Chapter 16

Consequences and Options for Human Health

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Main Messages

Human health is both a product and a determinant of well-being. Measures to ensure ecological sustainability would safeguard ecosystem services and therefore benefit health in the long term (*high confidence*). In this chapter, health is the central concern, while noting the reciprocal relationships with other determinants of well-being. Negative health effects of ecosystem disruption are already evident in many parts of the world. In the long term, some ecosystem change is inevitable. To limit the damage to human health caused by these changes, mitigation strategies that reduce the driving forces of consumption, population increase, and inappropriate technology use are needed.

Ecosystem disruption damages health through complex pathways. Local conditions exert a very strong influence on the nature, extent, and timing of the effects on health. Social adaptations may minimize, displace, or postpone effects of ecosystem disruption on human health, but there are limits to what can be achieved. Human societies have developed methods (such as agricultural systems or water supplies) that allow natural resources to be appropriated for social benefit. Piped water supplies and other man-made resource appropriation systems provide human populations with a buffer in times of environmental change. These social adaptations are usually designed to minimize local impacts. Many effects of ecosystem disruption on health are displaced, either geographically (such as the costs of rich countries' overconsumption) or into the future (for example, long-term consequences of climate change or desertification).

To understand the potential negative health impacts of ecosystem change, two aspects need to be considered: the current vulnerability of the population affected and their future adaptive capacity. These two considerations are closely related, since vulnerable populations are less able to plan and implement adaptive responses. Vulnerability and adaptive capacity are also tied to other aspects of well-being (material minimum, freedom and choice, social relations and security).

Decisions about health and ecosystems must consider how one is related to the other. Choices that are 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. The health sector can make an important contribution to reducing the damage caused by environmental disruptions, but the greatest gains will be made by interventions that are partly or wholly placed in other sectors. The health sector bears responsibility for revealing the links and indicating which interventions are needed. Decision-makers need to consider the connections between health and other sectors. Where there are trade-offs, it is important for politicians, regulators, and the public to understand the consequences of taking one path in preference to another.

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 priority for healthy public policy (*high confidence*). The links between ecosystems and human health are seen most clearly among deprived communities, which lack the "buffers" that the rich can afford. Within poor communities, poverty-related diseases are more prevalent among women and children, often due to culturally related resource distribution. Poor communities are the most directly dependent upon productive ecosystems. This means that the poorest and most disadvantaged communities can be among the first to benefit from ecosystem protection. There are economic considerations also: a healthy community is more capable of sustaining local ecosystems than an unhealthy one.

Where ill-health is caused, directly or indirectly, by excessive consumption of ecosystem services, substantial reductions in overconsumption would have major health benefits while simultaneously reducing pressure on life-support systems (*high confidence*). Both human health and the environment would benefit from a reduction in overconsumption. This would improve health in the short term as well as contribute to short-term ecological sustainability. Implementing better transportation practices and systems could lead to decreased injuries, increased physical activity in sedentary populations, as well as reduction in local air pollution and greenhouse gas emissions. Integrating national agriculture and food security policies with the economic, social, and environmental goals of sustainable development could be achieved, in part, through ensuring that the environmental and social costs of production and consumption are more fully reflected in the price of food and water. Reduced consumption of animal products in rich countries would have benefits for human health and for ecosystems.

Society needs to balance technological and institutional development. To achieve this balance, governments must incorporate environmental, social, and health costs (both gains and losses) into measurements of progress.

Approaches that perpetuate or worsen social inequalities may protect the health of privileged populations, but are likely to result in the worst global health outcome overall. Globalization processes increasingly link the health and well-being of privileged with poor populations. A selective approach whereby the health and well-being of a small fraction of the global population is promoted at the expense of the majority entails a high risk for both populations.

16.1 Introduction

There are well-defined relationships between health and the other components of well-being as defined in the MA framework. Material lack, for example, is a strong determinant of health (and indeed of other aspects of well-being). Both at the country level and within countries, poorer communities have a worse health profile than richer ones. Among poor communities, women and children often bear the largest burdens of disease (WHO 2002). At the global level, poorer countries are still battling traditional hazards such as lack of clean water and sanitation, which contribute considerably to the burden of disease in these countries. For example, the African region with 11% of the world's population has over 50% of the world's burden of disease resulting from infectious and parasitic diseases; in contrast, in the European region, with 14% of the world's population, the burden of disease in this category is less than 2% of the world's total (based on WHO regions, measured in ''disability-adjusted life-years'' (WHO 2002). (See Box 16.1.)

On the other hand, the lack of good health is a major determinant of poverty. For example, it is estimated that Africa's GDP could have been $100 billion larger if malaria had been eliminated some 35 years ago (WHO 2000). GDP declines by about 1% when more than 20% of the population is infected with HIV (WHO 2002); see also reports of the Commission on Macroeconomics and Health (WHO 2001).

Several studies have shown an important connection between social relations and health. People with good social networks live longer and are generally healthier (Skrabski et al. 2003). Similarly, people who fall ill recover faster when good social networks are in place. Lack of security (or vulnerability) is also associated with morbidity or mortality, although the relationship is often confounded with material lack (that is, vulnerable communities are often poor). Communities and individuals can be vulnerable for other than economic reasons. For instance, all inhabitants of low-

BOX 16.1

Disease Burden and Summary Measures of Population Health

The disease burden encompasses the total amount of disease or premature death within the population. Comparing burden fractions attributable to several different risk factors requires, first, knowledge of the severity/disability and duration of the health deficit, and second, the use of standard units of health deficit. The widely used Disability-Adjusted Life Year (DALY) is the sum of:

- years of life lost from premature death (YLL)
- years of life lived with disability (YLD).

YLL takes into account the age at death. YLD takes into account disease duration, age of onset, and a disability weight that reflects the severity of the disease.

To compare the attributable burdens for disparate risk factors we need to know (1) the baseline burden of disease, in the absence of the particular risk factor, (2) the estimated increase in the risk of disease/death per unit increase in risk factor exposure (the "relative risk"), and (3) the current or estimated future population distribution of exposure. The avoidable burden is estimated by comparing projected burdens under alternative exposure scenarios.

An example of an application of this method in the field of ecosystem change and health is the assessment of the burden of disease attributable to climate change.

lying islands are vulnerable to the effects of sea level rise, although their individual responses will vary depending on economic and social conditions (Nurse and Sem 2001). Lack of control is another important cause of vulnerability. Many indigenous populations, for example, face ecosystem changes introduced by forces outside their control (such as economic interests), and these threats can have an impact on their overall well-being, including their mental health.

For most diseases, the burden of disease is not borne evenly by all members of a community. For example, children and pregnant women are at much greater risk for morbidity and mortality from malaria, particularly if malnourished, whereas morbidity and mortality due to heat waves is highest among the elderly (Kilbourne 1997; Greenwood and Mutabingwa 2002). In general, the vulnerability of a population to a health risk depends on 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 (Woodward et al. 1998). These factors are not uniform across a region or nation; rather, there are geographic, demographic, and socioeconomic differences. Failure to understand the reasons why particular population subgroups are vulnerable to a health outcome can reduce the effectiveness of response options.

Exposure to hazards is often a function of resources, with the resource-poor most likely to be in harm's way. For example, in impoverished communities, economically tied to large urban centers, but unable to afford safe housing, mudslides cause hundreds of deaths each year (IFRCRCS 2002). Even where there is no economic or social differentiation in the exposure to hazards, the impacts on health may vary considerably from place to place or group to group.

Figure 16.1 describes the links between ecosystem services and well-being with a focus on human health. Note that ecosystem integrity and human health do not always go hand in hand, in the short term at least. Populations may flourish in degraded environments, but only where it is possible to import resources and services from elsewhere.

16.1.1 Overview of Health in the Context of Ecosystems

Definitions of health vary across cultures. Some cultures focus on physical evidence of bodily structure and function; others have a much broader conception. For instance, for the indigenous people of New Zealand, the Maori, dimensions of health include access to heritage and a sense of communion with the environment (Durie 2001). In its constitution, the World Health Organization defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." However it is framed, health serves both as a cause of well-being and as a consequence. In the absence of good health, it is difficult to claim a state of well-being, but many of the components of well-being (such as shelter, sustenance, and social relations) are themselves important determinants of health status.

Each of the categories of services provided by ecosystems is relevant to health. For instance, provisioning services include the production of food and fiber. In their capacity as regulators of the environment, ecosystems influence the quality and flow of water and the local climate. If these services are impaired, the impacts on health tend to be direct, and relatively acute. More difficult to demonstrate are the effects of cultural services provided by ecosystems—these are nonmaterial benefits such as spiritual, recreational, and aesthetic outcomes. But even if these aspects of human experience are not encompassed in the definition of health, they do have an influence on physical and mental functioning. The history of colonization, for example, shows clear links between loss of spiritual and cultural identity and rates of disease and premature mortality (Kunitz 1994).

The links between ecosystem change and cultural services are described in detail in the next chapter. The effects of ecosystem disturbance on human health may be relatively direct, or occur at the end of long causal chains, dependent on many intermediate events, and subject at many points to modifying influences. There are also relatively direct links between human health and the health of animal populations that share a common environment (Epstein et al. 2003). (See also MA *Current State and Trends,* Chapter 14.)

As an example of long causal chains, environmental changes affecting river flows might lead to disputes over water rights, social unrest, forced migrations of large populations, conflict, and, indirectly, increased rates of disease and injury (WCD 2000). The connections between ecosystem functioning and human health may be bi-directional. Thus where there is environmental disruption leading to poor health, there may be compounding effects and "vicious cycles" established (Woodward et al. 2000). For example, land degradation and soil loss leads to crop failure, hunger, and health problems. These health problems will more likely be experienced by women and children, and, as such, can affect not only current but future health through poor growth, increased disease burdens in later life, less productivity, etc. But there are effects in the other direction also: populations with high levels of chronic health problems can put less energy and time into growing crops, preventing erosion, and managing agricultural resources.

