3

Global environmental change and health: integrating knowledge from natural, socioeconomic and medical sciences

Rik Leemans[#]

Abstract

Environmental problems, such as air quality, pollution and toxicity, have historically strongly been linked with health issues. The earliest environmental policies were targeted to negate health impacts. This focus has become less obvious during the last decades when environmental problems became more diffuse and covered larger areas and regions. Nowadays, degradation of natural resources, climate change and the decline in biodiversity are the major environmental problems. To deal effectively with these problem international conventions and national policies strongly relate also to developmental issues, equity and improved human well-being.

The Millennium Ecosystem Assessment (MA; www.millenniumassessment.org), a four-year international work programme designed to meet the needs of decision-makers for scientific information on ecosystem change, has taken up the challenge to comprehensively assess the consequences of environmental change for ecosystems, ecosystems services and human well-being. The MA focuses on how changes in ecosystem services have affected human well-being, how ecosystem changes may affect people in future decades, and what types of responses can be adopted at local, national or global scales to improve ecosystem management and thereby contribute to human well-being and poverty alleviation. Health is one of the central themes in the Millennium Assessment.

Keywords: ecosystems; ecosystem services; integrated assessment; human well-being; global change; UN conventions; Millennium Ecosystem Assessment

Introduction

Environmental problems, such as air quality, pollution and toxicity, have historically strongly been linked with health issues. The earliest environmental policies were actually targeted to negate health impacts. For example, in the early days of industrialization, the burning of coal in small local furnaces caused severe pollution in cities. Newspaper headlines clearly linked smog events to death incidences. This led to respiratory diseases and adversely impacted health. In the middle of the last century, the causal relationships between air-pollution and health were clearly understood. This led to a series of diverse policies. In general smoke stacks were raised, improved furnaces and, in some cases, transitions to other fuels

[#] Environmental Systems Analysis Group, Wageningen Univ., P.O. Box 47, 6700 AA Wageningen, The Netherlands. E-mail: rik.leemans@wur.nl

were implemented. Health concerns were the prime reason for the revolutionary shift from coal to natural gas in The Netherlands. In a military-like campaign, 90% of all households were coupled to the natural gas grid in less than 7 years, after large amounts of natural gas were discovered close to the village of Slochteren. Simultaneously, the Dutch coal mines were closed. This event rapidly improved air quality in The Netherlands. Also many became aware of the immediate threat of toxic substances that were cumulating in the environment and food chains. Carson's book 'Silent Spring' (1962) is widely recognized as the onset of increasing awareness of environmental threats and the urgency to mitigate them.

However, many of the measures taken did not really reduce pollution levels but merely diluted them. The immediate health effects were much less obvious and could only be assessed by detailed and long-term epidemiological research. Acidification, for example, became a regional problem because high smoke stacks allowed for long-distance spreads and caused problems thousands of kilometers away. Acidification only became obvious when the quality of remote poorly buffered lakes in Scandinavia and Canada rapidly deteriorated. Whole ecosystems were killed and the water was crystal-clear (or almost dead). Such regional or continental environmental problems did not have direct health effects but only cumulative effects of long-term exposures to relatively low doses. The need for policy development was not governed by health concern any more but by valuable and vulnerable (eco)systems. Critical load assessments are a nice example of this change (Alcamo et al. 1987). In these days, environmental problems also more and more became resource problems (e.g. Meadows et al. 1972), which also shifted the focus of environmental problems away from health issues.

In the 1980s the link between health and the environment became stronger again for a short period after the ozone hole over Antarctica was discovered. This hole and the thinning of the ozone layer elsewhere cause an increase in UV radiation with again serious health impacts (e.g. skin cancer). When the problem was fully understood, international policy agreements rapidly supported a reduction and later a complete ban of substances that destroy the ozone layer. Nowadays, the ozone layer is recovering.

