MA developed four scenarios to explore plausible future changes in drivers, ecosystems, ecosystem services and human well-being: (i) *Global Orchestration:* globally-driven development patterns, with an emphasis on economic growth, social responsibility and access to public goods; (ii) *Order from Strength:* regionalized development orientation, with emphasis on national security and economic growth; (iii) *Adapting Mosaic:* regionalized development orientation, with an emphasis on local adaptation and flexible governance; and (iv) *TechnoGarden:* globally driven development patterns, emphasizing scientific innovations and green technologies (see Box 3.1 for a general description of scenarios). These scenarios were not designed to explore the entire range of possible futures for ecosystem services; other scenarios could be developed that would have more optimistic or more pessimistic outcomes for ecosystems, their services and human well-being.

The scenarios were developed using both quantitative models and qualitative analysis. For some drivers (such as land-use change and carbon emissions) and some ecosystem services (such as water withdrawals and food production), quantitative projections were calculated using established, peer-reviewed global models. Other drivers were estimated qualitatively. For example, estimations were made for economic growth and rates of technological change, changes in the supply of ecosystem services (particularly supporting and cultural services such as soil formation and recreational opportunities) and for rates changes in human well-being indicators, such as human health and social relations. In general, the quantitative models used for these scenarios addressed incremental changes but failed to address thresholds, risk of extreme events or impacts of large, extremely costly or irreversible changes in ecosystem services. These phenomena were addressed qualitatively by considering the risks and impacts of large but unpredictable ecosystem changes in each scenario.

The MA used these scenarios to explore the complexity and richness of the contested future. Limitations, uncertainties and flaws in the data and assumptions, together with interactions between these different inputs, mean that the precise modelling of the health impacts of changes in drivers are likely to remain elusive for many years. Nonetheless, the MA scenarios aim to use the best available evidence today to assess future changes in

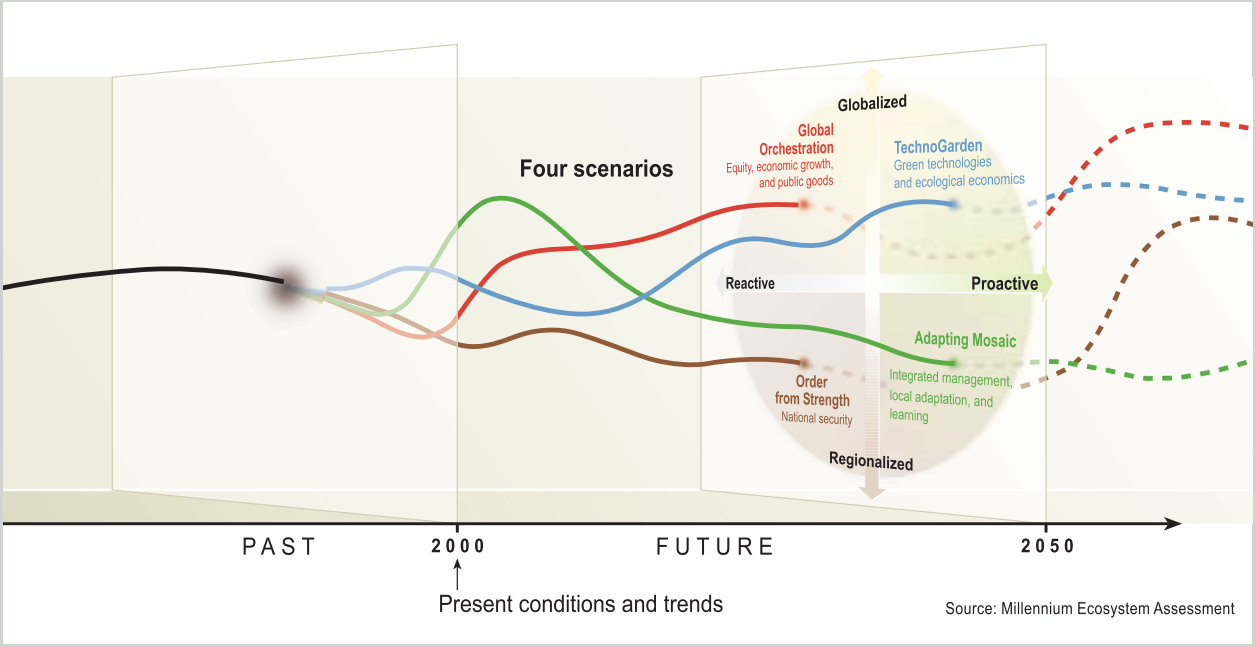
Box 3.1 Scenario exercises

Scenarios are plausible, challenging and relevant stories about how the future might unfold that can be told in both words and numbers (S2). They are not forecasts, projections or predictions and usually are not assigned probabilities, including those within the MA. Scenarios attempt to envision future pathways, including critical uncertainties and thresholds. They also try to provoke questions, widen perspectives and illuminate key issues, thereby supporting more informed and rational decision-making.
Previous global scenario exercises have focused on social, economic and some environmental drivers but largely have omitted important aspects of ecology and health. The MA scenarios, developed by an iterative process over several years, explicitly have included ecological change in both the quantitative models and the storylines (S3). In addition, they have enabled a first-order attempt to assess future health.
Scenarios are based on a coherent and internally consistent set of assumptions about key driving forces and relationships. They are constrained within "riverbeds" of likelihood. Many principles act to constrain plausible futures. These include the laws of physics, the principles of economics, demographic inertia and plausible rates of technological and social evolution and adaptation.

ecosystem services and their relationships to human well-being, including human health (see Box 3.2).

There has been limited inclusion of health variables in past global scenario exercises. Modelling techniques to forecast future population health status remain in the early stages of development. However, the models used by the MA provide estimates for some key indicators of human health, including global population and the per capita regional availability of water and food production. Many other aspects relevant to future health are restricted to qualitative assessments.

Box 3.2 Health dimensions of the four MA scenarios



Millennium Ecosystem Assessment Scenarios

The MA developed four scenarios to explore plausible futures for ecosystems and human well-being. The scenarios explored two global development paths (globalized versus regionalized societies and economies) and two different approaches for ecosystem management (reactive and proactive). In reactive management, problems are addressed only after they become obvious, whereas proactive management attempts to maintain ecosystem services for the long term. These scenarios were selected to explore contrasting transitions of global society up to the year 2050.

- Globalized world with reactive ecosystem management; an emphasis on equity, economic growth, and public goods such as infrastructure and education (also called *Global Orchestration*);
- Regionalized world with reactive ecosystem management; an emphasis on security and economic growth (also called *Order from Strength*);
- Regionalized world with proactive ecosystem management; an emphasis on local adaptations and learning (also called *Adapting Mosaic*); and
- Globalized world with proactive ecosystem management; and an emphasis on green technologies (also called *TechnoGarden*).

The MA scenarios were developed with a focus on conditions in 2050, although they include some information to the end of the century.

Global Orchestration

This scenario depicts a globally connected society in which policy reforms that focus on global trade and economic liberalization are used to reshape economies and governance. There is an emphasis on the creation of markets that allow equitable participation and provide equitable access to goods and services. These policies, in combination with large investments in global public health and the improvement of education worldwide, generally succeed in promoting economic expansion and lifting many people out of poverty into an expanding global middle class. Supranational institutions in this globalized scenario are well-placed to deal with global environmental problems such as climate change and fisheries' decline.

Continues on page 32

However, there is a reactive approach to ecosystem management. People generally are confident that ecological problems can be overcome by improved policies and technological advances. Nonetheless, underestimation of environmental problems increases the risk of ecological and social surprises, including emerging infectious diseases and widespread conflict.
Health improves substantially, especially in developing countries. Income increases in industrial and developing countries too. Food production per person improves and the percentage of undernourished children is reduced from its current level of over 30% to 20%. The absolute number of malnourished children declines also. Total population growth is lowest in this scenario and the burden of diseases such as HIV/AIDS, malaria, tuberculosis and depression is reduced as poor populations gradually improve their living standards, benefit from better, more inclusive governance and see that their children have greater opportunities. Improved vaccine development and distribution allows populations in this scenario to cope with the next influenza pandemic. The impact of other new diseases, such as SARS, is limited by public health measures including vaccines. Global health organizations are better funded and regional health capacity improves, including for primary health care, laboratories and hospitals. Regional shortfalls in food harvests should be managed adequately by effective food relief programmes.

On the negative side, increased nutritional availability combined with an emphasis on a market-based approach to public health is likely to raise the prevalence of obesity and type II diabetes everywhere. The complications, particularly from diabetes occurring at an earlier age of onset and a possible increase in cancer, are likely to result in a heavy burden on health services.