The difference between direct and indirect effects applies to the temporal and spatial scales over which these effects occur. Owing to the many intermediate factors that may be involved,

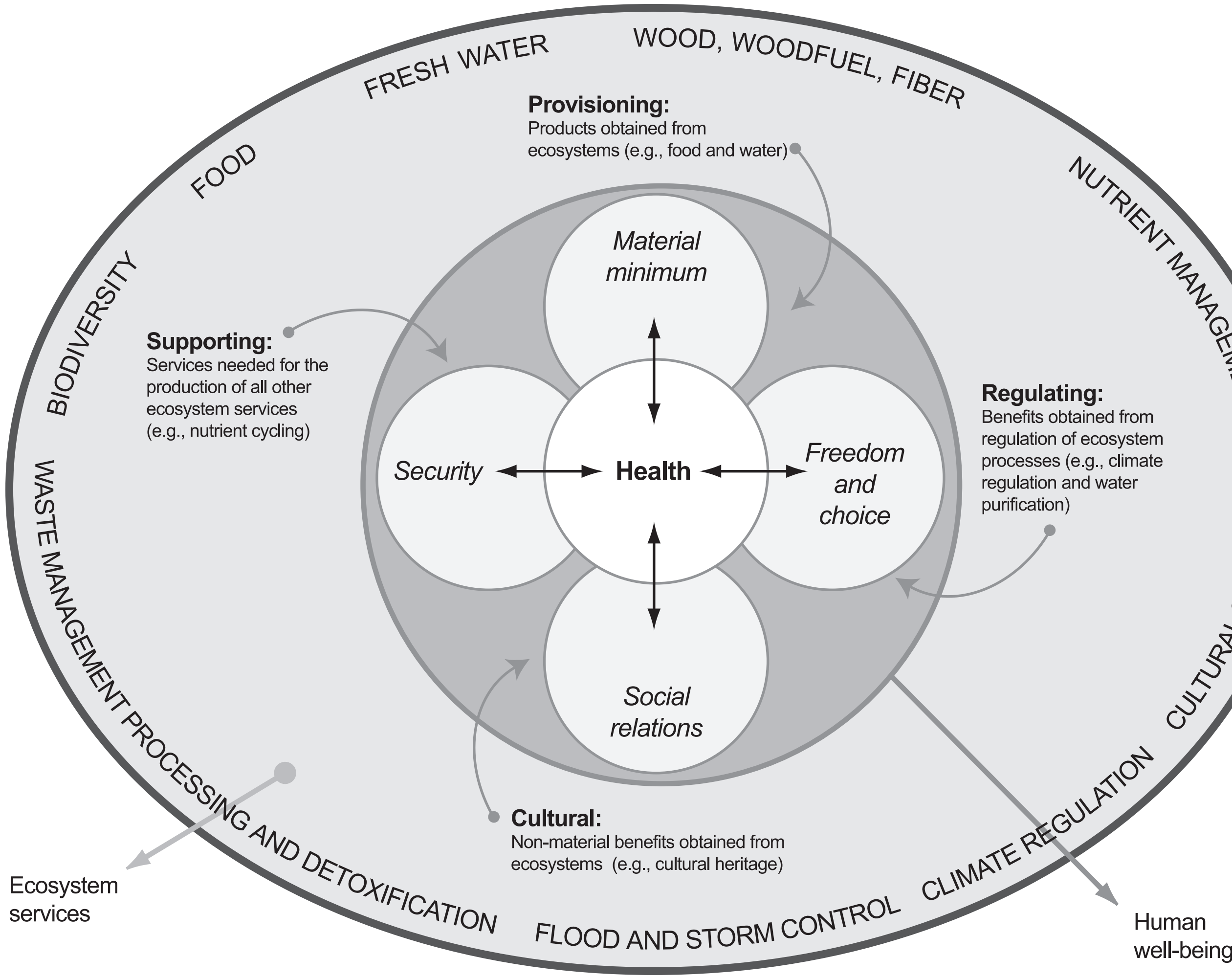

Figure 16.1. Associations between Health, Other Aspects of Human Well-being, and Ecosystem Services

there are frequently considerable time-lags between ecosystem change and health outcomes. For example, loss of biodiversity may lead to higher mortality and morbidity via diminishing supplies of bio-pharmaceuticals, but this would be apparent only after some years. In terms of spatial scales, we are most familiar with local effects (such as flooding and mudslides on steep denuded hillsides). More difficult to identify, but perhaps even more important for human health in the long term, are regional and global changes such as acid rain, stratospheric ozone depletion, and the accumulation of greenhouse gases.

Environmental and health policies are often determined without regard for one another, but there are important instances in which decisions have been swayed by health considerations. Removing lead from vehicle fuels is one case—this resulted from the accumulating evidence of risks to child health and has had far reaching consequences for ecosystems worldwide (Reuer and Weiss 2002).

16.1.2 Impacts of Ecosystem Goods and Services on Health

There are established links between the state of ecosystems and the condition of populations that depend on these ecosystems. Some of these links are shown in Table 16.1, which attempts to summarize the complex relationships between ecosystem goods and services (as defined in the Millennium Ecosystem Assessment, and described in detail in previous chapters) and the major categories of disease. The table indicates the likely strength of the associations, based on knowledge of ''downstream'' causal pathways leading to disease. There is a high level of uncertainty about these judgments, because few studies provide quantitative evidence of associations between ecosystem change and disease.

16.1.2.1 Biodiversity

Biodiversity underpins the resilience of the ecosystems on which humanity depends. Loss of biodiversity is occurring at an unprecedented rate, driven by overexploitation of productive ecosystems, other land use changes, climate change, pollution events such as oil spills, the transboundary migration of pollutants and hazardous substances, introduced species, and biotechnology. (See MA *Current State and Trends,* Chapter 4.) This depletion of biodiversity threatens vital ecosystem services, including food, fuel and fiber, fresh water, nutrient cycling, waste processing, flood and storm protection, and climate stability. One obvious direct impact of the loss of biodiversity is a reduction in sources of potential therapeutic chemicals. In general, the links between biodiversity loss and human health are difficult to demonstrate scientifically, due to the many factors that may confound such an association, difficulties in modeling nonlinear relationships, and lack of suitable data at appropriate scales (Sieswerda et al. 2001; Huynen et al. 2004). The clearest evidence of an association

Table 16.1. Relationships between Ecosystem Services and the Major Categories of Disease. Strength of evidence: "+ + +" High, "+ +" Medium, "+" Low, "?" Uncertain, "–" None or not known.

		Biodiversity	Food	Fresh Water	Wood	Nutrients	Waste	Climate Regulation, Flood and Storm Control	Cultural Services
Infectious parasitic diseases	Diarrhea	+ + +	+ + +	+ + +	–	–	+ + +	+ + +	–
	Malaria	+ + +	–	+ + +	–	–	+	+ +	–
	Other vector-borne disease	+ +	–	+ +	–	–	+	+ +	–
	Acute respiratory infection	+ +	+	–	+ +	–	?	?	–
	Other infectious diseases	+ +	+	+ +	?	?	–	?	–
Noncommunicable diseases	Chronic diseases	+ +	+	+	+ +	?	+ +	+	–
	Malnutrition	+ + +	+ + +	+	?	+ +	+	+ +	–
	Mental conditions	+ +	?	+	?	?	+	+ +	+ +
Injuries	Poisonings	–	+	–	?	+	+	–	–
	Drowning	–	–	–	–	–	–	+ +	–

probably comes from studies showing that high species diversity can be an important influence on reduced transmission of zoonotic diseases such as Lyme disease (Ostfeld and Keesing 2000). (See MA *Current State and Trends,* Chapter 14.)

Diversity and health are linked also in agriculture, where mono-cropping has been associated with increased vulnerability to acute food shortages and longer-term nutrient deficiencies (Waltner-Toews 2001). There is limited evidence of an association between experience of the natural world and reduced sickness rates and improved healing (Frumkin 2001).

Human societies have flourished by developing methods (such as settled agriculture and water storage) that enhance productive ecosystem services for social benefit. Especially in countries dominated by market economies, these adaptations are often designed to minimize short-term, local ecological disturbances, while maximizing profits. There is a mismatch of scale between social and ecological systems (Berkes and Folke 1998).

One result of this is that effects of ecosystem disruption on health are often displaced geographically (such as the costs of rich countries' overconsumption—climate change being a good example, in which many of the adverse health effects are likely to appear first in low carbon-emitting countries) or postponed into the future (for example, long-term consequences of climate change or desertification). But in general, the links between ecosystem change and human health are seen most clearly among impoverished communities, who lack the ''buffers'' that the rich can afford.

16.1.2.2 Food

The health of human populations is entirely dependent upon the services of productive ecosystems for food. This is most obvious in poor countries—especially in rural areas—where food is derived almost exclusively from local sources. Human dependence on ecosystems for nourishment is less apparent, but ultimately no less fundamental, in richer urban communities. Historically, loss of productive ecosystem services has led to the collapse of whole civilizations. For example, it has been suggested that the Mayan empire was lost near the end of the first millennium as a result of soil erosion, silting of rivers, and drought, leading to agro-ecosystem failure (UNEP 2002; Haug et al. 2003). See also MA *Current State and Trends,* Chapter 5; MA *Multiscale Assessment,* Chapter 2.

Few studies have attempted to quantify the links between food-producing ecosystems and human health. From first principles, such links might be seen most readily among vulnerable populations that live on marginal lands. Childhood stunting was associated with local land degradation in one such study (GRID/Arendal 1997). Birth weight was associated with land environment classification in Papua New Guinea (Allen 2002).

Undernutrition remains a major health problem in poor countries, where poverty is a consistently strong underlying determinant (WHO 2002; FAO 2003). Global burden of disease estimates indicate that in the year 2000, among the poorest countries, about a quarter of the burden of disease was attributable to childhood and maternal undernutrition. Among the rich countries, diet-related risks (mainly overnutrition) in combination with physical inactivity accounted for a third of the burden of disease. Worldwide, undernutrition accounted for nearly 10% of global DALYs (WHO 2002).

Aggregate food production is currently sufficient to meet the needs of all, yet of the present world population of just over 6 billion, about 800 million are underfed (FAO 2003), while hundreds of millions are overfed (WHO 2003a).