The destruction of the ozone layer was the first global environmental problem. In the late 1980s and '90s many more followed. First, deforestation and the global decline in biodiversity were seen as a large threat to the many ecosystems of the world. Then, climate warming as a consequence of increased atmospheric concentrations of greenhouse gases was identified as a major emerging problem. Impacts on ecosystems, floods, droughts, agriculture and sea level rise were seen as major impacts, which argued for mitigation. IPCC's first assessment (McG. Tegart, Sheldon and Griffiths 1990), however, already provides a comprehensive account for the impacts on human health. They already highlight the health consequences of reduced food production, heat waves, vector-borne diseases and others, but little was done with this information. Only in the 3rd assessment report (McCarthy et al. 2001), health was again assessed more prominently. Only after the extremely warm European summer of 2003, in which many thousands of people died due to access heat, health and the environment was again at the front pages of all newspapers.

The international conventions that resulted from the 1972 and 1992 Environmental conferences in, respectively, Stockholm and Rio de Janeiro established and re-emphasized the environment as a major policy issue. In between, environmental issues and resource use were regarded as finite. The publication of the Bruntland report (1987) marked a milestone in our understanding and emphasized sustainable

development. This was reiterated in the World Development Goals and later also Millennium Development Goals from the Summit on Sustainable Development in 2001 in Johannesburg. All these conventions and internationally accepted policy targets have nowadays one thing in common: they link the environment to development, poverty reduction, improvement of equity, education and sustainability and, more generally to the improvement of human well-being. Although health is not often explicitly mentioned, health is regarded as a major constituent of human well-being.

This paper presents an ongoing effort, the Millennium Ecosystem Assessment, to assess the relationship between ecosystems, ecosystem services and human well-being and how environmental change has affected this. The aim is to discuss the possibilities to link health issues more comprehensively with environmental issues.

The Millennium Ecosystem Assessment

The MA is a four-year international work programme, which was launched by United Nations Secretary-General Kofi Annan in June 2001, designed to meet the needs of decision-makers for scientific information on the links between ecosystem change and human well-being. The MA focuses on how changes in ecosystem services have affected human well-being, how ecosystem changes may affect people in future decades, and what types of responses can be adopted at local, national or global scale to improve ecosystem management and thereby contribute to human well-being and poverty alleviation. Human development is thus about creating the conditions in which people can develop their full potential while conserving essential ecosystems and providing ample ecosystem services. Development is thus about expanding the choices people have to lead lives that they value.

Parties to the Convention on Biological Diversity (CBD; http://www.biodiv.org), the Convention to Combat Desertification (CCD; http://www.unccd.int), the Ramsar Convention on Wetlands (http://www.ramsar.org) and the Conservation of Migratory Species of Wild Animals (CMS or Bonn Convention; http://www.wcmc.org.uk/cms) have asked the MA to provide scientific information to assist in the implementation of these treaties. The MA will also address the needs of other stakeholders, including national governments, the private sector, organizations of indigenous peoples and other non-governmental organizations (NGOs). The MA is closely coordinated with other international assessments that focus in greater depth on particular sectors or drivers of change, such as the Intergovernmental Panel on Climate Change (IPCC; http://www.ipcc.ch), the Global International Waters Assessment (GIWA; http://www.giwa.net) and the Land Degradation Assessment (LADA; http://www.fao.org/ag/agl/agll/lada/default.stm). This improves the political legitimacy of the assessment.

The MA follows a similar rigour in its assessment as the IPCC. Such scientific assessments apply the judgment of experts to existing knowledge to provide scientifically credible answers to policy-relevant questions. Included material must therefore be published in the peer-reviewed literature. In the MA, each chapter is reviewed twice by individual experts and representatives of the conventions and national governments. Authors must respond adequately to each comment. The whole review process is overseen by a dedicated review board. This process guarantees scientific rigour. At the start of the assessment, all conventions that requested the MA, were requested to provide their ‘user needs’. These needs were updated regularly. Additionally, frequent progress reports are made to the major Conferences of Parties

of each convention. These outreach activities will enhance the utility of the MA. The final reports, which are due in 2005, will be approved by the MA board, with representatives of all the conventions, international organizations, the private sector and national governments.

During the design phase of the MA, it also became apparent that a comprehensive presentation of underlying definitions, concepts and theories must be developed first. A writing team was established, which resulted in the Millennium Ecosystem Assessment's Ecosystem and Human Well-being: a Framework for Assessment (2003). This publication has further directed the assessment of the different working groups.