Adverse ecological surprises, such as runaway climate change, may be of sufficient magnitude to have serious adverse health consequences including severe damage to infrastructure and economic conditions. Many environmental conditions needed for good public health could worsen. For example, microbiological water pollution in developing countries could become an even more important source of ill-health than at present. Environmental contamination with persistent pollutants and heavy metals could increase and cause unexpectedly severe harm to health. The scenario is vulnerable to institutional failure, resulting in an increased inequality of the distribution of the greater resources predicted in this scenario.

Order from Strength
This scenario represents a regionalized and fragmented world that is concerned with security and protection, and where regional markets are emphasized. Governments, businesses and citizens focus inwardly in response to perceived threats, including those from global terrorism. There is a progressive breakdown of global cooperation, and increased compartmentalization or fragmentation of economic, social and security arrangements. Scientific and cultural exchange declines. Countries and policy-makers act upon their own short-term interests, viewing that strategy as the best defence against economic insecurity and other forms of instability. Generally the environment is seen as of secondary importance to security and other challenges. Also there is a belief in the ability of humans to rely upon technological innovations to resolve environmental challenges they face, or yet to emerge. The industrial world regards certain regions of the developing world as unimportant or too chaotic for prolonged and serious social, economic and policy investment.

This scenario has the lowest investment in human capital. Poor countries face major obstacles in improving the health status of their citizens. Institutions critical to good governance remain particularly weak, exacerbating health gaps. Social and political institutions are overwhelmed by powerful lobby groups with narrow interests, particularly the promotion of security for privileged minorities.

The death or migration of knowledge-rich adults further weakens the human capital assets of developing countries. Inequality increases within and between developing and industrialized countries. In some regions the scarcity of ecosystem services reaches critical levels, generating poverty traps and violent conflict.

Infant and maternal mortality rates remain high in developing countries, as does the morbidity from obstructed labour including infections, epilepsy and fistulas. Prevention and cure of important diseases is neglected. Undernutrition increases regionally, exacerbating cognitive maldevelopment and epidemics. International efforts to tackle diseases of poverty weaken. Poverty and population pressures in certain regions force increased contact between humans and nonagricultural ecosystems to obtain bushmeat and other forest goods, leading to more outbreaks of haemorrhagic fever and zoonoses.

New and resurgent diseases become common in developing countries. Few, if any, penetrate to industrialized countries, indeed some aspects of health improve. While the modelling results predict substantial global population increase in this scenario over the next 50 years, this is highly questionable, illustrating a case where the constraints and assumptions built into the models lead to implausibility.

This scenario is more likely than others to experience only a modest increase in total


FAO/18851/L. Balderi

population; social, political and economic instability in many regions contributes to temporary and fluctuating population declines and increases. It is also possible, though of low probability, that a more chronic disease could cross from a non-domesticated animal species into humans. As with HIV, this could colonize human populations slowly and then more rapidly, including those in industrialized countries. The higher emphasis on security in this scenario causes a high opportunity cost to health research. The higher risk of terrorism increases anxiety for people with larger incomes.

TechnoGarden
Technology and market-oriented institutional reform are used to achieve solutions to environmental problems in this scenario. Ecological engineering substitutes for, and repairs, many ecosystem services, decoupling

improved human well-being from ecosystem service loss. These changes co-develop with the expansion of property rights to ecosystem services, such as requiring people to pay for pollution they create or paying people for providing key ecosystem services through actions such as preservation of key watersheds. Interest in maintaining, and even increasing, the economic value of these property rights, combined with an interest in learning and information, leads to a flowering of ecological engineering approaches for managing ecosystem services.

Technological improvements in the development of alternative energy sources facilitate greater availability of energy at relatively low prices. Cost-effective seawater desalinization makes possible the broader irrigation of deserts that currently are sparsely populated and higher crop yields, improving food production capacity. Global nutrition improves substantially, driving virtuous cycles of consequent social and

economic improvements, especially among poor tropical populations. Medical breakthroughs extend life expectancy and improve the quality of the later years of life. Technological, surgical, genetic, pharmacological, nutraceutical and other scientific advances increase human carrying-capacity on a global scale. Heat-stable, single-dose oral vaccines that confer lifetime immunity to multiple diseases are developed. Water pollution and indoor air pollution are eliminated almost entirely. Societies could use new technologies for greater expression, strengthening social, family and human capital.

This utopian scenario could unravel, however, if institutional improvements fail to match the pace of technological advance. In that event, public health could be undermined in many regions and many forms of inequality could increase, even in a scenario yielding an absolute increase in the production of ecosystem services. Virtual reality could be misused to pacify and condition people in ways that reduce freedom. Devastating engineered diseases could be released accidentally or deliberately. Cheap robots could reduce danger, drudgery and servitude but also increase unemployment and human exploitation. Family and social ties could loosen if children bond to virtual nurses rather than flesh-and-blood playmates. Audiences desensitized by excessive diets of virtual violence and pornography could challenge civil society norms if whetted appetites demand ever-increasing doses.

Increased calorie-dense food could exacerbate the global epidemic of obesity and diabetes. Technology could narrow dietary diversity, including of micronutrients. Excessively sedentary lifestyles in childhood could reduce the use of large muscles leading to poorly developed gross motor coordination. In later life, increasingly sedentary behaviour could exacerbate health conditions associated with physical inactivity, thus cancelling out other medical advances improving the health of the elderly. Designer drugs could prove more dangerous and addictive than promised. Discrimination based on genetic profiles for employment and insurance could become routine. Diseases targeting specific genetic characteristics could be engineered for ethnic cleansing or other forms of genocide. New diseases could also arise or be more widely disseminated by new technologies, as occurred with several infectious diseases in the twentieth century.

Adapting Mosaic

In this scenario there is a strong emphasis on learning about socioecological systems through adaptive management. This focus is linked with balancing human, manufactured and natural capital. Confidence in the ability of humans to better manage socioecological systems is balanced by humility and an active preparation for ecological surprises. Political and economic power devolves to regions, with great regional variation, and 'learning while managing' is widely acclaimed as an approach to good governance, management and problem-solving.

However, eventually the focus on local governance leads to failures in managing the global commons. Problems such as climate change, marine fisheries' collapse and pollution worsen, leading to increased global environmental surprises. Slowly communities realize that addressing certain issues requires an approach to management on a broader scale. This evolves through the development of community networks focused on ecological units rather than existing political borders that do not necessarily match ecosystem boundaries.

This scenario is thus characterized by greater regional pride and more cultural and social diversity. Mental health improves, including that of minority populations, reducing alcoholism, domestic violence, depression and intravenous drug use. Knowledge and practice of traditional health systems is preserved better in this scenario. The revival of traditional health systems could assist the commercialization of new pharmaceuticals.

Food supplies per capita decline, especially in sub-Saharan Africa and south Asia, but this is partly compensated for by a more equal distribution. Globally, the number (but not percentage) of calorie-malnourished children is predicted to increase by about 6% by the year 2020, but then fall.

On the negative side, the global capacity to provide emergency relief for disasters such as famine, epidemics or earthquakes, is likely to decline. This is important because many regions are unlikely to develop sufficient critical masses of expertise or economies of scale to foster the new technologies needed to maintain high living standards. This could lead to regional setbacks and new poverty traps.

A dearth of global leadership could delay or undermine the establishment of effective global environmental treaties. Climate change and other large-scale environmental problems therefore may be comparatively severe in this scenario, exacerbating their long-term adverse health effects. The degree to which ideas, technology and capital circulate internationally is crucial to health improvement. Without the transfer of regional and global expertise, areas that are disadvantaged now are likely not only to persist but also may become more disadvantaged.

3.1 Critical drivers and other factors affecting future changes to health

The MA defines a driver as any natural or human-induced factor that indirectly or directly causes a change in an ecosystem (S7). A direct driver is one that unequivocally influences ecosystem processes. Important direct drivers include changes in climate, plant nutrient use, land-use management and change, diseases and invasive species. An indirect driver operates diffusely, by altering one or more direct drivers. Examples of indirect drivers include demographic, economic, sociopolitical, scientific, technological, cultural, lifestyle and religious factors.

Growing populations and growing economies are associated with higher consumption and increased pressure on ecosystems (SWG). The degree of pressure depends on human and ecosystem factors. Human factors include: demographics, technology, behaviour, policy and culture. But pressure also depends critically on the resilience of the ecosystem in question. In some cases, conservation measures may reduce the human pressure on ecosystems considered to be nearing a critical threshold. In other cases, a small incremental increase in pressure may result in an unexpected, non-linear adverse ecosystem response, such as the collapse of a marine fishery or a coral reef ecosystem.