This imbalance has been driven primarily by social factors, though ecological factors may play an increasingly important role in the future. In poor countries, the number of people per hectare of arable land increased from three in 1961–63 to five in 1997–99 (WEHAB 2002a). Poverty and hunger have tended to force people onto marginal drought-prone lands with poor soil fertility. Where the conditions of poor communities are overshadowed by the need to earn foreign exchange for debt repayments, this can lead to the displacement of subsistence farming by cash crops grown for global corporations (Graber et al. 1995; McMichael 2001).

Agricultural production tripled in the last four decades, mainly through growth in yield. However, food production has not kept pace with population increase in many countries and improvements in yield appear to have slowed (UNEP 2002; WEHAB 2002a). It has been estimated that today, nearly a quarter of usable land has reduced productivity and about a billion people are affected by land degradation either through soil erosion, water logging, or salinity of irrigated land (DFID/EC/UNDP/World Bank 2002; UNEP 2002).

Providing sufficient food for an expected human population of 8–9 billion people will require major investments in poverty alleviation (Mellor 2002). There are also important trade-offs that have to be made between various possible uses of productive land. Including population health considerations in this weighing of choices could have important policy implications. The issue of overconsumption of food is relevant here, for several reasons. First, from economic first principles, overconsumption of food is encouraged by economic and trade practices, which prioritize short-term profit while externalizing longer-term environmental and social costs. Second, reductions in animal-based food consumption in rich countries could have important ecological benefits (WHO 2003a). Intensive meat production, in particular, has major adverse impacts on ecosystems (Leitzmann 2003, Reijnders and Soret 2003). (See also MA *Current State and Trends,* Chapter 8.)

16.1.2.3 Fresh Water

Fresh water is a key resource for human health; it is used for growing food, drinking, washing, cooking, and for the recycling of wastes. Of all available water globally, only 2.5% is fresh, and less than 1% is readily available in lakes, rivers, and underground. Worldwide, almost 4% of the global burden of disease is currently attributable to unsafe water, inadequate sanitation, and poor hygiene. In the next century, water resources will be strongly affected by trends in population, land use, and the management of freshwater ecosystems. Increasing demand for food, in particular, will worsen water scarcity. It is estimated that by 2025 nearly half the world population will live in river basins where water is scarce and 70% of readily available water supplies will be used (WEHAB 2002d). Water scarcity can lead to use of poorer quality sources of fresh water, which are more likely to be contaminated, tending to cause increases in water-related diseases.

At present, 1.1 billion people lack access to safe water supplies, while 2.6 billion people lack adequate sanitation (WHO/UNICEF 2004; UNESCO 2003a). Lack of improved water and sanitation is strongly associated with poverty, although this relationship varies between regions (WHO 2002). Along with sanitation, water availability and quality are well recognized as important risk factors for infectious diarrhea and other major diseases (Esrey 1996; Pruss et al. 2002; Strina et al. 2003; Thompson et al. 2003).

The associated effects on human health are severe. Poor countries, with inadequate provision of water and sanitation, will be most vulnerable to these effects that impact most severely on children. (See Table 16.2.) In addition to direct effects, there can be indirect health effects. For example, during a water shortage, women may have to walk further and spend additional time to supply households with water. This additional time and energy expenditure may affect a woman's health and her ability to earn an income and to care for household members.

The effects of climate change on water resources are difficult to forecast because of the many factors that influence rainfall, runoff, and evaporation. Nevertheless the best estimates are that climate change may increase the number of people affected by water stress by about 0.5 billion in 2025 (Arnell 1999). Increases in temperature would worsen water quality by increasing the growth of microorganisms and decreasing dissolved oxygen. Water-related disasters—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 and a reduction in low river flows (IPCC 2001). Heavy rainfall would tend to adversely affect water quality by increasing chemical and biological pollutants flushed into rivers and by overloading sewers and waste storage facilities. In some parts of the world, climate change also may increase requirements for irrigation water because of increased evaporation. (See also MA *Current State and Trends,* Chapter 7.)

16.1.2.4 Wood Fuel

Most of the world's population has no access, or limited access, to electricity supplies, and about two billion people must rely on wood, dung, and agricultural residues for heating and cooking, while rich countries typically consume 25 times as much energy per capita as do poor countries (WEHAB 2002b).

Lack of clean, safe power causes a range of health impacts. About half of the world's population still uses solid fuels for cooking and 0.5% of DALYs worldwide have been attributed to indoor air pollution from this source, particularly among women and children. Urban air pollution, resulting from the combustion of fossil fuels for transport, power generation, and industry, accounted for a further 0.5% of DALYs (WHO 2002). Outdoor air pollution aggravates heart and lung disease (Kunzli et al. 2000). Indoor air pollution causes a major burden of respiratory diseases among both adults and children (Ezzati et al. 2002; Smith and Mehta 2003).

Energy supplies are a fundamental factor in sustainable development and are also needed to provide and maintain modern health services. The need to spend considerable time collecting fuel can preclude proper education, especially of women, with indirect adverse effects on health through illiteracy, lost work opportunities, family health, and large family size. More indirectly still, energy use is linked to health effects via desertification, acidification, ambient air pollution, and climate change.

16.1.2.5 Nutrient Management

Application of agricultural fertilizers and organic wastes (including sewage) can improve agricultural yields but may also lead to increased concentrations of nitrogen and phosphorus in surface waters and coastal sea areas (Smil 2000). This can cause certain cancers (Wolfe and Patz 2002) and eutrophication in both marine and freshwater ecosystems, with overgrowth of bacteria, phytoplankton, macrophytes, and microalgae.

In turn, these problems can lead to increases in water-borne diseases and poisoning from harmful algal blooms (UNESCO 2003b). There are likely to be other ecological mechanisms by which increased nutrients can lead to human diseases, but further research is required to clarify these (NRC 1999; Townsend et al. 2003).

16.1.2.6 Waste Management, Processing, and Detoxification

Well-functioning ecosystems absorb and remove contaminants. For example, wetlands can remove excess nutrients from runoff, preventing damage to downstream ecosystems (Jordan et al. 2003). Inadequate management of solid waste increases human exposure to infectious disease agents (for example, via contamination of water with feces, or via disease vectors). This leads to a range of communicable diseases, especially diarrheal illness (WHO/UNICEF 2004; UNESCO 2003a). Of the 2.6 billion

Table 16.2. Water and Sanitation-related Diseases (WHO 2003c)

Disease	Disease Burden, in Disability-Adjusted Life-Years (thousands)	Mortality (deaths per year)	Relationship of Disease to Water Supply and Sanitation
Diarrheal diseases	61,966	1,797,970	strongly related to unsanitary excreta disposal, poor personal and domestic hygiene, unsafe drinking water; 90% of deaths in children under 5
Infection with intestinal helminths (ascariasis, trichuriasis, hookworm disease)	2,882	9,360	strongly related to unsanitary excreta disposal, poor personal and domestic hygiene; 133 million people suffer from high-intensity intestinal helminth infections
Schistosomiasis	1,702	15,370	strongly related to unsanitary excreta disposal and absence of nearby sources of safe water; 160 million people infected
Trachoma	2,329	150	strongly related to lack of face washing, often due to absence of nearby sources of safe water; 500 million people at risk; 6 million visually impaired
Malaria	46,486	1,272,390	related to poor water management, water storage, operation of water points, and drainage; 90% of deaths in children under 5
Onchocerciasis	484	(<5)	related to poor water management in large-scale projects
Dengue fever	616	18,560	related to drainage water organically polluted, open sewers, eutrophied ponds
Lymphatic filariasis	5,777	417	related to poor water management, water storage, operation of water points, and drainage

people who lack adequate sanitation, the majority live in Asia (Cairncross 2003).

When recycled appropriately, human waste can be a useful resource that promotes soil fertility (Esrey 2002). However, where waste contains persistent chemicals such as organochlorines or heavy metals, recycling onto land can lead to the accumulation of these pollutants and increased human exposure through food and water; this may contribute to a wide range of chronic diseases.

16.1.2.7 Climate Regulation

Climate regulation is an important property of Earth's natural systems. Each of the ecological services referred to above is sensitive to climate, and will be affected by climate change. Although climate change will have some beneficial effects on human health, most effects are expected to be negative (IPCC 2001).

Direct effects such as increased mortality from heat waves are readily predicted but indirect effects are likely to predominate (IPCC 2001; WHO/WMO/UNEP 2003). Human health is likely to be affected indirectly by changes in productive ecosystems and the availability of food, water, and energy supplies. These changes will in turn affect the distribution of infectious diseases, nutritional status, and patterns of human settlement. Changes in the geographic distribution, abundance, and behavior of plants and animals affect, and are affected by, biodiversity, nutrient cycling, and waste processing.

Attempts have been made to estimate the global burden of disease attributable to climate change (WHO 2002). But so far only a small fraction of the health outcomes associated with climate change have been included in the global burden of disease calculations, selected on the basis of sensitivity to climate variation, predicted future importance, and availability/feasibility of quantitative global models. (See Box 16.2.)

16.1.2.8 Flood and Storm Control

Climate extremes, including floods, storms, and droughts, have local and sometimes regional effects, both directly through deaths and injuries, and indirectly through economic disruption and population displacement. Extreme climate events are expected to increase as a result of climate change (WHO/WMO/UNEP 2003).

Health effects of climate extremes include physical injuries, increases in communicable diseases due to crowding, lack of clean water and lack of shelter, poor nutritional status, and adverse effects on mental health (Hajat et al. 2003).

One example was the floods along the Yangtze River in 1998. For years, loggers had been cutting forests along the river's watershed, and farmers and urban developers had gradually moved to occupy the river's flood plains by draining lakes and wetlands. Record rains fell in the Yangtze basin in the summer of 1998, and these degrading practices amplified the flooding, leaving 3,600 people dead, 14 million homeless, and $36 billion in economic losses. Restoring the ecosystem's flood control services would now take decades and billion of dollars (UNEP 2002).