The MA conceptual framework

Ecosystem services are the benefits people obtain from ecosystems (Millennium Ecosystem Assessment 2003). Provisioning, regulating, supporting and cultural services are distinguished (Figure 1). Ecosystem services include products such as food, fuel and fibre; regulating services such as climate regulation and disease control; and non-material benefits such as spiritual or aesthetic benefits. Health is strongly linked to both provisioning services such as food production and regulating services, including those that influence the distribution of disease-transmitting insects and of irritants and pathogens in water and air. Health can also be linked to cultural services through recreational and spiritual benefits.

Human well-being has also multiple constituents, including the basic material for a good life, freedom and choice, health, good social relations, security, and peace of mind and spiritual experience (Figure 1). How well-being, ill-being or poverty are experienced and expressed depends on context and situation, reflecting local physical, social and personal factors such as geography, environment, age, gender and culture. In all contexts, however, ecosystems are essential for human well-being through their provisioning, regulating, cultural and supporting services.

Human intervention in ecosystems can amplify the benefits to human society. However, evidence in recent decades of escalating human impacts on ecological systems worldwide raises concerns about the spatial and temporal consequences of ecosystem changes detrimental to human well-being.

Changes in ecosystem services affect human well-being in many ways. The MA conceptual framework (Figure 2) assumes that a dynamic interaction exists between people and ecosystems, with the changing human condition serving to drive change in ecosystems both directly and indirectly and with changes in ecosystems causing changes in human well-being. At the same time, many other factors independent of the environment change the human condition, and many natural forces are influencing ecosystems.

The problem posed by the growing demand for ecosystem services is compounded by increasingly serious degradation of the capability of ecosystems to provide these services. In many parts of the world, this degradation of ecosystem services is exacerbated by the associated loss of the knowledge and understanding held by local communities – knowledge that sometimes could help to ensure the sustainable use of the ecosystem.

This combination of growing demands being placed on increasingly degraded ecosystems could seriously diminish the prospects for sustainable development. Human well-being is affected not just by gaps between ecosystem-service supply and demand but also by the increased vulnerability of individuals, communities and

nations. Productive ecosystems, with their array of services, provide people and communities with resources and options they can use as insurance in the face of natural catastrophes or social upheaval. While well-managed ecosystems reduce risks and vulnerability, poorly managed systems can exacerbate them by increasing risks of flood, drought, crop failure or disease.

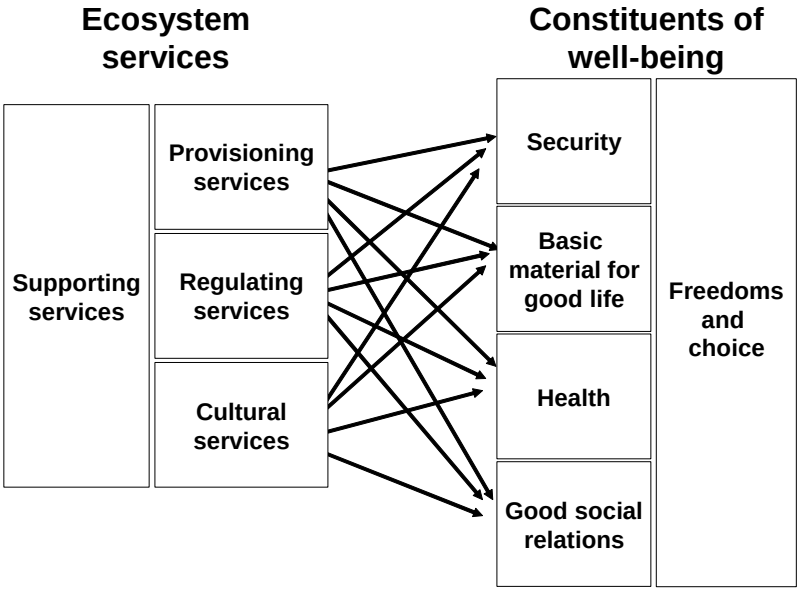

Figure 1. The different ecosystem services and constituents of human well-being and their linkages