3.1.1 *Direct drivers*

The direct drivers of change vary by location. Major current and projected drivers include changes in climate, land use, nutrient loading, invasive species, fishing, modification of rivers, water withdrawal and pollution (SWG). During the first half of the 21st century, the MA scenarios indicate that the array of both indirect and direct drivers affecting ecosystems and their services will remain largely the same as over the past half-century. However, the relative importance of different drivers will begin to shift and change. For instance, while the rate of global population growth is projected to decline gradually as global population peaks, shifts in demographic distribution will become relatively more important as a driver. By the end of the century, climate change and its impacts may be one of the most important direct drivers of change for ecosystems and their services.

3.1.2 *Indirect drivers*

World population probably will peak before the end of the 21st century at fewer than 10 billion people (S7). The global population growth rate peaked at 2.1% per year in the late 1960s and fell to 1.35% per year by 2000 when the global population reached 6 billion. Population growth over the next several decades is expected to be concentrated in the poorest urban communities in sub-Saharan Africa, south Asia, and the Middle East. Populations in all parts of the world are expected to age during the next century. While industrialized countries will have the oldest average populations, the rate of ageing could be extremely fast in some developing countries.

In the 200 years for which we have reliable data overall growth of consumption has outpaced increased efficiencies in production processes, leading to absolute increases in global consumption of materials and energy (S7). This means that in practice, economic growth tends to increase consumption of energy and materials.

In the MA scenarios, the range of per capita income growth is 200–400% between 2000 and 2050 (S7). Increasing per capita income is thus anticipated further to intensify per capita consumption in most parts of the world. Implicit in this prediction is the assumption that the linked socioecological system can provide sufficient human and ecosystem services to feed and otherwise provide for this larger and wealthier population. However, without major changes in technology, culture, or both, the pressure on ecosystems seems likely to increase, as a result. For example, as incomes rise, diets tend to become higher in protein.

Suburban housing development replaces natural tropical forest.

3.2 Plausible future changes in ecosystems and the health effects in different sectors and regions

Rapid conversion of ecosystems is projected to continue under all MA scenarios in the first half of the 21st century (S9.ES). Rates of conversion of ecosystems are highly dependent on future development scenarios and in particular on changes in population, wealth and technology. The most land-conserving scenarios are those that include increasingly efficient agricultural production, lower meat consumption and lower population increases.

Under all four MA scenarios, the projected changes in drivers result in significant growth in consumption of ecosystem services, continued loss of biodiversity and further degradation of some ecosystem services (SWG).

- During the next 50 years, demand for food is projected to grow by 70–80% and demand for water by 30–85%. Water withdrawals in developing countries are projected to increase significantly under all scenarios, although they are projected to decline in OECD countries.
- Food security is not achieved by 2050; child malnutrition will be difficult to eradicate.
- Habitat loss and other ecosystem changes are projected to lead to a global decline in local diversity of native species by 2050.
- A severe deterioration of the services provided by freshwater resources (such as aquatic habitat, fish production and water supply for households, industry and agriculture) is found in the scenarios that are reactive to environmental problems. Less severe but still important declines are expected in the scenarios that are more proactive in addressing environmental problems.

The scenarios identify certain 'hot spot' regions of particularly rapid decline in per capita ecosystem services, including sub-Saharan Africa, the Middle East and south Asia (S9). Water withdrawal is likely to expand rapidly in sub-Saharan Africa, requiring an unprecedented investment in new water infrastructure. Under some scenarios, this rapid increase in withdrawals will cause a similarly quick increase in untreated return flows to freshwater systems, which could endanger public health and aquatic ecosystems. This region could experience not only accelerating intensification of agriculture but also further expansion of agricultural land onto natural land. Further intensification could lead to a higher level of contamination of surface and groundwater. In south Asia the pressure on ecosystems could lead to sociopolitical breakdowns that interfere with the well-being of the population and its further economic development.

Desertification, or land degradation in dryland ecosystems, is projected to pose a particularly significant threat to human development (C22). Land degradation refers to the loss of primary production, often through soil erosion but also through changes in vegetation and through processes such as salinization and shifting sand. Approximately 10–20% of drylands suffer from one or more forms of land degradation *(medium certainty)*. The combination of low current levels of human well-being (high rates of poverty, low per capita GDP, high infant mortality rates); a large and growing rural population; the high variability of environmental conditions in dryland regions; and the high sensitivity of local populations to changes in ecosystem services; means that continuing land degradation could have profoundly negative impacts on the well-being of a large number of people.

The MA scenarios found that dryland ecosystem services are particularly vulnerable to substantial and persistent reductions in ecosystem services driven by climate change, water stress and intensive use (S.SDM). Many of the most vulnerable drylands are found in sub-Saharan Africa and central Asia. Subsidies of food and water for people in vulnerable drylands can have the unintended effect of increasing the risk of even larger breakdowns of ecosystem services in future years. Local adaptation and conservation practices can mitigate some losses of dryland ecosystem services, although it will be difficult to reverse trends towards loss of food production capacity, water supplies and biodiversity in drylands.

The per capita supply of food is projected to increase under all four scenarios, and diets in developing countries will become more diversified (S.SDM). Food security is likely to remain out of reach of many. Child malnutrition will be difficult to eradicate even by 2050, despite increasing food supply under all four scenarios and more diversified diets in poor countries. The *Order from Strength* scenario leads to the highest projected number of malnourished children in 2050 – about 180 million compared with about 170 million children today.

In the more promising scenarios related to health, the number of undernourished children is reduced and the burden of epidemic diseases such as HIV/AIDS, malaria and tuberculosis also falls (S11). Improved vaccine development and distribution could allow people to cope comparatively well with the next influenza pandemic, while the impact of other new diseases, such as SARS, should also be limited by well-coordinated public health measures.

In the *Order from Strength* scenario, the health and social conditions for rich and poor countries diverge and a negative spiral of poverty, declining health and degraded ecosystems could develop (S11). Demographic pressures in developing countries, combined with static or deteriorating nutritional status of local populations, could drive increased contact between humans and non-agricultural ecosystems, as people seek out bushmeat and other forest goods. This could lead to more outbreaks of haemorrhagic fever and zoonoses. Sleeping sickness could increase, as poverty forces humans to penetrate tsetse fly–infested regions. New diseases could emerge from the interaction of multiple factors, as in the case of the Nipah virus (see Box 1.1).

The loss or depletion of certain ecosystem services can be accommodated through substitutes. However, under the MA scenarios, an increasing number of people may be unable to replace satisfactorily, or escape from, the effects of depleted ecosystem services (S11). It is possible to substitute some depleted ecosystem services with human services and improved technology. In many other cases, however, exploitation of ecosystem services of another type or in another locale is merely intensified. Impacts often fall on the more vulnerable human populations globally. For instance, ecosystem impacts of the consumer demand for wood in developed countries may drive deforestation in poorer tropical regions. In other cases, the sustainability of services available to future generations may be at risk (e.g. in the case of deep-sea fisheries). The number of people affected by depleted ecosystem services will increase as world population grows, and as an increasing number and variety of ecosystems approach critical limits in their ability to provide certain services.

3.3 Possible thresholds, regime shifts or irreversible changes

The dual trends of growing exploitation of ecosystem services and the generally declining condition of most ecosystems are unsustainable and likely to lead to irreversible changes. Having crossed a threshold, recovery is generally slow, costly and may be impossible. Thresholds may become lower as anthropogenic impacts simplify systems and reduce their intrinsic resilience to change (C5).

Non-linear (including accelerating, abrupt and potentially irreversible) changes have been commonly encountered in ecosystems and their services (S.SDM). Usually, changes in ecosystems and their services are gradual and incremental, most are detectable and predictable - at least in principle *(high certainty)*. However, there are many examples of non-linear and sometimes abrupt changes in ecosystems. In these cases the ecosystem may change gradually as a result of a particular pressure, until a critical threshold is reached, at which point changes occur relatively rapidly as the system shifts to a new state. Some of these non-linear changes can be very large and have severe impacts on human health. Capabilities for predicting some non-linear changes are improving. However, for most ecosystems, while science often can warn of the potential risks from non-linear changes that may result from increased pressures on ecosystems, it cannot predict the threshold levels where non-linear changes will be encountered.

Examples of non-linear ecological events include runaway climate change, desertification, fisheries' collapse, eutrophication and major disease. Adverse non-linear social events include severe conflict, governance failure and increasing fundamentalism and nationalism. Multiple and interacting adverse events could also occur (S11). For example, widespread food insecurity - resulting from severe climate change, institutional failure and increasingly damaged soils - could worsen inequality and lead to widespread conflict. Numerous other losses in ecosystem services, while individually less dramatic, also are likely to influence human health adversely. Their plausible cumulative effect ranges from modest to immense. The cumulative effects of these also will depend on social and ecological resilience. If capacity is eroded, vulnerability increases and can contribute to a vicious cycle of even more impacts resulting in immense damage to human health.