Globally, the number of people killed, injured, or made homeless by natural disasters is increasing (WHO/WMO/UNEP 2003). An important reason for this is increasing settlement on coasts and floodplains that are exposed to extreme events. A number of case studies at the local scale have shown that human interactions with ecosystems have also contributed to increasing human vulnerability. Healthy ecosystems provide a buffer against the damaging effects of climate extremes. For example, forests absorb rainfall and reduce rapid increases in runoff, reducing flooding and soil erosion. Coral reefs and mangroves stabilize coastlines, limiting the damaging effect of storm surges. (See MA *Current State and Trends,* Chapters 9 and 16.)

In many areas the only land available to poor communities is that with few natural defenses against weather extremes. In recent decades, there has been a large migration to cities and more than half the world's population now lives in high-density urban areas. Such migration and increasing vulnerability means that even without increasing numbers of extreme events, losses attributable to each event will tend to increase (WHO/WMO/UNEP 2003).

BOX 16.2

Global Burden of Disease Attributable to Climate Change (WHO/WMO/UNEP 2003)

- Climate change will affect the pattern of deaths from exposure to high or low temperatures. However, the effect on actual disease burden cannot be quantified, as we do not know to what extent deaths during thermal extremes are in sick/frail persons who would have died soon. In 2030, the estimated risk of diarrhea will be up to 10% higher in some regions than if no climate change occurred. Since few studies have characterized this particular exposure-response relationship, these estimates are uncertain.
- Estimated effects on malnutrition vary markedly among regions. By 2030, the relative risks for unmitigated emissions, relative to no climate change, vary from a significant increase in the Southeast Asia region to a small decrease in the Western Pacific. Overall, although the estimates of changes in risk are somewhat unstable because of regional variation in rainfall, they refer to a major existing disease burden entailing large numbers of people.
- The estimated proportional changes in the numbers of people killed or injured in coastal floods are large, although they refer to low absolute burdens. Impacts of inland floods are predicted to increase by a similar proportion, and would generally cause a greater acute rise in disease burden. While these proportional increases are similar in industrial and developing regions, the baseline rates are much higher in developing countries.
- Changes in various vector-borne infectious diseases are predicted. This is particularly so for malaria in regions bordering current endemic zones. Smaller changes would occur in areas where the disease is currently endemic. Most temperate regions would remain unsuitable for transmission, because either they remain climatically unsuitable (as in most of Europe) or socioeconomic conditions are likely to remain unsuitable for reinvasion (for example, in the southern United States). Important causes of uncertainty in these forecasts include extrapolation between regions and the factors that translate potential into actual transmission.
- If our understanding of broad relationships between climate and disease is accurate, then climate change may already be affecting human health. The total current estimated burden is small relative to other major risk factors measured under the same framework. However, in contrast to many other risk factors, climate change and its associated risks are increasing rather than decreasing over time.

16.1.2.9 Cultural, Spiritual, and Recreational Services

Cultural services may be less tangible than material services but are nonetheless highly valued by people in all societies. People obtain diverse nonmaterial benefits from ecosystems. These benefits include recreational facilities and tourism, aesthetic appreciation, inspiration, a sense of place, and educational value. There are traditional practices linked to ecosystem services that have 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 that of gardens, may benefit physical and mental health. There is limited evidence that this may help in the prevention and treatment of depression, drug addiction, behavioral 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. Such contact with nature need not be physical; for example, some benefit may be obtained purely from visual or even visualized (imaginary) contact. On the other hand, it would follow that knowledge of the loss of valued ecosystems, even if such knowledge is indirect, may cause a profound sense of loss, and even harm health.

16.1.3 Health in Scenarios

The effects of ecosystem change on well-being in future decades are explored in this assessment using four scenarios. (See MA *Scenarios,* Chapter 11.) Each scenario describes a plausible future for the linked global socioecological system. Health is an ''integrating'' outcome of the distribution and interaction of ecosystem and human services. Institutions—the main legal, cultural, and attitudinal currents that flow through society—were found to be a crucial determinant of the protection of ecosystem services, human services, and human health.

In three of the four scenarios, global health was found—very broadly—to improve, while in one scenario the health of low-income populations, which currently constitute the majority of the global population, remained unchanged or worse. Importantly, caveats were identified in the three more optimistic scenarios, whereby each could have significant adverse health effects.

Society needs to balance technological and institutional development. Belief in the ability of technology alone to solve the human predicament is unwarranted. On the other hand, the size and environmental impact of the still-growing global population requires the extension and deepening of many forms of technology. The incorporation of economic, social, and health costs into measurements of progress is an important institutional change to facilitate this balance, by providing measurable feedback.

Approaches that perpetuate or worsen social inequalities may protect the health of privileged populations but are likely to result in the worst global health outcome overall. Globalization processes increasingly link the health and well-being of privileged with poor populations. A selective approach whereby the health and well-being of a small fraction of the global population is promoted at the expense of the majority entails a high risk for both populations. Humans possess the cognitive and organizational capacity to maintain or even improve global health in the next decades, but this will require substantial goodwill, cooperation, and work.

16.1.4 Typologies of Response Options and How They Apply to Health

International, national, and community responses to global ecosystem changes include policies aimed at stopping and reversing the extent and rate of change (mitigation) and response options designed to effectively reduce the current and future impacts of those changes (adaptation). It is recognized that an unusual degree of anticipatory thinking is required to develop proactive response options for reducing potential future ecosystem impacts. Such options should complement, not replace, mitigation policies to slow or avert the process of change itself.

The impacts of ecosystem changes will be site-specific and path-dependent; that is, they will depend on local circumstances (Yohe and Ebi 2005). For example, malaria epidemics occur following rainy seasons in some regions, while epidemics occur during droughts in others. Further, these impacts will not be experienced evenly across a population; there will be particularly vulnerable subgroups. Therefore, public health response options (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, and also whom the interventions should target. Interventions can focus on local, national, regional, and international scales; and within these, vulnerable subgroups.

As discussed in Chapter 3, the nature of the response options can be legal, economic and financial, institutional, social and behavioral, technological, and cognitive. As discussed in Chapter 19, within each of these, there may be gender issues that could affect not only the efficiency and effectiveness of interventions, but also future development. Effects on health may be complex, and follow a variety of causal pathways. For example, developments in agriculture that have dramatically lowered the cost of food in many countries have removed the threat of undernutrition, but have provided conditions for the emergence of new disease-causing agents (such as antibiotic-resistant *Salmonella*) (Waltner-Toews 2001).

The vulnerability of a particular population to the potential health impacts of ecosystem change will depend on the degree to which individuals and systems are susceptible to, or unable to cope with, these changes. Vulnerability depends upon the level of exposure, the sensitivity (or exposure-response relationship); and the response options in place to reduce the burden of a particular adverse health outcome (Ebi et al. 2005).

Populations, subgroups, and systems that cannot or will not adapt are more vulnerable, as are those who are more susceptible to ecosystem change. Population subgroups may not have the resilience to adapt because of a lack of material resources, lack of relevant information, lack of effective governance and civil institutions, and lack of public health infrastructure (Woodward et al. 2000). The effective targeting of interventions requires understanding which demographic or geographic subpopulations may be most at risk, the factors that contribute to their vulnerability, and which of these factors can be modified within the context of a particular time and location. Thus individual, community, and geographical factors determine vulnerability.

Response options can aim to reduce current and/or future vulnerability. Adaptive capacity describes the general ability of institutions, systems, and individuals to adjust to potential damages, to take advantage of opportunities, and minimize the long-term consequences (Smit et al. 2001). Specific options arise from the adaptive capacity of a population. Adaptive capacity encompasses coping capacity (what could be implemented now to minimize potential damage from ecosystem change) and the response options that have the potential to expand future coping capacity. Specific options arise from the coping capacity of a community, nation, or region. The primary goal of building adaptive capacity is to reduce future premature death, avoidable disease, and disease-related discomfort and disability in a population arising from ecosystem change. Examples illustrating these various concepts are shown in Table 16.3.

Response options encompass both spontaneous responses to ecosystem change by affected individuals and planned interventions by governments or other institutions. Examples of the latter include watershed protection policies or effective public warning systems for drinking water quality. In many cases, continuing and strengthening established interventions may be the best approach to reducing vulnerability and increasing adaptive capacity, while in other cases, new response options will need to be developed (Ebi et al. 2005). Increasing the adaptive capacity of a population shares similar goals with sustainable development—to increase the ability of nations, communities, and individuals to effectively and efficiently cope with the changes and challenges of ecosystem change. (See Chapter 19.) Public health scientists describe response options in terms of primary, secondary, and tertiary prevention. Primary prevention aims to prevent exposure to risk of disease in an otherwise unaffected population (for example, the supply of bednets to all members of a population at risk of exposure to malaria). Secondary prevention entails preventive actions in response to early evidence of health impacts (for example, strengthening disease surveillance and responding adequately to disease outbreaks such as the West Nile virus outbreak in North America). Tertiary prevention consists of measures to reduce long-term impairments and disabilities and to minimize suffering caused by existing disease. In general, secondary and tertiary prevention is less effective, and more expensive, than primary prevention.

The attributes of different risks affect the choice of response options, including spatial extent (the extent of land cover change or of an epidemic); speed of onset (how rapidly the event occurs, either building slowly like a drought or coming quickly like a flash flood; the slow spread of malaria or the rapid speed of an outbreak of influenza); the number of potentially affected individuals (the response to an isolated case of plague versus an epidemic of dengue fever); the onset-to-peak interval (how long it takes from the first detection to the maximum level of the hazard, such as the first impacts of a flood to its peak magnitude, or the first detected cases of a disease to its maximum prevalence); and the expected frequency or return period (frequency of drought or floods, periodicity of disease epidemics).

Other factors affecting choice of responses include knowledge and understanding of the underlying processes or causes; capacity to predict, forecast, and warn; capacity to respond (institutional and otherwise); how the risk might change over time and with ecosystem change; and ethical appropriateness.