In recent decades the world has witnessed not just dramatic changes to ecosystems but equally profound changes to social systems that shape both the pressures on ecosystems and the opportunities to respond. The relative influence of individual nation states has diminished with the growth of power and influence of a far more complex array of institutions, including regional governments, multinational companies, the United Nations, and civil-society organizations. Stakeholders have become more involved in decision-making. Given the multiple actors whose decisions now strongly influence ecosystems, the challenge of providing information to decision-makers has grown. At the same time, the new institutional landscape may provide an unprecedented opportunity for information concerning ecosystems to make a major difference. Improvements in ecosystem management to enhance human well-being will require new institutional and policy arrangements and changes in rights and access to resources that may be more possible today under these conditions of rapid social change than they have ever been before.

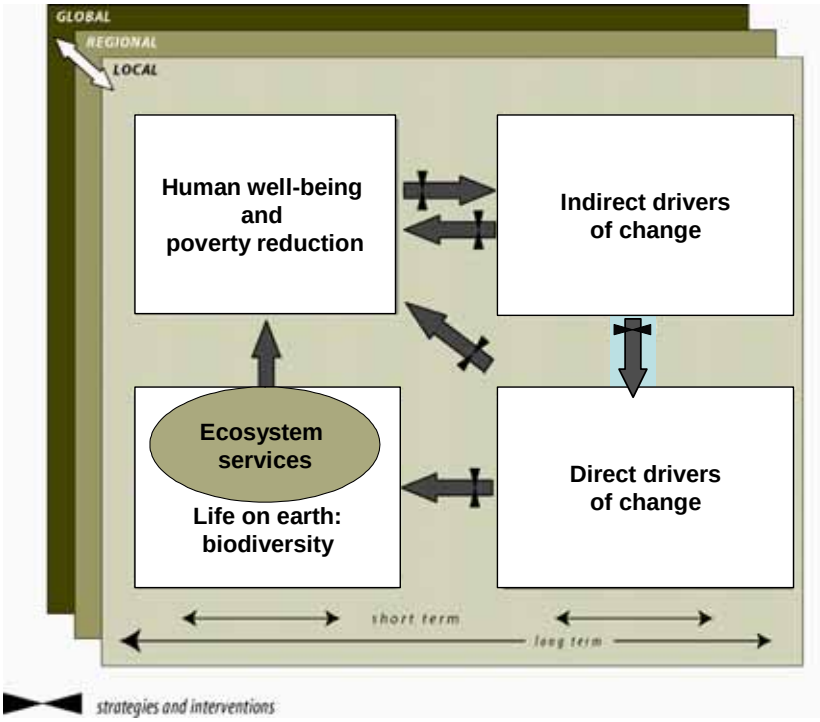

Figure 2. The conceptual framework of the Millennium Ecosystem Assessment

A full assessment of the interactions between people and ecosystems requires a multi-scale approach because it better reflects the multi-scale nature of decision-making, allows the examination of driving forces that may be exogenous to particular regions, and provides a means of examining the differential impact of ecosystem changes and policy responses on different regions and groups within regions. Additionally, in the more local assessment, local and indigenous knowledge can more easily be incorporated into the assessment.

Health is in many respects a strong integrative component of human well-being, since changes in economic, social, political, residential and behavioural circumstances all have health consequences. These factors also strongly influence ecosystems. There is more evidence that changes in ecosystems and in ecosystem services affect livelihood, income and migration and could well lead to political conflicts (e.g. Biggs et al. 2004), than there is on the direct consequences of ecosystem changes for human health. Therefore health in the Millennium Assessment is treated somewhat separately from the other components of well-being (Figure 3) and is addressed in the assessment report in dedicated chapters (e.g. the health synthesis chapter of the responses working group) and in a dedicated summarizing synthesis volume (also with strong contributions of WHO).