The vulnerability of human well-being to sudden adverse ecological and social changes and other non-linear events varies among the scenarios (S11). Scenarios are characterized by the likelihood of non-linear changes, by the level and quality of preparedness to them and by social coping capacity. High levels of human capital, and other forms of capital, do not always guarantee preparedness and in some cases may lead to complacency. Likelihood, preparedness and resilience interact in any given scenario to determine the overall vulnerability of human well-being to non-linear events. Vulnerability to non-linear social and ecological events is greatest in the *Order from Strength* scenario. Among the other scenarios, it varies according to the kind of event and its scale, especially in the case of *Adapting Mosaic. Global Orchestration* is more vulnerable to ecological rather than social non-linear events.

Experiment in agriculture in deserts and drylands.

4. *What actions are required to address the health consequences of ecosystem change?*

In principle, two courses of action are available whereby disease and injury caused by ecosystem disruption may be avoided. One avenue is the prevention, limitation, or management of environmental damage (mitigation strategies). A second course of action involves making necessary changes to protect individuals and populations from the consequences of ecosystem change (adaptation strategies). We do not elaborate on the first approach because it is not unique to health and is explored at length in each of the other MA reports. In this section we begin by outlining ways of reducing human vulnerability to the effects of ecosystem change. We draw attention, however, to the connections between actions taken to reduce human vulnerability and actions that may protect the environment. In many instances, similar actions will indeed serve both goals. Nonetheless, where populations are weighed down by very immediate problems, such as a heavy burden of disease, it may be much more difficult to advance sustainable development and environmental management strategies that require a longer-term perspective. In this context, the MDGs offer a framework for international action.

4.1 Reducing vulnerability

Two closely-related issues need to be considered to understand the potential negative health impacts of ecosystem change: current vulnerability states and capacity for future adaptation (R16). In many cases, the forces that place human populations at risk (such as poverty and high burdens of disease) also impair their capacity to prepare for the future. The burden of HIV/AIDS in Africa, for example, is a major impediment to all development programmes, including those focused on sustainable land use, ecosystem protection and poverty reduction.

Populations, subgroups and systems that cannot or will not adapt are more vulnerable (R16). Some population subgroups may not have the resilience to adapt because of a lack of material resources, relevant information, and public health infrastructure, as well as a lack of effective governance and civil institutions. Appropriate targeting of interventions requires understanding of the demographic or geographical


A Waak/PAHO

Many of the health consequences of ecosystem change are borne by children - through increased morbidity and mortality from diseases related to unsafe water and sanitation, indoor air pollution, as well as vector-borne diseases such as malaria.

subpopulations most at risk, the factors that contribute to their vulnerability, and factors that potentially may be modified within the context of a particular time and setting. Individual, community and geographical factors determine vulnerability.

4.2 The Millennium Development Goals

The Millennium Development Goals (MDGs) were adopted by the United Nations General Assembly following endorsement of the Millennium Declaration by heads of state and government representatives at the United Nations Millennium Summit in September 2000.

The MDGs aim to improve human well-being by reducing poverty, hunger, and child and maternal mortality; ensuring education for all; controlling and managing diseases; reducing gender disparities; ensuring sustainable development; and pursuing global partnerships. For each MDG, targets have been set to be achieved by 2015 – referring to 1990 as the baseline. The goals are not comprehensive, and even if all were achieved, this would not ensure equitable and sustainable development.

The United Nations Millennium Project established Millennium Task Forces to address the individual goals and identify specific interventions for each goal. Some approaches considered for achieving the MDGs may be relatively sparing of ecosystems; others would very likely incur much heavier environmental costs (R19).

The ongoing degradation of ecosystem services is a significant barrier to achieving the MDGs and the harmful consequences of this degradation could grow significantly worse during the first half of the 21st century. The MDGs can best be met through integrated, synergistic strategies rather than isolated interventions. Particular emphasis needs to be placed on the sustainable intensification of existing cultivated ecosystems in order to satisfy growing demand for food - alongside the preservation of other important ecosystem services, e.g. water filtration and purification. Balancing such dual objectives is a major challenge, particularly as many social and economic issues also need to be addressed in order to reduce hunger (R19).

Deforestation in Latin America.

Learning to run a nursery for agroforestry in the dry country of South Nyanza, Kenya.

As part of a strategy for achieving the MDGs, improved ecosystem management needs to address a complex set of drivers of environmental change through cross-sectoral policies, institutional actions, and investments at local, national, regional and global levels (see Box 4.1). Improved capacity for cross sectoral policy-making is required not only at local levels, but also at global levels e.g. to address issues such as climate change and depletion of international fisheries (R19).

Box 4.1 Ecosystem change and the MDGs and Targets

Goal 1. Eradicate extreme poverty and hunger

Target 1: Halve, between 1990 and 2015, the proportion of people whose income is less than US$ 1 per day. The Millennium Declaration identifies global poverty as the most daunting of all global problems. A clear understanding of the complex and dynamic relationship between poverty and the environment is required in order to address this. Numerous interventions, many with ecosystem implications, are possible to halt the negative spiral of poverty and environmental degradation. Many of these interventions have positive impacts for health, education and other goals. For example, granting land or resource tenure to poor rural people can increase conservation incentives, capital investment in production and livelihood security.

Target 2: Halve, between 1990 and 2015, the proportion of people who suffer from hunger. FAO estimates that 840 million people go to bed hungry each night. Hunger is at least as much of an economic (income) and social (equity and distribution) issue as it is an issue related to ecosystem services. Access to adequate food is particularly important for poor rural populations. Interventions that increase agricultural yield and area have significant implications for ecosystem services. The MA findings illuminate many aspects of these complex and dynamic relationships. The way that ecosystems are managed has a significant impact on the availability and price of food and thus on the achievement of this target (R19).

Goal 2. Achieve universal primary education

Target 3: Ensure that by 2015 children everywhere, boys and girls alike, will be able to complete a full course of primary schooling. The expansion of primary education is likely to have many long-term positive impacts for ecosystem services, especially by enhancing human capital and individual and social capability. Yet better education fosters increased hope, expectations and capacity that some could view as potentially increasing the short- to mid-term pressure on ecosystem services by increasing the per capita ecological footprint. In the long run, however, education is likely to reduce the total size of this footprint. A better-educated population is likely to be in a stronger position to protect, preserve and restore essential ecosystem services, including by accelerating the demographic transition in countries where fertility rates remain high or above replacement level.

Goal 3. Promote gender equality and empower women

Target 4: Eliminate gender disparity in primary and secondary education preferably by 2005 and at all levels of education no later than 2015. Gender equity is an essential goal in itself and critical for meeting the other MDGs. The date set for achieving gender parity in primary and secondary education is 2005 - 10 years before the other goals. Among the more than 780 million adults who cannot read or write, nearly two thirds are women. Many poor populations are particularly dependent on locally available ecosystem services for their health and other elements of well-being (R19). Women and girls are especially vulnerable. Often they lack not only proportionate access to already limited economic resources but also frequently bear disproportionate responsibility for providing the human services that partially compensate for diminished local ecosystem services, such as collecting water and fuelwood from often-increasing distances. Such heavy labour constrains the ability of girls to attend school and can sap energy and concentration even when they do.

Goal 4. Reduce child mortality

Target 5: Reduce by two thirds, between 1990 and 2015, the under-five mortality rate. Despite progress in some countries reducing child mortality in children less than five years old, still more than 10 million children die unnecessarily each year, almost all in poor countries. In many countries, infant and childhood mortality rates are falling more slowly, in some countries rates have stagnated or are rising. Undernutrition is the underlying cause of a substantial proportion of all child deaths. The systematic application of an ecosystems approach to the MDGs, as well as synergies from the other goals, will benefit reduction of the under-five mortality rate, including through improved nutrition of children and mothers (R19).

Unhygienic and unsafe environments place children's health at risk. The causal links between infectious disease and ecosystems and their services are complex but are seen most clearly among impoverished communities that lack the buffers that the rich can afford (R16). Ingestion of unsafe water, inadequate water for hygiene and lack of access to sanitation contribute to millions of children's deaths, a significant portion from diarrhoea. Degraded and modified ecosystems, especially those that allow considerable amounts of standing water, are frequent sources of water- and vector-borne diseases (such as diarrhoeal diseases, malaria and dengue fever) to which children are susceptible. Poor nutritional status and micronutrient deficiencies among children decrease their immune and non-immune host defences, making many of them more vulnerable to infectious diseases.

UNAIDS/S. Pirozzi

Goal 5. Improve maternal health

Target 6: Reduce by three quarters, between 1990 and 2015, the maternal mortality ratio. Maternal mortality can be reduced by increasing health and gender equity through the provision of knowledge about reproductive alternatives, antenatal care, nutrition and disease. Ensuring that women have greater control over their reproductive health, including access to family planning, can help reduce population growth and consequent pressures on ecosystems.