Many of the possible response options to ecosystem change lie primarily outside the direct control of the health sector. They are rooted in areas such as sanitation and water supply, education, agriculture, trade, tourism, transport, development, and housing. Inter-sectoral and cross-sectoral integrated options are needed to reduce the potential health impacts of ecosystem change. These integrated interventions should address the social, economic, and demographic driving forces of and responses to ecosystem change.

Figure 16.2 follows an epidemiological, causal pathway approach (Corvalan et al. 2000). This highlights the main driving forces that are linked to health determinants (existing infrastructure, social values, and general social, economic, and demographic conditions); the specific exposures at different levels (either as distant, often indirect, or proximate, often direct, as well as ranging from global to local scales); the health impacts (or the positive health consequences if seen from the point of view of ecosystem protection); how these links are modified by population vulnerability; and how society (or individuals) respond, in the form of interventions at all levels (improving on the basic conditions under driving forces, reducing exposures or providing health-specific interventions).

16.2 Response Options and Actions outside the Health Sector

Factors that need to be considered when evaluating evidence that the protection of ecosystems avoided adverse health impacts include: the strength of the evidence; the plausibility of the association (that is, a probable or demonstrated etiologic chain); the presence of supporting or contradictory evidence from non-human systems; the extent that contextual factors and competing influences could explain the adverse health impact; the policies and interventions in place that could affect the exposure-response

Table 16.3. Examples of Current and Future Vulnerability and Adaptation (Kovats et al. 2003)

Definition	Current example	Future example
Vulnerability: degree to which individuals and systems are susceptible to or unable to cope with the adverse effects of climate change	populations living in areas on the fringe of the current distribution of malaria are at risk for epidemics if the range of the *Anopheles* vector changes	whether these populations might be vulnerable in the future depends, in part, on the implementation of effective prevention activities
Adaptation Baseline: the adaptation measures and actions in place in a region or community to reduce the burden of a particular health outcome	the exposure-response relationship is influenced by the current prevention measures aimed at reducing the burden of a disease; for example, the number of elderly adversely affected by a heat wave will depend on the numbers that have access to and use air conditioning during a heat wave	increasing access to and use of air conditioning will decrease the percentage of the elderly population that could be adversely affected by future heat waves; for example, the consequences of the 1995 heat wave in the midwestern United States were greater than those for a similar heat wave in 1999, in part because of programs established in the interim
Coping Capacity: the adaptation strategies, policies and measures that could be implemented now; specific adaptation plans arise from a region or community's coping capacity	a number of cities in mid-latitude countries have the level of material resources, effective institutions, and quality of public health infrastructure to establish and maintain early warning systems for heat waves; until implemented, these systems are within a city's coping capacity	over time, strategies, policies, and measures can move from being possible to being implemented (that is, being part of the adaptation baseline); for example, providing universal access to adequate quantities of clean water is not yet possible, although significant progress has been made
Adaptive Capacity: the general ability of institutions, systems, and individuals to adjust to potential damage, to take advantage of opportunities, or to cope with the consequences	adaptive capacity is the theoretical ability of a region or community to respond to the threats and opportunities presented by climate change. It is affected by a number of factors and encompasses coping capacity and the strategies, policies, and measures that have the potential to expand future coping capacity; for example, education of women provides a range of benefits to a population that results in increased ability to deal with challenges and changes	over time, it is hoped that regions and communities will increase their adaptive ability and their resilience to what future climates will bring

relationship; and the timing, scale, and location of the assessment (Scheraga et al. 2003). Assessments made at one point in time or at one location may provide different answers when the evaluations are repeated over time or over larger geographic areas.

16.2.1 Case Study: Climate Change, Land Use Changes, and Tick-borne Diseases—Illustrative Example from Sweden

Diseases transmitted by blood-sucking ticks are especially sensitive to changes in the local environment, particularly alterations caused by land use or by land cover changes and changed climatic conditions. (See MA *Current State and Trends,* Chapter 14.) The climate sets the limit for both the altitude and latitude distribution of ticks and is important for tick population density. Biodiversity and species composition may affect the transmission of pathogens in nature and, hence, the risk of disease in an area (LoGiudice et al. 2003).

Ixodid ticks, which live for up to three years, may transmit several diseases, of which the most important are Lyme disease and the severe form of tick-borne encephalitis. The latter is endemic in Europe and in most western parts of Eurasia, whereas Lyme disease is prevalent throughout the temperate zones of the Northern Hemisphere. About 85,000 cases of Lyme disease are reported in Europe annually compared to 15–20,000 cases in the United States (Steere 2001).

Over the last two decades, the incidence of Lyme disease and tick-borne encephalitis has increased in endemic regions. This is partly because of increased reporting through greater awareness among health personnel and the general public. However, case studies from Sweden have shown that a real increase in both tick population density and in disease incidence has occurred since the early 1980s, and that ticks have expanded their distribution range northward (Talleklint and Jaenson 1998). These changes have been associated with milder and shorter winters (Lindgren et al. 2000; Lindgren and Gustafson 2001).

Research findings have enabled preliminary predictions to be made every year in early spring; that is, prediction of whether the coming year is a potentially high-risk year for tick bites. Swedish newspapers, radio, and television news now address the risk of tick-borne encephalitis and Lyme disease repeatedly each year when the tick-activity season starts. High-risk areas are shown, new risk areas pointed out, and effective preventive measures are mentioned, such as removal of thick undergrowth vegetation in parks and gardens, and daily body inspection for rapid detection and removal of ticks. The latter decrease the risk for Lyme disease but do not protect against the transmission of tick-borne encephalitis. Before the high-risk season begins, tick-borne encephalitis vaccination is made easily accessible for people living or working in or visiting endemic areas.

16.2.2 Case Study: Responding to the Risk of Water-borne Campylobacteriosis

From hunter-gatherer societies through agricultural societies to industrial societies, human settlements have always centered on a

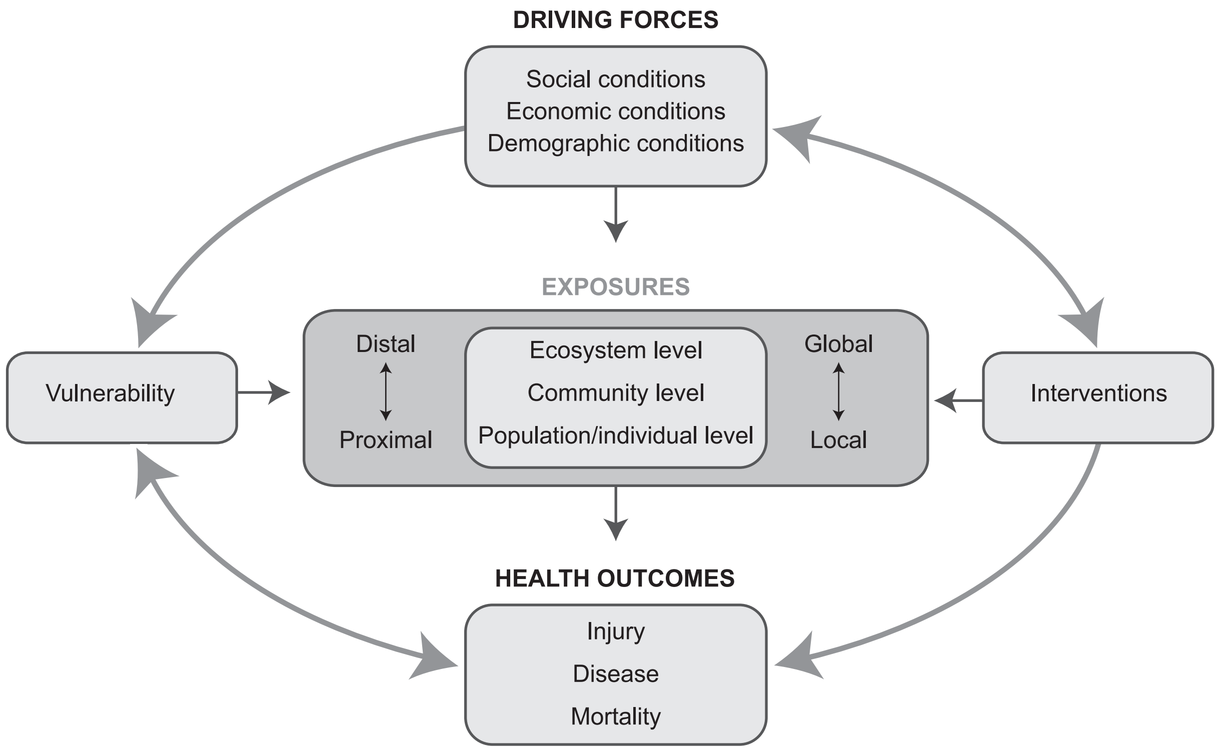

Figure 16.2. Causal Pathway from Driving Forces, through Exposures to Health Outcomes, in the Context of Ecosystem Change. The impacts are modified by the population's vulnerability and the interventions implemented.

reliable supply of good quality fresh water. When supplies have been disrupted, the effects of thirst upon health are immediate and can be rapidly fatal. When water quality has been compromised, we have seen some of the largest disease outbreaks the world has known. Human settlements have, therefore, always been dependent on healthy freshwater ecosystems to supply potable water, and water catchment protection is so ingrained in public health culture that it is often taken for granted. In modern times, water treatment plants have fulfilled a ''magic bullet'' role and have arguably taken the edge off the perceived importance of catchment protection—that is, until outbreaks of waterborne illness in rich countries started to seriously shake public confidence in public water supplies.