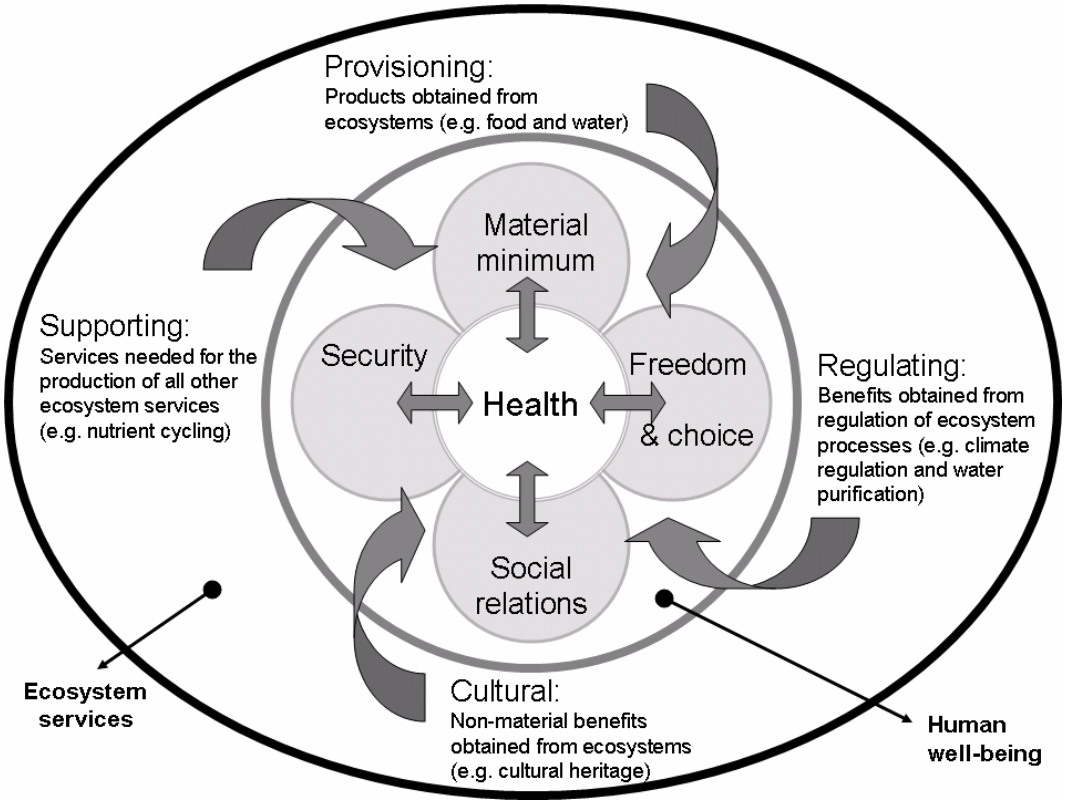

Figure 3. Health as in integral part of human well-being

The assessment process

The assessment process occurs at different levels. Each sub-regional assessment includes health elements, especially focusing on local conditions and knowledge. Wherever possible indigenous knowledge is included in these assessments as well. All the information, however, accumulates in the different global assessments. The assessment process should provide proper baseline data from series of reliable sources. We will make a large effort to make all these datasets available. This will help the peer review process and increase transparency.

Controversial issues must be discussed. If a uniting view cannot be established, opposing views with their arguments must be provided. For example, the value of an almost extinct species ranges from minus (the construction company that wants to build on the species' habitat), zero (direct use value) to infinite (the conservationist) and all values in between (lawyers, tourists, farmers, geneticists, etc). All their arguments are valid for certain conditions but are impossible to reconcile. The assessment must be sensitive to such controversies and must not produce opinionated or policy-prescriptive statements.

With respect to health and other impacts, IPCC (McCarthy et al. 2001) has taken a very sequential approach. Energy scholars used highly aggregated global models to define different future emissions paths. Carbon-cycle modellers and atmospheric chemists used that as input to their models to calculate the resulting atmospheric concentrations, which in turn were used by climate modellers to estimate patterns of climate change. Impact assessors used these climate-change scenarios to estimate impact levels. Many impact models do not produce real impacts but estimate the changes in relative risk of specific threats, such as diseases. The output is then

converted to single indicators, such as Disability-Adjusted Life Year (DALY), which is the only quantitative indicator of disease burden that reflects the total amount of healthy life lost, to all causes during a period of time (World Bank 2002).