Goal 6. Combat HIV/AIDS, malaria and other diseases

Target 7: Have halted by 2015, and begun to reverse, the spread of HIV/AIDS.
Most of the interventions needed to address HIV/AIDS are medical, educational and political rather than ecological. Reduced poverty and

improved gender equity will reduce livelihood choices, including prostitution, that increase the risk of HIV/AIDS. In some countries where the HIV/AIDS epidemic is very severe, such as parts of sub-Saharan Africa, the disease is having a direct impact on ecosystems, such as by lowering agricultural production. HIV/AIDS also has a direct impact on the economy by cutting production, earnings and taxes, thereby eroding the resources needed to deal with the epidemic (R19).

Target 8: Have halted by 2015, and begun to reverse, the incidence of malaria and other major diseases. One billion people live in malaria-endemic areas and malaria is responsible for over a million deaths annually. Malaria alone is responsible for 11% of the disease burden in Africa (R12). Ecosystem change, including forest

Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM)

clearance and irrigated agriculture, often is responsible for increasing the incidence of malaria. Better ecosystem management, in conjunction with primary and secondary prevention, is central to addressing this problem. Integrated vector management provides a range of environmental management tools within an ecosystem framework, including modification of the environment, biological and chemical controls.

Goal 7. Ensure environmental sustainability

Target 9: Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources. There is growing appreciation that the value of the human economy is subsidized by innumerable ecosystem services. As the ecological footprint of the human economy grows, thresholds of ecosystem service loss and degradation draw inexorably nearer, placing at risk the sustainability of human well-being and development. Preserving and restoring environmental integrity while reducing poverty when the global population continues to grow is an immense challenge. Improved ecological valuation methods that better account for the economic values of ecological goods and services ignored by markets are an important tool for meeting this challenge.

Target 10: Halve, by 2015, the proportion of people without sustainable access to safe drinking-water and basic sanitation. During the 1990s, around 80 million people per year, on average, gained access to an improved drinking-water supply; and a similar number, to improved sanitation. Still, in order to meet Target 10 of the MDGs, this achievement needs to be scaled up, so that an additional 100 million people per year, on average, gain access to an improved drinking-water supply, and an additional 140 million people per year, on average, gain access to improved sanitation. In many regions, achieving the targets on water and sanitation without parallel investments in water treatment can threaten freshwater and coastal ecosystems and the services they provide.

Target 11: By 2020, achieve significant improvement in the lives of at least 100 million slum dwellers. Urbanization is transforming the world fundamentally. Close to 50% of the world population lives in urban areas, compared with only 15% in 1900. Currently it is estimated that over 900 million people live in slums, roughly one third of the world's urban population. More than 70% of the urban population in the least developed countries and sub-Saharan Africa live in slum-like conditions. This number is set to increase to roughly 2 billion by 2020 unless current trends change substantially. The challenge is particularly acute in sub-Saharan Africa, where urbanization proceeds at a very high pace. The most extreme forms of environmental degradation tend to be found in slums. Chronic pollution of water sources, high disease prevalence and deterioration of public health conditions are common features in many of these unplanned urban settlements. This target has a limited overall impact on rates of urbanization and total urban demand for ecosystem services, since the targeted 100 million slum dwellers account for only a relatively small share of the total urban slum population (R1).

Goal 8. Develop a global partnership for development

Target 12: Develop further an open trading and financial system, including a commitment to good governance, development and poverty reduction, nationally and internationally. Globalization is a multifaceted collection of processes, a central part of which is the expansion of world trade. The MDGs aim to better harness globalization to reduce poverty. Goal 8 complements the first seven. It calls for an open, rule-based trading and financial system and increased aid and debt relief to countries committed to poverty reduction. There are significant opportunities to integrate aid and debt relief with innovative "debt for MDG" swaps (R19).

Targets 13-15: Address the special needs of least developed countries, landlocked and small island developing states and highly indebted poor countries. Many landlocked, small island and highly indebted nations lack the basic health, education and infrastructure capacities needed to gain adequate access to expanded markets and make the most of more open trade regimes. Therefore, special terms of trade, official development assistance and debt relief are required to finance new infrastructure and to address land and water sustainability issues.

Targets 16-18: In cooperation with developing countries and the private sector, address youth unemployment, access to affordable essential drugs and access to the benefits of new technologies. In harnessing globalization to reduce poverty and achieve sustainable development, the implications for ecosystems and their services must be a primary consideration. Recent estimates place the value of the world's ecosystems at more than the total value of the world's economy, taking into account the value of freshwater purification, pollination, clean air, flood control, soil stability and climate regulation (R19). Nevertheless, recognition of ecosystem services seldom penetrates policy debates. In making trade-offs between progress on human development goals and maintenance of ecosystem services, and in order to make better choices possible, improved ecological valuation methods need to be used to take more account of the economic values of ecological goods and services ignored by markets.

5. *How can priorities be established for actions to address the health consequences of ecosystem change?*

5.1 What considerations are important when setting priorities and what is science's role in informing decisions?

Priorities for actions addressing the human health consequences of ecosystem change should reflect the priorities and values of those who are affected by the action (R16). The final decisions about priorities therefore should be taken either by individuals or by their legitimate political representatives with reference to these values. Often decision-makers use multiple criteria (such as equity concerns, efficient use of scarce natural resources, political feasibility and cultural considerations) to set priorities. Scientific assessments can inform these decision-making processes. Assessments should strive to be policy-relevant without being policy-prescriptive, providing timely and useful information that allows stakeholders to judge how an action or inaction corresponds to their priorities.

Policy-relevant scientific assessments have led directly to many important decisions protecting public health from environmental risks. In many countries and settings, legislation regulating environmental exposures to lead, asbestos and secondary tobacco smoke, for instance, have been facilitated by evidence synthesized by health scientists who measured the links between environmental exposures and health outcomes, reached a reasonably broad consensus regarding health impacts, and presented these findings to policy-makers. Experiences implementing the Montreal Protocol on Substances that Deplete the Ozone Layer demonstrate that health considerations also can be important in decisions by local policymakers and stakeholders to address global environmental issues. This experience may encourage decision-makers similarly to address the health aspects of other risks, such as desertification, biodiversity loss and climate change.

5.2 How can we measure the size and distribution of the health effects of ecosystem change?

In the last decade, new approaches have been developed to assess the overall effects of environmental risks and other risks to population health. Where it is possible to measure the effect of an ecosystem alteration on the rates of

specific diseases, this can also be used to estimate the overall 'burden of disease' caused by that change. This can be described in terms of disability-adjusted life years (DALYs). DALYs represent the sum of years of life lost from premature death (e.g. the actual age at death compared with natural life expectancy) and the number of years of life lived with a disability (e.g. the duration of the disease, weighted by a measure of its severity). These measures allow health impacts experienced as a result of multiple causes or through multiple causal pathways to be summed together. For example, the combined effects of climate change on morbidity and mortality from infectious diseases, malnutrition, and the impacts of natural disasters can be aggregated into a single DALY measurement. Potentially this allows direct comparisons of the effects of different ecological changes (or any other risk factors) on population health and can act as a guide for rational priority-setting for an action (R16).

It is important to consider which subsections of the population are most affected by ecological changes, including the distribution of disease by age, gender, social status, ethnicity and geographical region. Global estimates for the year 2000 indicated that among the poorest countries with the highest mortality rates, between one-sixth and one quarter of the disease burden was attributable to childhood and maternal undernutrition. Children and pregnant women are at much greater risk from malaria, both in terms of morbidity and mortality, particularly if they are malnourished. Morbidity and mortality due to heatwaves, meanwhile, is highest among the elderly.

Burden-of-disease assessments depend on access to quantitative data sufficient to relate changes in exposure to the incidence of specific diseases. Within the environmental health field, such assessments have been carried out most successfully among defined or discrete population groups, in relation to localized environmental factors characterized by a set of well-defined dose-response health effects, e.g. air pollution exposures or environmental lead exposures. Such assessment is more difficult to apply in the case of ecosystem effects acting through more diffuse causal pathways. For example, reduced availability of fresh water could affect health adversely by increasing a range of water-borne diseases and also by reducing agricultural production. However, any quantitative projections of these effects are likely to have a higher degree of uncertainty than the examples just described. This is due to the multitude of other important causal factors (such as weather conditions during growing seasons) and diverse causal pathways of the impacts. For instance, water availability may influence not only plant growth rates but also agricultural pests and diseases, all of which in turn affect overall yields.

Considerations of timescale are equally important. Comparative risk assessments of the burden of disease attributable to climate change indicate that health impacts are modest compared with other risk factors over the brief time frames in which many political decisions are taken (a five-year horizon, at most). However, they become considerably more significant when impacts are considered over several decades. They are, therefore, of greater relevance where far-sighted policy-makers make decisions with long time horizons. Examples include large capital investments, such as planning decisions on the reconstruction of urban combined sewage systems or building on flood-prone areas. These would benefit from consideration of changing risks over decades rather than years. The burden-of-disease framework also fails to take account of differences between environmental risk factors that could be readily addressed by robust policies as new information becomes available about health impacts (e.g. urban air pollution), and other impacts (such as biodiversity loss) which may be irreversible.