Campylobacterosis is a gastrointestinal disease that may be spread by food or by water and was first recognized as an ''emerging'' human disease in the late 1970s. Campyobacteriosis is now the most commonly reported infectious disease in rich countries. The disease is prevalent among domesticated animals such as poultry, sheep, and cattle, and transmission to humans depends on ''survival trajectories'' followed by the pathogen between excretion from the reservoir and ingestion by the case (Skelly and Weinstein 2003). The life-cycle of this organism can be complex and its survival in the environment is subject to the influence of a variety of abiotic factors. Pastoral farming has a major impact on both water flow and quality. As vegetation is lost from hillsides and riverbanks, the volume and speed of runoff increases. The natural purification of water percolating through soil and vegetation is also reduced. This exposes both livestock and humans downstream to a variety of zoonotic pathogens, including *Campylobacter, Cryptosporidium,* and *Giardia.*

Current preventive measures for controlling transmission and infection with *Campylobacter* include food and farm hygiene, thorough cooking (or irradiation) of food, use of pasteurized milk and chlorinated water supplies, and control of the disease in domestic and domesticated animals (Chin 2000). Although compliance with these measures is difficult to formally assess, there is little question that they contribute significantly to a reduction of the disease burden, and should be maintained and encouraged on that basis. However, they have failed to arrest the rapid rise of campylobacteriosis. It is appropriate, therefore, to also consider public health interventions based on restoring the health of freshwater ecosystems.

Slowing runoff is important because of the limited survival of fecal pathogens, whose half-lives are more likely to be exceeded before human exposure occurs. Waters from catchments with native vegetation are least likely to contain viable pathogens; revegetation could therefore be advocated as a public health intervention. Importantly, it is not only the direct transmission of *Campylobacter* in drinking or recreational water exposure that will be affected. If livestock infections are also decreased as a result of regrowth of native plants in water catchments, the number of human infections acquired occupationally (farm, abattoir) and by the food-borne route (animal products) will also be reduced.

The lesson from this case study is that, in many cases, scientifically based public health interventions can be devised only with an understanding of the ecology of the disease.

16.2.3 Case Study: Linking Ecosystems and Social Systems for Health and Sustainability—River Catchments

The management of river catchments poses an emerging ''upstream'' public health issue—spanning concerns regarding the safety and sustainability of freshwater ecosystems, socioeconomic development, and multistakeholder governance processes. As such, river catchment management has implications for both the environmental and socioeconomic determinants of health and exemplifies the importance of response options and actions *outside* the health sector.

During the 1990s, water governance priorities shifted from their developmental focus on infrastructure provision (domestic water supply, sanitation, and irrigation) to recognize the critical need for an ecosystems approach that manages freshwater resources as an integral part of natural cycles (UNCSD 1998; World Water Forum 2000; Helming and Kuylenstierna 2001). Priorities for water resource management at the turn of the twenty-first century include recognition and maintenance of: (1) catchments as critical to the management of freshwater ecosystems—enabling fresh waters to be viewed within a landscape or systems context; (2) the socioeconomic, ecological, and human health values of freshwater ecosystems, their services, and functions; (3) processes that support freshwater ecosystem integrity, structure, function, and adaptive capacity, including quality, quantity, and timing of flow (Baron et al. 2002); and (4) protecting the determinants of health through catchment management.

The place-based links between environmental and socioeconomic determinants of health were examined in a case study of catchment (ecosystems) and community (social systems) in New Zealand's Taieri River catchment. In the Taieri Catchment & Community Health Project, public health issues of concern ranged from the direct health impacts associated with the ecological determinants of water-related disease to the indirect health impacts of catchment management, freshwater ecosystem change, and rural sustainability—mediated through socioeconomic determinants of health (Duncanson et al. 2000; Hales et al. 2003; Skelly and Weinstein 2003).

The Taieri catchment case study combined knowledge generation with actions to address the social and ecological dimensions of catchment and community health issues. The multi-method study examined the links between ecosystem change and the determinants of health through socioecological analysis of knowledge strengths and deficits in the catchment; community-oriented participatory action research with diverse catchment stakeholders; and selected collaborative research initiatives—including a whole catchment questionnaire survey and specific biophysical studies. All phases of the research were based on building collaborative relationships with community reference groups (including residents living throughout the 5,650 square kilometer rural catchment) and co-researchers (included agencies, researchers, and indigenous organizations involved with science and decision-making regarding environment, health, development, and conservation issues in the catchment).

The catchment case study drew attention to the linked role of ecosystems and social systems as a mutually reinforcing basis for health, experienced as healthy living systems, livelihoods, and lifestyles. There was a transition from a research-initiated project through a "Community-University Partnership" to the "Taieri Alliance for Information Exchange and River Improvement" (the TAIERI Trust). This trust represents a shift from separate university and community interests to an integrated organization combining the interests of community, academic, and agency stakeholders to foster the health and sustainability of the river and local communities. This collaborative approach to knowledge, participation, and action demonstrates the application of successful decision-making processes into the research setting.

This case study strengthens the argument that place-based actions outside the health sector can respond to environmental and socioeconomic concerns—building resilient ecosystems and social systems that provide a double dividend for health and sustainability. Research and experience in the Taieri catchment case study led to the recommendation for ECO-PAR (Ecosystem-based Community-oriented Participatory Action Research) as a generic approach to integrated, collaborative health, and sustainability research. ECO-PAR is founded on interaction between knowledge, participation, and action and facilitates a unified approach to ecosystems, social systems, health, and sustainability (Parkes et al. 2003).

16.2.4 Case Study: Ciguatera (Fish Poisoning) and Ecological Change

Certain marine algae produce potent toxins that cause illness when consumed via contaminated fish or shellfish. The number and geographic distribution of harmful algal blooms appears to have increased in recent decades, in parallel with other changes in marine ecosystems, nutrient contamination of waterways, and climatic change (van Dolah 2000). There are several clinical syndromes associated with these events. The most common is ciguatera (fish poisoning) caused by consuming reef fish contaminated with algal toxins.

Traditional environmental health practice has focused on direct effects of pollutants on human health. Ciguatera is an example of a different kind of environmental problem. Morris (1999) writes, "Harmful algal blooms are an example of an alternative paradigm, in which human-induced stress on complex living systems leads to the emergence of new, potentially harmful microorganisms (or the reemergence of 'old' pathogens from previously restricted environmental niches), which, in turn, cause human disease."

Figure 16.3 illustrates some of the potential social and ecological drivers of ciguatera and the pathways to health impacts. Indirect drivers of change (population increase and resource consumption) affect direct drivers (global climate change and land use change). Rise in sea surface temperature, contaminated runoff, and other anthropogenic factors lead to disturbance of the marine ecosystem (including coral bleaching), increased growth of toxic algae, and contamination of reef fish. This, in turn, causes

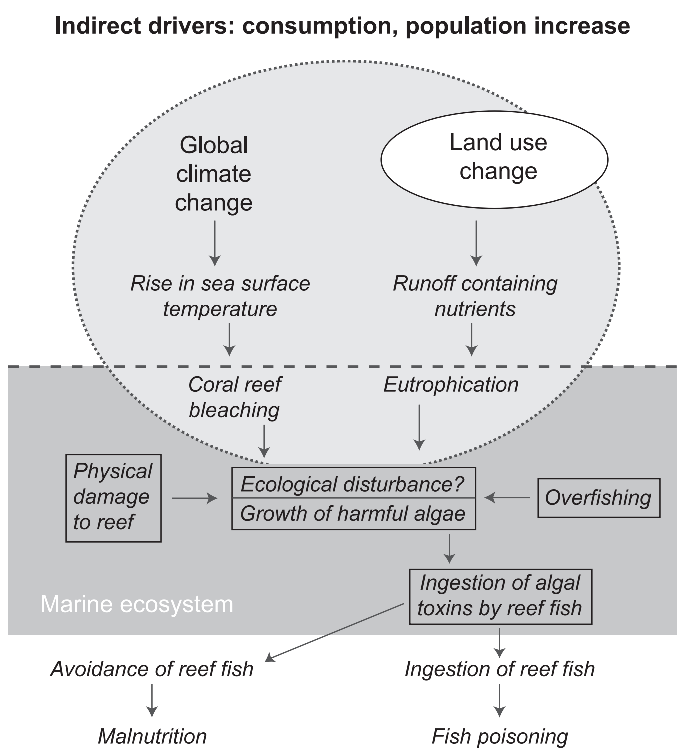

Figure 16.3. Potential Ecological Pathways in Fish Poisoning (Ciguatera)

ciguatera in people consuming the reef fish, or alternatively, it causes people in island communities to avoid this important protein source, potentially leading to malnutrition.

16.3 Response Options and Actions by the Health Sector

In order to respond effectively to threats from ecosystem change, the health sector must be able to carry out effective monitoring and surveillance of disease and risk factors for disease; interpret data provided by surveillance systems; use surveillance data in conjunction with environmental and other data to develop models to predict disease occurrence; link changes in disease rates to specific environmental factors; and intervene to remove the causes of disease or to lessen the damage they cause (Wilson and Anker 2005).

Tracking death registrations through periods of extreme weather is an example of the first condition for effective response (Hajat and Kovats 2002). An example of the second is the capacity to relate changing patterns of communicable disease to climate variability (Hales et al. 1999a; Hales et al. 1999b). The 2003/2004 epidemic of severe acute respiratory syndrome showed how quickly new pathogens can spread around the world. The source of SARS is not known but organisms of the kind that caused SARS frequently emerge from human disruption of biota-rich ecosystems. In this instance, public health systems in a large number of countries responded effectively to the threat of a global epidemic and provide an example of the third category of response options (WHO 2003b).

Pressures on the health sector as a result of ecosystem disturbance are likely to be most acute in developing countries. Ways in which these pressures could be reduced include:

- strengthening environmental health services;
- providing technical and financial assistance to implement the Health for All strategy, including health information systems and integrated databases on development hazards;
- strengthening advocacy and health communications at all levels; reviewing delivery of basic health services at the local level to ensure that priority problems of poor people are adequately addressed;
- making 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;
- implementing long-range health and human resource planning to train, recruit, and retain staff and developing codes of conduct for international recruitment of health professionals;
- strengthening health services for displaced communities and those affected by war or famine or environmental degradation;
- implementing health impact assessment of major development projects, policies, and programs and monitoring indicators for health and sustainable development (WEHAB 2002c).

The following sections examine in more detail some of the actions that can be taken by the health sector to lessen harmful effects of ecosystem damage on human populations.