The Millennium Assessment tries to improve on this linear approach by closely following the interactions and linkages in its conceptual framework (Figure 2). The steps involved in the assessment are the following:

1. **Identify systems.** The Millennium Assessment selected a series of major systems. These are cultivated land, drylands, forests and woodlands, urban areas, inland water, coastal regions, marine ecosystems, polar regions, mountains and islands. Selection criteria were based upon the uniqueness of these systems themselves and/or the inimitability of its problems (or drivers).
2. **Identify services**. The Millennium Assessment classified all possible ecosystems services into provisioning services, which include all goods produced or provided by ecosystems, regulating services, which include all the benefits obtained from regulation of ecosystem processes, cultural services, which include the non-material benefits obtained from ecosystems, and the supporting ecosystems, which underlay all other services and maintain the conditions for life on earth. Biodiversity is not considered to be a specific ecosystems service because it is related to all others.
3. **Identify drivers**. Indirect drivers that operate at a distance, such as demography, economy and technology, and direct drivers, such as land-use change and pollution, are distinguished. All these drivers operate at different scales. Some cannot be influenced by local decision-makers (i.e. exogenous drivers) but only by national decision-makers (i.e. endogenous drivers). Changing scales also means that different sets of drivers have to be addressed.
4. **Identify the links to and interactions with human well-being** (cf. Figure 1). Not all the links are equally important. Some act directly, others act indirectly. Drivers that impact ecosystems often only indirectly affect human health.
5. **Select appropriate indicators to depict change**. Indicators should be representative for the component or process that they describe; they should be sensitive to changes; they should be reliable and acceptable for a larger user community.
6. **Assess status and trends, using these indicators and baseline data**. Here the analysis must include a description of the conditions before and after changes in drivers. Such changes should be communicated with the appropriate indicators. Figure 4 illustrates this with a hypothetical example of conversion of forest to grassland.

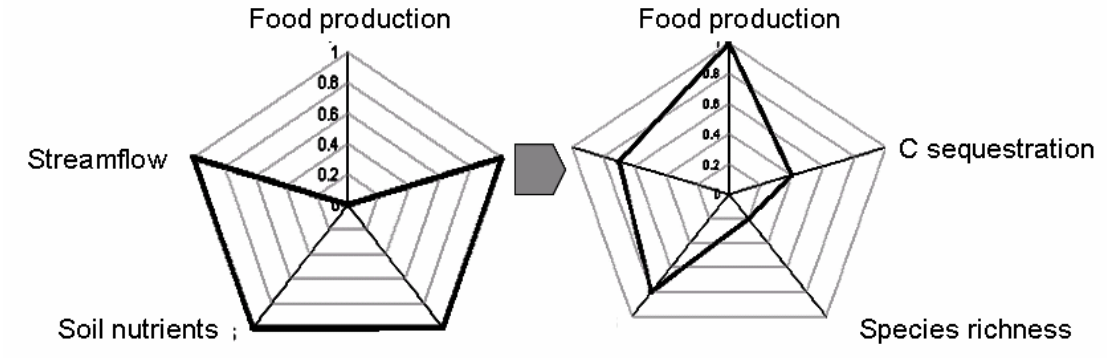

Figure 4. Changes in different indicators for a conversion of natural forest to cropland