Burden-of-disease evaluation is thus an appropriate tool for estimating and aggregating health impacts attributable to one particular ecosystem mechanism or to a range of ecosystem mechanisms. This tool potentially can aid priority-setting and decision-making to address ecosystem change. However, burden of disease assessment should be regarded as only one component of evidence as such evaluations cannot account fully for complex causal pathways, long timescales and potential irreversibility. These important properties need to be included in final considerations about any response to ecological change (R16).

Box 5.1 Interventions to reduce ecosystem change's pressures on health services - examples of promising responses

Vaccination campaign in El Salvador.

- Provide technical and financial assistance to implement the Global Strategy for Health for All, including health information systems and integrated databases on development hazards.
- Strengthen advocacy for the provision of basic preventive and curative health care at all levels. Review delivery of basic health services at the local level to ensure that priority problems of poor people are addressed adequately.
- Make essential drugs affordable and available to the world's poorer nations including, where necessary, alterations in the multilateral trade system, national policies and institutional drug supply management.
- Implement long-range health and human resource planning to train, recruit and retain staff. Develop codes of conduct for international recruitment of health professionals.
- Strengthen health services for displaced communities and those affected by war, famine or environmental degradation.
- Implement health impact assessment of major development projects, policies and programmes and monitor indicators for health and sustainable development.

5.3 What kinds of intervention options are available?

Responses to ecosystem changes include: mitigation (reducing or reversing the extent and rate of change) and adaptation (increasing systems' resilience to change - to reduce the current and future risks and take advantage of opportunities posed by those changes) (R16). Decisions on priority actions should include the best evidence available on the likely effectiveness of any intervention in either class. Mitigation and adaptation response options can include legal, economic and financial, institutional, social and behavioural, technological or cognitive measures and actions. They encompass both spontaneous responses to ecosystem change and planned (anticipatory) interventions by affected individuals and institutions such as governments. Responses that protect human health very often involve actions outside the health sector (see Box 5.1).

The health sector bears responsibility for informing decision-makers about the health effects of ecosystem changes and potential interventions. Where there are trade-offs to be made, for instance between more effective long-term mitigation and a faster rate of present-day economic growth, it is important for politicians, regulators and the public to understand the health consequences. These can be included alongside economic or other costs when setting priorities. Optimally, decision-makers may assign a higher priority to win-win options – for example, specific greenhouse gas mitigation measures that lead not only to long-term reductions in the risks of deaths in heatwaves, floods, droughts etc. but also bring benefits in terms of fewer deaths from air pollution in the short-term.

In almost every type of policy or community response to ecosystem changes, the consequences for health may be either positive or negative (R16). The outcome will depend on how the policy or regulation is framed, and what account is taken of contingencies and local circumstances. For instance, global trade and economic agreements have greatly facilitated the increased quantities and diversity of food products available in many markets around the world, which may be beneficial to health. In other settings, however, globalized trade in food may have contributed to diminished food access and security, deepening poverty, and deteriorating standards of public health.

A microscopic view of the tiny crustacean Mesocyclops. *Certain* Mesocyclops *species have been identified in Viet Nam and other Asian locales as highly efficient predators of the* Aedes aegypti *larvae, the main mosquito vector of dengue fever, and are important for controlling the disease.*

Adaptation interventions need to be designed at spatial and temporal scales appropriate to the health outcome of concern, taking into consideration the social, economic and demographic driving forces (R16). They also should be targeted towards particularly vulnerable groups that have the least capacity to adapt to ecosystem change. Such targeting requires understanding of which demographic or geographical subpopulations may be most at risk, the factors contributing to their vulnerability and which of these can be modified feasibly and effectively. Some of the most important determinants of vulnerability to any particular level of risk are the level of material resources, effectiveness of governance and civil institutions, quality of public health infrastructure, access to relevant information and existing burden of disease. These factors are not uniform across a region or nation; rather, there are geographical, demographic and socioeconomic differences.

Cross-sectoral policies that promote ecologically sustainable development and address underlying driving forces also will be essential (R16). Agenda 21 and the Rio Declaration on Environment and Development describe a comprehensive approach to ecologically sustainable development incorporating cross-sectoral policies. In defining the options that may be available through cross-sectoral policies, the following strategies are of specific relevance to health.

- Integrated action for health, making use of tools such as health impact assessment of major development projects, policies, programmes and indicators for health and sustainable development.

Examining a cup of water for Aedes aegypti *larvae in a community in north Viet Nam. This is a simple way to examine the effectiveness of interventions. Large-scale trials in the region involving the introduction of* Mesocyclops *into water tanks and containers have eliminated dengue in a number of locales. This is an example of improved environmental management of vector-borne disease yielding health benefits and also helping to minimize the impacts on ecosystems from excessive use of chemically-based vector control tools.*

- Including health in sustainable development planning efforts such as Agenda 21, multilateral trade and environmental agreements, and poverty reduction strategies.
- Improvement of intersectoral collaboration between different tiers of government, government departments and NGOs.
- International capacity-building initiatives that assess health and environment linkages and use the knowledge gained to create more effective national and regional policy responses to environmental threats.
- Dissemination of knowledge and good practice on health gains from intersectoral policy.

5.4 How should priorities for these options be established?

The process for deciding priority options varies across jurisdictions, institutions and cultures. The MA has identified a series of elements that tend to improve outcomes for ecosystems and human well-being (R18.ES) including the following.

- Use of best available information with consideration of the full range of effects of policies, including trade-offs, across ecosystem services.
- Where possible, valuation of both marketed and non-marketed ecosystem services.
- Aim to maximize efficiency (benefit per unit investment) but not at the expense of effectiveness (overall benefit).
- Consideration of equity and vulnerability in terms of the distribution of costs and benefits.
- Recognition that not all values at stake can be quantified, thus quantification can provide a false objectivity in decision processes that have significant subjective elements.
- Provision of regular monitoring and evaluation.

Use of certain quantitative tools may support priority setting. In the health sector, risk assessments are conducted (e.g. using burden of disease tools) to estimate the direct health gains that could be obtained from alleviating a particular risk factor. Cost-effectiveness analysis (CEA) may be used to assess the health benefits of policy options directly against financial costs in order to select options that maximize health efficiency.

However, many policies have effects across multiple ecosystem services, often with long-term, diffuse and uncertain effects on both health and non-health aspects of well-being. In these cases decision-making may be supported better by a combination of techniques, including cost-benefit analysis (which value diverse benefits in the same units, usually monetary); analysis of the distribution of costs and benefits across different socioeconomic groups; and qualitative considerations of the precautionary principle.

Once a decision to intervene has been made, cost-effectiveness criteria also can be used to select a preferred intervention among various alternatives (R16). Increasingly, approaches such as CEA are used to set priorities among interventions that will bring similar health gains - when the main factor that distinguishes between the interventions is their cost. Policy-makers can use cost-effectiveness ratios (e.g. dollars per DALY) of the various options to select those that provide the greatest health gains for any specified level of resources. Thus, CEA can be useful to compare similar kinds of policies whose effects are limited mainly to the health sector and are comparable in terms of deaths or DALYs. An analysis of cost-effectiveness across different socioeconomic groups can be conducted in order to gain more information about how interventions are likely to benefit particularly vulnerable groups in the population.

5.5 How can stakeholders and policy-makers be involved?

In order to affect either official policy or individual behaviour, it is necessary to take account of how risk is perceived among vulnerable communities. Effective risk communication strategies maximize the chances that policy interventions will enjoy popular support, and thus be successfully implemented. .

Vulnerable communities that are most likely to be affected by ecological changes should be involved throughout the entire policy-focused assessment process, not as an afterthought. Community engagement in the process provides access to local knowledge about the effects of ecological factors, ensures that the assessment addresses the issues of greatest concern to those affected, and maximizes the probability that any recommended change in policy or behaviour will be adopted. If a source of information is not widely trusted, it is unlikely that recommended changes will be accepted. Community surveys have shown that some groups tend to be regarded as highly trustworthy; others (such as government agencies) are treated with caution. Health care providers tend to be regarded as one of the high-trust groups, underlining again their important role in explaining the significance of healthy ecosystems.

Consultation should make the best use of the expertise of both stakeholders and researchers. Engagement of all relevant groups will also result in credible research with rapid translation into practice. Stakeholders may have expert local knowledge but inaccurate ideas of the true nature of risks associated with different factors; researchers should have more exact knowledge of disease processes and relative risks but may estimate inappropriately how general concepts apply to local situations. Accurate and accessible reporting of assessment results can remedy inaccurate risk perceptions and enhance the public's ability to evaluate science and policy issues. In many past policy experiences, poor reporting misled and disempowered a public that is affected increasingly by applications of science and technology.