16.3.1 Improved Decision-making in the Health Sector

Decisions affecting ecological systems, whether by politicians or private organizations and individuals, are determined by a wide range of inputs. These include empirical evidence, value systems, and financial constraints. Despite this complexity, the health community has an important role to play in presenting evidence of likely public health consequences from any environmental change. Important policy decisions such as legislation on environmental lead, asbestos, and secondary tobacco smoke are largely dependent on health scientists measuring the links between these exposures and health outcomes, reaching a reasonably broad consensus, and presenting these findings to policy-makers. In these cases, the demonstration of a clear and significant health risk has taken precedence over other competing influences. Although most of the success stories are for environmental factors acting at a local level, examples such as the Montreal Protocol on CFC emissions show that health considerations can also be important in influencing decisions on global environmental issues.

16.3.2 Methods for Measuring and Prioritizing Environmental Influences on Health

In recent years, there have been important methodological developments in the linkages between environment and disease databases and in quantitative analytical techniques demonstrating relationships between them. (See Box 16.3.)

These linkage methods could potentially be applied to wide-area ecological measures other than climate. One such study correlated World Resources Institute measures of ''ecological disintegrity'' against data on life expectancy, infant mortality, and percent low-birth-weight babies for 203 countries (Sieswerda et al. 2001). There was a ''modest relationship'' between the ecological and health measures, but Sieswerda et al. pointed out that these relationships are inconsistent, the data are of uneven quality, and that other factors (such as GDP) appear to have a stronger influence. Another linkage study found no evidence of a negative relationship between loss of biodiversity and human health at the global scale (Huynen et al. 2004).

In the last decade, the World Health Organization promoted the use of ''burden of disease'' assessments. These measures express the total health effect (including both mortality and morbidity) of any disease or risk factor. The most widely used units of disease burden are DALYs, the sum of years of life lost from premature death (taking into account the age of death compared to natural life expectancy) and the number of years of life lived with a disability (taking into account the duration of the disease and weighted by a measure of the severity of the disease) (Murray et al. 1994); One advantage of these measures in the context of environmental change is that they allow impacts of different causal pathways to be combined, such as the combined effects of climate change on infectious diseases, malnutrition, and the impacts of natural disasters (WHO/WMO/UNEP 2003). This potentially allows direct comparisons of the effects of different ecological changes and can therefore help set priorities.

Burden-of-disease assessments depend on access to sufficient quantitative data to relate changes in the risk factor to the incidence of specific diseases. In the environmental health field, they have therefore been most successfully applied to discrete and relatively localized environmental factors with well-characterized health effects, such as air pollution and environmental lead. It is more difficult to apply these assessments to ecosystem changes acting through more diffuse causal pathways. For example, it is plausible, or even probable, that the reduced availability of fresh water would adversely affect health by increasing a range of water-borne diseases and through effects on agriculture, therefore negatively impacting food availability. It is, however, impossible to make accurate quantitative measurements of their contribution, in the context of the multitude of other causal factors, such as human behavior and economic influences on agricultural production.

BOX 16.3

Developments in Linking Disease to Environmental Factors

Advances in computing power and software have facilitated linkages between environmental and disease databases, and have therefore made epidemiological analyses of large-scale ecological change considerably more feasible. Exposure and disease data can be linked either in time or space. Time series methods are particularly well developed for studying the effects of air pollution. In essence, the process involves linking observations of temporal (typically daily) variations in exposure with a disease outcome measure at the same point, or with an appropriate time-lag afterwards. The quantitative relationship between the pollutant and disease outcome of concern can be defined by regression techniques (after specifying an appropriate error structure, and controlling for the effects of confounders such as seasonal variations) (Corvalan et al. 1997).

Geographic information system software can be used to link predictor and disease outcome data in space as well as over time. In addition, a wide range of satellite sensors provide detailed information on ecological characteristics such as vegetation, altitude, and climate, with complete global coverage at low or no cost. As for time series studies, regression techniques (again taking account of potential confounders and spatial auto-correlation between data points) can be used to quantify the relationship between ecological characteristics and disease outcomes.

The majority of studies of this type have been applied to specific diseases on a sub-national scale. Many of them are designed to generate predictive maps for disease control, but are equally applicable to measuring the effect of specific ecological characteristics (such as the proportion of land area covered by forest) and therefore allow estimation of the disease effects of alterations in these ecological conditions.

On a global scale, most attention has been focused on investigating the link between climate (and therefore climate change) and vector-borne disease. For example, maps of climate variables have been linked to maps of the distribution of both malaria (Rogers and Randolph 2000) and dengue (Hales et al. 2002) in order to define the climatic conditions under which each disease is most likely to occur. These statistical models can then be applied to scenarios of future climate change, to project plausible climate-driven changes in disease distribution into the future.

Linkage methods have been tried recently with broad area ecological measures, other than climate (Sieswerda et al. 2001). There was a "modest" but inconsistent relationship between the ecological and health measures, the data were of uneven quality, and other factors (such as GDP) appear to have a stronger influence. Another linkage study found no evidence of a negative relationship between loss of biodiversity and human health at the global scale (Huynen et al. 2004). Soskolne and Broemling (2002), in recognizing the importance that the health sector contributes, emphasize that methods are needed for developing sensitive measures capable of linking ecological degradation with health outcomes. Herein lies a challenge for eco-epidemiologists.

Considerations of time scale are important: the burden of disease attributable to climate change is modest compared to other risk factors over the short time scales for which most political decisions are taken (a five-year horizon, at most), but is more significant when impacts are considered over several decades (WHO/WMO/UNEP 2003). The discount rate chosen for DALY calculations has a very large effect on the rankings of long-term problems like climate change. The rate at which future gains and losses are discounted can be modified for the DALY formula, but the burden-of-disease framework fails to take into account that some environmental changes, such as biodiversity loss, are irreversible. There is no means of weighting effects from which there is no recovery. Finally, such frameworks do not account for the different valuation that people give to health risks over which they have direct individual control, compared to those controlled by the community as a whole or by other agencies. For example, there is greater concern over deaths among passive smokers rather than active smokers. Ecological changes usually fall into the category of externally imposed change.

Burden-of-disease assessments are therefore appropriate for aggregating health impacts through a range of mechanisms and can potentially aid in priority setting and decision-making in the context of ecosystem change. However, they must be considered as only one component of evidence, as they do not take full account of features such as complex causal pathways, long time-scales, potential irreversibility, and individual versus community responsibility (WHO/WMO/UNEP 2003). These important properties need to be included in the final considerations about any response to ecological change.

16.3.3 Methods for Selecting Interventions to Protect Health

Chapter 3 of this volume reviewed ways in which the effects of the environment on health and well-being may be measured. This chapter covers economic costing, environmental health indicators developed by WHO and subsequently applied in a variety of settings, and health impact assessment (Corvalan et al. 1999; Confalonieri 2001). When policy-makers contemplate decisions that impinge on human health they must make choices, and HIA is a means of laying out these choices so that significant consequences are not overlooked. These might include, for example, the effects on the health of communities and individuals of large-scale transport planning (Freeman and Scott-Samuel 2000).

HIA is a cousin of environmental impact assessment; both are related to integrated impact assessment (Hubel and Hedin 2000, Milner 2004). None require major changes to be applied to assessments of ecosystem change. For instance, Mutero (2002) adapted this approach to examine the effect of irrigation projects along the Tana River in Kenya on rates of schistosomiasis. HIA is not a "black box" for generating policy—it does not avoid the need for assumptions, approximations, improvisations, and value judgments; but it offers a systematic approach to collecting and appraising information, and for this reason, has the potential to improve the quality of decisions that affect the state of ecosystems and human health.

Cost-effectiveness analysis is increasingly used to select among different interventions to improve public health. Costs of interventions (usually measured in monetary terms) are considered alongside their resulting health gains (usually measured as deaths, or DALYs, averted). Outcomes from these analyses are quoted as cost-effectiveness ratios (for example, DALYs per dollar) as a measure of the value for money of the intervention, often along with aggregate costs and benefits, to represent the overall impact of the intervention. When applied in a rigorous and standardized manner, cost-effectiveness analysis can provide an objective ranking of the efficiency of different interventions. This allows policy-makers to select those that provide the greatest health gains for any specified level of resources.

Cost-effectiveness analysis requires quantitative data on all significant costs and benefits, which in turn requires an understanding of all the important links between the intervention and eventual health outcomes. Cost-effectiveness analysis has been employed where the intervention is clearly and directly linked to a health outcome, with relatively complete quantitative data on the relationships, such as selecting different options to improve water supplies to reduce diarrhea. Conceptually, it could equally be applied to decisions that act higher up the causal chain, such as the effect of land use policies on child health. This is seldom done, however, because the links are more diverse and complex, introducing greater uncertainty into the analysis. There are ways to determine the monetary value of nonmarket systems but these are not widely agreed upon.

16.3.4 Addressing Risk Perception and Communication

In order for any research on the health effects of ecological change to affect either official policy or individual behavior, it is necessary to take into account how risk is perceived. A deliberate and well-informed approach to community risk will maximize the chance of effective changes through policy interventions that enjoy popular support (Slovic 1999).

Any assessment of ecological change and health should be influenced by the risk perceptions of those communities that are most likely to be affected. That is, ecological assessments should involve open and frequent stakeholder participation from the beginning of the process rather than as an afterthought (Parkes et al. 2003). This approach of community engagement in the process serves the purpose of accessing local knowledge about the effects of ecological factors, ensuring that the assessment addresses issues of greatest concern to those affected and maximizing the probability that any recommended change in policy or behavior 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, while others (such as government agencies) are treated with caution (Maeda and Miyahara 2003). Healthcare providers tend to be one of the "high trust" groups, underlining again the important role they can play in explaining the significance of healthy ecosystems.

Any such consultation should make the best use of the expertise of both stakeholders and researchers. Stakeholders may have expert local knowledge but may have 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 inappropriately estimate the applicability of general concepts to local situations.

Accurate and accessible reporting of assessment results can remedy inaccurate risk perceptions and can enhance the public's ability to evaluate science/policy issues; the individual's ability to make rational personal choices is enhanced. In the past, poor reporting misled and disempowered a public that is increasingly affected by applications of science and technology (Myers and Raffensperger 1998). Stakeholder engagement will make it more likely that the research is credible and is translated into practice.