WHO/Pierre Virot

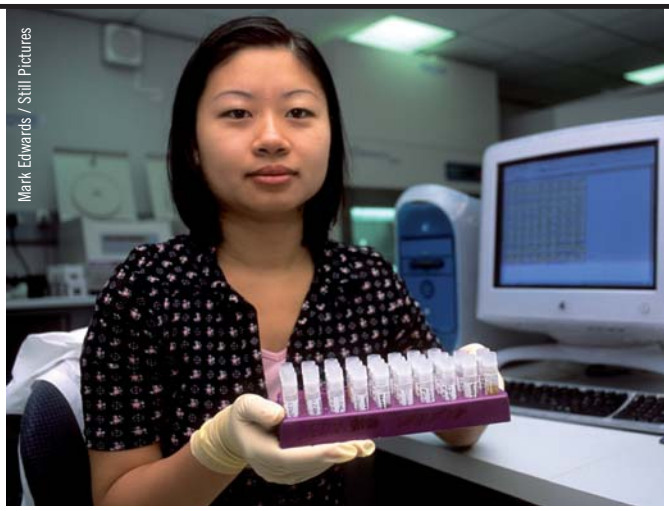
Emotive and economically important issues such as global environmental change present additional challenges to risk communication and to understanding risk perception. It is important to avoid overrepresentation of the views of a minority of the population who may emphasize only one aspect of an issue (special interest groups, for instance, may focus only on the need to conserve ecosystems without reflecting wider societal interests in enhancing economic growth too). Such groups can include industries that perceive action to protect the environment to be harmful to business. They may have significant resources to promote assessments of risks or public perceptions that are consistent with their own financial interests, not necessarily the interests of the wider population.

5.6 How does uncertainty affect priority-setting?

There are unavoidable uncertainties about the impacts of global environmental changes on public health. These include the potential magnitude, timing and effects of global environmental change; sensitivity of health to changes in ecosystem services; effectiveness of different courses of action in addressing potential impacts; and the shape of future societies (e.g. changes in socioeconomic and technological factors, and associated disease burdens). Traditional epidemiological methods are not well-suited to such issues as they are designed to test the influence of discrete risk factors on well-defined health outcomes (such as smoking's effect on lung cancer) and to emphasize avoidance of an incorrect identification of a harmful effect. In contrast, global environmental change has diverse and wide-ranging rather than discrete effects on individuals or small areas and an absence of control groups. It may be difficult or impossible to reverse, so false negative effects are equally as important as false positives. However, new epidemiological methods are being developed to predict the emerging health impacts of environmental change.

The level of uncertainties and the unsuitability of standard approaches lead many scientists to avoid attempting to answer some questions posed directly by decision-makers. For example, a policy-maker may ask whether a particular mitigation strategy is likely to lead to overall benefits or harm to health. Scientists tend to respond with a scientifically more rigorous and less uncertain answer to a small part of the equation (such as a demonstration that climate variations cause increases or decreases in disease vector abundance in a specific location).

It is important that scientific assessments attempt to give direct answers to decision-makers' questions, even if they can be only very approximate. However, it is essential that any such assessments be accompanied by an accurate and understandable description of underlying assumptions, associated uncertainties and the implications of the uncertainties for the potential outcomes of decisions being made. Sometimes it is argued that the existence of these uncertainties precludes policy-makers from taking action to mitigate and adapt to global environmental change. This is misleading, since decision-makers (from politicians to individual citizens) make many decisions with uncertain outcomes every day. An informed decision is better than an uninformed one. Uncertainties attached to potentially large and irreversible risks strengthen rather than weaken the case for precautionary action.



HIV Research, Gaborone; Botswana-Harvard Partnership for HIV Research and Education.

Indigenous residents of an Indonesian forest region use a Global Positioning System (GPS) to map boundaries, prevent illegal logging and thus protect vital ecosystem services upon which they depend.

Scientific assessments can provide decision-makers with a range of information on how actions to deal with global environmental change may address their concerns. These include, for example, identifying interventions that provide the greatest health protection for the lowest costs and that correspond to their values, such as fairness and equity. It may appear that by providing several different approaches to priority-setting and failing to recommend specific courses of action, the scientific community is providing a poor service. This is not the case. By presenting different kinds of approaches, assessments can be "policy-relevant, but not policy-prescriptive"- helping to clarify the current state of knowledge in relation to decision-makers' values but leaving them with the final decision on whether and how to act. Scientists fail in their responsibilities when they describe current scientific understanding of issues in a manner that does not relate to decision-makers' concerns; provides information biased towards particular subgroups or special interests; or hides uncertainties in an assessment of an action or inaction.

6. *What are the policy implications of the most robust findings and key uncertainties?*

A robust finding is defined as one that holds under a variety of approaches, methods, models and assumptions and that is expected to be relatively unaffected by uncertainties. In this context, addressing key uncertainties regarding ecosystem change and human health, potentially may lead to new and robust findings in relation to the questions addressed in this report, or may provide greater accuracy regarding quantification of the magnitude or timing of costs, benefits, ecosystem changes, impacts on human well-being or on responses.

6.1 Policy implications of the most robust findings

Ecosystem services are indispensable to the well-being of people everywhere. Local conditions exert a very strong influence on the nature, extent and timing of the effects of a particular ecosystem disruption on health. In general, the links between ecosystem change and human health are seen most clearly among impoverished communities. These lack the buffers that the rich can afford and often are most directly dependent on productive ecosystems for their health (R16).

- Changes in ecosystems have a more direct influence on human well-being among poor populations than among wealthy populations.
- Social adaptations may minimize, displace or postpone the health effects of ecosystem disruption, but there are limits to what can be achieved.
- Even wealthy populations cannot be insulated fully from the degradation of ecosystem services.
- Policies and actions to reduce vulnerability need to be comprehensive and sensitive to broader driving forces and issues of scale but at the same time account for differences between settings and locales.
- Broad frameworks should not be taken automatically as reliable guides to local conditions.

Major inequalities exist in the access to ecosystem services (R16). Historically, poor people have lost access to ecosystem services disproportionately as demand for those services has grown. Where a population is weighed down by disease related to poverty, and lack of entitlement to essential resources such as shelter, nutritious food or clean water, the provision of these resources should be the first priority for public health policy. Such changes could improve health in the short term and contribute to long-term ecological sustainability.

Growing populations and growing economies are associated with higher consumption; this increases pressures on ecosystems. At the same time, wealthier societies have a greater capacity to protect ecosystems and the services they provide. Therefore, the degree of pressure depends on technologies, behaviours, policies, social systems and other factors. Economic growth tends to increase consumption of energy and materials. Efficiency gains and shifts of consumption patterns from goods to services tend to reduce energy and materials' consumption intensity (per unit of output). Nonetheless, such savings have been outpaced by the overall global demand for, and consumption of, energy and materials so that absolute consumption of ecosystem services continues to grow.


UNEP / Georgios Angelaeis / TopFoto.co.uk


UNEP / Samantha Dorr/TopFoto.co.uk

- Where ill-health is directly or indirectly a result of excessive consumption of ecosystem services (such as food and energy), substantial reductions in consumption would have major health benefits and simultaneously reduce pressure on life-support systems.
- Introducing less-polluting transportation systems and reducing vehicle dependence could lead to fewer injuries, more physical activity among sedentary populations and reductions in local air pollution and greenhouse gas emissions.
- Integration of national agricultural and food security policies with the economic, social and environmental goals of sustainable development could be achieved, in part, by ensuring that the environmental and social costs of production and consumption are reflected more fully in the price of food and water.
- In rich countries, reduced consumption of animal products and refined carbohydrates would have benefits for both human health and ecosystems.

Measures to ensure ecological sustainability could safeguard ecosystem services and therefore benefit health in the long term (R16). A healthy community is more capable of sustaining local ecosystems, so inequalities in access to ecosystem services could become ecologically unsustainable. The goals of ecological sustainability and human health are mutually reinforcing. Choices made about the management of ecosystems can have important consequences for health, and vice versa. Consideration of ecosystem change enlarges the scope of health responses by highlighting 'upstream' causes of disease, injury and premature death. Consideration of social determinants of ecosystem change enlarges the scope of ecosystem management. The health sector can make an important contribution to reducing the damage caused by environmental disruptions, but the greatest gains would be made by interventions that are partly or wholly placed in other sectors.

To achieve the goal of enhancing human well-being while conserving ecosystems, wide-ranging reforms of governance, institutions, laws and policies are required. Effective management cannot focus on a single approach (markets, local control, government control etc.). Response strategies must be tailored to the specific social and environmental context. Effective management of the ecosystems in any particular region cannot be achieved through a narrow focus on responses at any one scale (local, national, regional or global). International agreements are indispensable for addressing ecosystem-related concerns but they tend to work most effectively when focused on narrowly defined issues.

Market mechanisms do not automatically address poverty and equity goals. Intervention strategies will be more effective in reducing poverty when they respect different degrees, and types of use, of ecosystem services by different communities. Poverty reduction strategies must take into account the important role ecosystems can play to improve the health and well-being of the world's poorest. Markets can be modified to ensure that poverty and equity goals are met but still use scarce environmental and natural resources efficiently to meet those goals. For example, the benefits of reducing effluent emissions into fresh water can be internalized by imposing emissions taxes on the polluters.

6.2 Policy implications of key uncertainties

A cascade of uncertainties is associated with legal, market, institutional and behavioural responses. Integration across response strategies can mitigate and reduce elements of uncertainty but it is unlikely that it can be eliminated in any important context. Main current uncertainties include:

- a limited ability to quantify and predict the actual relationships between biodiversity changes and changes in ecosystem services for particular places and times (C29);
- the absence of quantitative models linking ecosystem change to many ecosystem services (S13);
- limited information on the details of linkages between human well-being and the provision of ecosystem services, except in the case of food and water (C29); and
- limited information on the economic consequences of changes in ecosystem services at any scale.

Can society achieve a "sustainability transition" in which human well-being is improved without critical degradation of ecosystems and their goods and services? Ingenuity, technological progress and social reorganization are facilitating decreased energy and material intensity per unit of economic output. This, together with the possibility of increased ecosystem service intensity and substitution, suggests that pressure on ecosystem services can one day be decoupled from equitable growth in human well-being. In the near future, however, humankind's ecological 'footprint' inevitably will expand further due to population growth, poverty reduction goals and the parallel expansion of affluence and consumption.

Unavoidable uncertainties about the impacts of global environmental changes on public health should not be an excuse for delaying policy decisions. A precautionary approach to policy-making may be most appropriate, given the potential for serious and irreversible adverse human health impacts of ecological degradation. ■

Appendix A Abbreviations, Acronyms and Figure Sources

BSE	bovine spongiform encephalopathy
CBD	Convention on Biological Diversity
CEA	cost-effectiveness analysis
CO_2	carbon dioxide
DALY	disability-adjusted life year
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
MA	Millennium Ecosystem Assessment
MDG	Millennium Development Goal
NGO	nongovernmental organization
OECD	Organisation for Economic Co-operation and Development
PCBs	polychlorinated biphenyls
SARS	severe acute respiratory syndrome
UNCCD	United Nations Convention to Combat Desertification

Figure sources

Several figures used in this report were redrawn from figures included in the technical assessment reports in the chapters referenced in the figure captions. Preparation of several figures involved additional information as follows:

Figure SDM 1 – *Harmful effects of ecosystem change on human health.* The figure represents a synthesis of information on ecosystem health links from throughout the MA; most importantly from C14, R12, R16 and S11.

Figure 1.4 – *Access to improved water and sanitation facilities globally.* The source figures (C7 Fig 7.13 and 7.14) are based on World Health Organization and United Nations Children's Fund, *Global Water Supply and Sanitation Assessment 2000 Report,* Geneva, World Health Organization – updated for 2002 using the WHO online database.

Figure 1.5 – *Child mortality.* The figure is based on the most recent child mortality statistics reported in the *World Health Report 2005, Make every mother and child count,* Geneva, World Health Organization, 2005.

Figure 1.6 – *Percentage of households using solid fuel for cooking.* The figure is based on data cited in R16, originally reported in the *World Health Report 2002, Reducing risks, promoting healthy life,* Geneva, World Health Organization, 2002.

Appendix B Assessment Report Tables of Contents

Note that text references to CF, CWG, SWG, RWG, or SGWG refer to the entire working group report. ES refers to the Main Messages in a chapter.

Ecosystems and Human Well-being: A Framework for Assessment

CF.1 Introduction and Conceptual Framework
CF.2 Ecosystems and Their Services
CF.3 Ecosystems and Human Well-being
CF.4 Drivers of Change in Ecosystems and Their Services
CF.5 Dealing with Scale
CF.6 Concepts of Ecosystem Value and Valuation Approaches
CF.7 Analytical Approaches
CF.8 Strategic Interventions, Response Options, and Decision-making

Current State and Trends: Findings of the Condition and Trends Working Group

C.SDM Summary
C.01 MA Conceptual Framework
C.02 Analytical Approaches for Assessing Ecosystem Conditions and Human Well-being
C.03 Drivers of Change (note: this is a synopsis of Scenarios Chapter 7)
C.04 Biodiversity
C.05 Ecosystem Conditions and Human Well-being
C.06 Vulnerable Peoples and Places
C.07 Fresh Water
C.08 Food
C.09 Timber, Fuel, and Fiber
C.10 New Products and Industries from Biodiversity
C.11 Biological Regulation of Ecosystem Services
C.12 Nutrient Cycling
C.13 Climate and Air Quality
C.14 Human Health: Ecosystem Regulation of Infectious Diseases
C.15 Waste Processing and Detoxification
C.16 Regulation of Natural Hazards: Floods and Fires
C.17 Cultural and Amenity Services
C.18 Marine Fisheries Systems
C.19 Coastal Systems
C.20 Inland Water Systems
C.21 Forest and Woodland Systems
C.22 Dryland Systems
C.23 Island Systems
C.24 Mountain Systems
C.25 Polar Systems
C.26 Cultivated Systems
C.27 Urban Systems
C.28 Synthesis

Scenarios: Findings of the Scenarios Working Group

S.SDM Summary
S.01 MA Conceptual Framework
S.02 Global Scenarios in Historical Perspective
S.03 Ecology in Global Scenarios
S.04 State of Art in Simulating Future Changes in Ecosystem Services
S.05 Scenarios for Ecosystem Services: Rationale and Overview
S.06 Methodology for Developing the MA Scenarios
S.07 Drivers of Change in Ecosystem Condition and Services
S.08 Four Scenarios
S.09 Changes in Ecosystem Services and Their Drivers Across the Scenarios
S.10 Biodiversity Across Scenarios

Secretariat Support Organizations

The United Nations Environment Programme (UNEP) coordinates the Millennium Ecosystem Assessment Secretariat, which is based at the following partner institutions:
Food and Agriculture Organization of the United Nations, Italy
Institute of Economic Growth, India
International Maize and Wheat Improvement Center (CIMMYT), Mexico *(until 2002)*
Meridian Institute, United States
National Institute for Public Health and the Environment (RIVM), Netherlands *(until mid-2004)*
Scientific Committee on Problems of the Environment (SCOPE), France
UNEP-World Conservation Monitoring Centre, United Kingdom
University of Pretoria, South Africa
University of Wisconsin-Madison, United States
World Resources Institute (WRI), United States
WorldFish Center, Malaysia

Maps and graphics: Emmanuelle Bournay and Philippe Rekacewicz, UNEP/GRID-Arendal, Norway

The production of maps and graphics was made possible by the generous support of the Ministry of Foreign Affairs of Norway and UNEP/GRID-Arendal. Funding for this publication also was provided by the Global Change Research Programme in the United States Environmental Protection Agency's Office of Research and Development, National Center for Environmental Assessment.

This report was prepared by the World Health Organization as a contribution to the Millennium Ecosystem Assessment, with contributions from:

Communications coordination: Nada Osseiran
Editing and design coordination: Elaine Fletcher
Text editor: Jo Woodhead
Graphic design: www.paprika-annecy.com

Front cover photos
Above: The dependency of half of the world's population on fuelwood for domestic cooking and heating is a significant factor in respiratory diseases from indoor air pollution, and can contribute to deforestation and ecosystem change. Photo credit: Nigel Bruce, University of Liverpool.
Below: Artemisia annua, the botanical source of the artemisinin compound, used in artemisinin-based combination therapies (ACTs) to treat forms of malaria that have become resistant to other anti-malarial medications. Photo credit: Scott Bauer, ARS Photo Unit, United States Department of Agriculture (USDA).

Front inside cover photo: Market in La Paz, Bolivia. Photo credit: A. Waak/Pan American Health Organization/World Health Organization (PAHO/WHO).

Back cover photo: Fishing in Vietnam. Photo credit: UNEP/Ta Hai/TopFoto.co.uk.

Photo (this page): Ethiopia; Collecting water. Photo credit: M. Marzot, Food and Agriculture Organization (FAO)/17067.

CBD

CMS

GEF

ICSU
International Council for Science

IUCN
The World Conservation Union

Ramsar
CONVENTION ON WETLANDS
(Ramsar, Iran, 1971)

UNITED NATIONS FOUNDATION

UNDP

UNEP

UNESCO

ISBN 92 4 156309

9 789241 563093