Technically intensive, externally driven interventions may produce rapid results but at the risk of marginalizing local communities. Interventions that engage local communities and transfer expertise are more likely to result in ecologically sustainable improvements.

16.4 Cross-sectoral Response Options and Actions

16.4.1 Health, Social Development, and Environmental Protection

Trends in inequality, resource consumption and depletion, environmental degradation, population growth, and ill health are closely interrelated (McMichael 1995). This means that better health, in the long term, will depend on cross-sectoral policies that promote ecologically sustainable development and address underlying driving forces. Agenda 21 and the Rio Declaration on Environment and Development describe a comprehensive approach to ecologically sustainable development incorporating cross-sectoral policies (McMichael 2000). The broader topic of sustainable development is discussed further in the next chapter. Examples of specific relevance to health are the following strategies, developed for the World Summit on Sustainable Development (WEHAB 2002c):

- mitigation strategies that reduce drivers 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 health impact assessment of major development projects, policies, and programs, 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 in poverty reduction strategies;
- improvement of inter-sectoral 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; and
- dissemination of knowledge and good practice on health gains from inter-sectoral policy.

The conventional indicators of population health, such as life expectancy, suggest that we have made considerable progress over the last hundred years in many parts of the world. Economic development and environmental protection are responsible for much of this improvement. An important lesson from history is that economic growth is a double-edged sword. On the one hand, it is the engine that generates wealth and opportunity; on the other hand, economic growth has tended to be socially disruptive and environmentally damaging. The experience of countries that industrialized early is that, initially, harmful effects predominated (Wohl 1983). What was needed to turn economic growth into social benefit was the development of robust, inclusive political processes and strong public institutions such as public health and local government (Szreter 1997).

What present-day summary indicators of health status fail to reveal is the gross inequalities within and among nations, between rural and urban areas, and among population subgroups. In some regions (such as southern Africa), life expectancy remains low and in, some instances, is falling further. Where gains have been made, they may be relatively fragile, as shown by the rapid deterioration of health statistics in Eastern Europe after the break-up of the Soviet Union. Underlying social and political factors include the change from politico-military colonialism to economic dependence, and migration from rural areas to urban centers resulting in unemployment, poverty, and social disruption (Avila-Pires 2003).

The accelerating rates of change brought about by high technology demand urgent solutions. On the positive side, the association of basic research with technological development proved to be a key factor in progress. But we need to find creative ways of extending its benefits to all. Technological progress implies social change and we must stimulate a corresponding effort from sociologists and philosophers to help us understand and cope with the swift pace of change.

16.4.2 Linking Health and Ecosystem Responses

For each category of ecosystem services, we have extracted from earlier sections of the report a sample of recommended responses. (See Table 16.4.) In each instance, we have listed some of the possible effects that these responses could have on human health. For simplicity these are illustrative lists, not intended to be exhaustive.

Table 16.4 makes the case that in almost every category of ecosystem response the consequences for health may be either positive or negative. The balance will depend on how the policy or regulation is framed and what account is taken of contingencies and local circumstances. Using trade and economic levers to widen food markets, for instance, has been successful in some instances and, of course, increased food supply can lead to better health (FAO 2003). However, in other settings, ''globalizing'' policies have led to deepening poverty, diminished food security, and deteriorating standards of public health. This illustrates the fact that national strategies to protect ecosystem services and human health can be successful only if the global policy context is supportive.

Policies addressing human health needs in relation to food and nutrition, water and sanitation, and energy services have been developed as part of the ''water-energy-health-agriculture-biodiversity'' process and are summarized in Box 16.4. Implementation of these policies will depend on national and local circumstances. For example, in industrialized countries, integrating national agriculture and food security policies with the economic, social, and environmental goals of sustainable development could be achieved, in part, through taxes on food products to ensure that the environmental and social costs of production and consumption are fully reflected in the price. Taxes should be one element in a package of policies designed to protect the environment without jeopardizing food security for the most vulnerable groups in society. With that proviso, a full-cost approach to food pricing may bring major benefits to health and ecosystems, for instance through reduced consumption of animal products (WHO 2003a). Improvements to traditional fuels and cooking devices could lead to the prevention or at least reduced emissions of local air pollutants, while implementing better transportation practices and systems could lead to increased physical activity in sedentary populations as well as reductions in greenhouse gas emissions (Von Schirnding and Yach 2002; WEHAB 2002b).

16.5 Conclusion

Ecosystem disruption damages health in a variety of ways and through complex pathways. The links between ecosystem change and human health are seen most clearly among impoverished communities (who lack the ''buffers'' that the rich can afford).

Table 16.4. Examples of Potential Health Implications of Sectoral Responses

Ecosystem services under threat	Possible Responses	Possible Consequences for Health
Floods and storm control	waste-water management vegetation of water catchments	▲ improved water quality (fewer enteric infections) ▼ disease vector proliferation (e.g., urban wetlands)
Food production	economic and trade policies to increase reach of global markets	▲ more food choices—improved nutrition ▲ decreased poverty, consequent improvements in health ▼ reduced food security—especially for the most vulnerable groups (deepening poverty and reduction in health status)
Climate regulation	reduce greenhouse gas emissions (e.g., vehicle emission standards) carbon sequestration (e.g., reforestation)	▲ improved air quality ▲ improved water quality ▼ decreased access to health services for the poor ▼ increased fire risk ▼ displaced populations ▼ reduced food production
Wood, woodfuel and fiber	economic incentives for re-forestation	▲ reduced flood risk ▼ increased fire risk
Freshwaterwater	charges to reduce wasteful consumption infrastructure (e.g., dams and dikes)	▲ improved access to sectors in the population ▼ decreased access for low income groups—water-related diseases ▼ new habitat for disease vectors
Wastes	increase recycling reduce amounts of waste	▲ decreased toxic emissions (e.g. from incinerated waste) ▼ vector-breeding sites—more mosquito-borne disease

Key: ▲ Improved health ▼ Impaired health

BOX 16.4

Examples of Responses to Improve Human Health (WEHAB 2002a, 2002b, 2002d)

Food and nutrition responses that can improve human health include:
- integrate national agriculture and food security policies with the economic, social, and environmental goals of sustainable development;
- ensure equitable access to agriculture-related services and products, with particular focus on food security and sustainable livelihood needs of the poor;
- orient market forces toward environmentally optimal solutions through appropriate policies and regulations;
- exploit and expand locally available resources for improved food security and promoting diversification for more effective risk management;
- focus on needs of rural areas through decentralized cooperative initiatives and improvements in rural infrastructure; and
- strengthen regional and international cooperation for food security and market stability.

Water and sanitation responses to improve human health:
- assign the role of water-related public awareness to the agency responsible for integrated water resource management at the country level;
- institute gender-sensitive systems and policies;
- raise awareness and understanding of the linkages among water, sanitation, and hygiene and poverty alleviation and sustainable development;
- develop in partnership with all relevant actors community-level advocacy and training programs that contribute to improved household hygiene practices for the poor;
- identify best practices and lessons learned based on existing projects and programs related to provision of safe water and sanitation services focused on children;
- create multistakeholder partnership opportunities and alliances at all levels that directly focus on the reduction of child mortality through diseases associated with unsafe water, inadequate sanitation, and poor hygiene;
- develop national, regional, and global programs related to the provision of safe water and improved sanitation services for urban slums in general, and to meet the needs of children in particular; and
- identify water pollution prevention strategies adapted to local needs to reduce health hazards related to maternal and child mortality.

Energy and fuel responses to improve human health:
- reduce poverty by providing access to modern energy services in rural and peri-urban areas;
- minimize the environmental impacts of traditional fuels and cooking devices;
- improve air quality and public health through the introduction of cleaner vehicular fuels; and
- implement better transportation practices and systems in megacities.

This extends to subpopulations within wealthier communities who have relatively less access to ecosystem resources.

Poor communities are the most directly dependent upon productive ecosystems for their health. Measures to promote ecological sustainability will (by definition) safeguard ecosystem services and therefore benefit health in the long term. This means that the poorest and most disadvantaged individuals and communities can be among the first to benefit from ecosystem protection, leading to improvements in health equity.

A healthy community is more capable of sustainable development than an unhealthy one. Therefore, where a population is weighed down by diseases 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 healthy public policy.

Where disease is caused by unhealthy levels of consumption (especially of food or energy), substantial reductions in this overconsumption would have major health benefits as well as reducing pressure on ecosystems. Both human health and the environment are likely to benefit from a redistribution of resources if this leads to basic entitlements being distributed more equitably and a reduction in overconsumption. Such changes could improve health in the short term as well as contribute to long-term ecological sustainability. Win-win outcomes of this kind depend on how these changes in resource use and management are achieved.

Local conditions are critical in shaping the health manifestations of ecosystem disruption. Empirical evidence supporting the link between ecosystems and health is difficult to find. Our knowledge is increasing but there are still many gaps. One reason for this is the many confounding factors (associated with environmental change and also determinants of health) that are hard to measure and to separate from the effect of interest.

The effects of ecosystem disruption on health are frequently displaced, either transferred geographically (such as the costs of rich countries' food overconsumption) or postponed (as in the case of long-term consequences of climate change or desertification). Decisions about health and ecosystems must consider how one is related to the other. Choices that are made about the management of ecosystems may have important consequences for health, and vice versa. Healthy ecosystems protect human health; healthy people protect their ecosystems.

Decision-makers need to consider the connections between health and other sectors. Where there are ''win-win'' options, these will be attractive to policy-makers; where there are tradeoffs, it is important for politicians, regulators, and the public to understand the consequences of taking one path in preference to another. The health sector bears responsibility for revealing the links between ecological services and health and indicating which interventions are needed: this is despite the fact that responses and interventions to protect human health are often carried out in other sectors.

Consideration of ecosystem change enlarges the scope of health responses by highlighting ''upstream'' causes of disease and injury. This implies that health considerations should weigh heavily in decisions on ecosystem responses. History shows that health is one of the most highly valued social outcomes.

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