7. **Develop scenarios for different non-implausible narratives.** The scenario working-group of the Millennium Assessment has developed four narrative scenarios that depict plausible alternative futures and illustrate a range of possible trajectories. Table 1 characterizes some of the aspects of these scenarios. The strengths of these scenarios are: they blend qualitative and quantitative aspects; they make trade-offs clear; they highlight surprises; and they illustrate effects of alternative policies successful in other sectors. One of the main objectives of these scenarios is to answer the question "how might ecosystems change in the future and what would the health implication of these changes be?".
   The four scenarios are:
   Global Orchestration: This scenario emphasizes the production of manufactured and human capital. There is a strong belief that market deregulation will improve social and economic well-being and, in the long run, ecological conditions. Ecosystem problems are dealt with reactively. The under-estimation of environmental concerns increases the risks of ecological surprises, including emerging infectious diseases.
   Technogarden: Technology and market-orientated institutional reforms are used to achieve solutions to environmental problems. Technological improvements are combined with better ecological engineering to optimize ecosystem services. It is assumed that ecological engineering is fairly successful and produces few adverse ecological surprises, and that the ability of societies to cope with these surprises is high.
   Order from Strength: The world is progressively compartmentalized as better-off populations focus inwardly in response to perceived threats. Limited benefits are provided for allied poor countries. The environment is seen as secondary, and there is a belief that technology can solve most environmental challenges. Parts of the developing world experience constant low-level violence, with periodic frank conflict.
   Adapting Mosaic: Society emphasizes the flexible management of socio-ecological systems, and the balancing of human with manufactured and natural capital. A mix of optimism and humility leads to the preparation for adverse ecological surprises. Political and economic power devolves, but, eventually, the focus on local governance leads to failures in managing the global commons. In response, communities develop ecologically-centred networks.
8. **Evaluate response options and strategies** and their context to understand what works where and why. There are two routes to avoiding disease and injury caused by ecosystem change. One is to prevent or limit environmental damage; the other way is to make whatever changes will protect individuals and populations from the consequences of ecosystem change. Both are assessed. One of the major preliminary finding is that policies and actions to reduce vulnerability to disease and injury have much in common with the steps that need to be taken to promote sustainable use of ecosystems.
9. **Use integrated assessment tools to identify and understand trade-offs and synergies** between different policy options. Where there are trade-offs, it is important for decision-makers and the public to understand the health consequences so that they can be included alongside economic or other costs when prioritizing decisions. Major trade-offs, for example, exist between infectious-disease risk and some development projects geared to food production, electrical power and economic gain.

Table 1. Health issues in the scenarios of the Millennium Assessment

Scenario		Possible outcomes	
	Health gap	High-income populations	Low-income populations
Global Orchestration	Low	Continued improvements, more anxiety. New medical technology.	Malnutrition, infectious diseases, diabetes. Chronic disease, slow improvement.
Techno-Garden	Lower	Improvement, less anxiety.	New vaccines. Increased food security. Wide improvement.
Adapting Mosaic	Far lower	Less diabetes, obesity and anxiety.	Rapid improvement, adoption of "orphan" diseases, elimination of hunger.
Order from Strength	High	Increased obesity, diabetes, anxiety better medical technology and surgery.	Epidemics, poor health care access, famine, conflict.

10. **Identify major uncertainties** in the baseline scenarios and response options. There are unavoidable uncertainties about the impacts of environmental changes on human health. These include the potential magnitude, timing and effects of environmental change; the sensitivity of health and other ecosystem services; the effectiveness of different courses of action to address the potential impacts; and the shape of future societies. Traditional epidemiological methods are not well-suited to such issues, as they are designed to test the influence of discrete risk factors on well-defined health outcomes (e.g. the effect of smoking on lung cancer), and emphasize avoiding an incorrect identification of a harmful effect. In contrast, environmental change has diverse and wide-ranging rather than discrete effects on individuals or small areas, an absence of control groups, and may be difficult or impossible to reverse, so that false negative effects are equally as important as false positives. Still, other approaches, such as scenario analysis, have to be developed to be able to communicate uncertainty to decision-makers and so comprehensively addressing their needs.
11. **Develop the assessment reports** and communicate major findings to the user community. Well-written technical summaries, summaries for decision-makers and synthesis reports for specific audiences, such as each convention or the private sector, all with clear illustrations, are needed to communicate the findings of the assessment. The Millennium Assessment has already appointed an outreach officer and is planning for an effective communication strategy (see also www.millenniumassessment.org).

One of the current outcomes of the health chapters of the millennium assessment is a risk assessment for health impacts of different ecosystems services (Figure 5). Here the direct effects of, e.g., water and food scarcity are listed. Also the direct physical impacts of sudden events such as gales and floods stand out. Changes in climate and decline of biodiversity are much more diffuse.

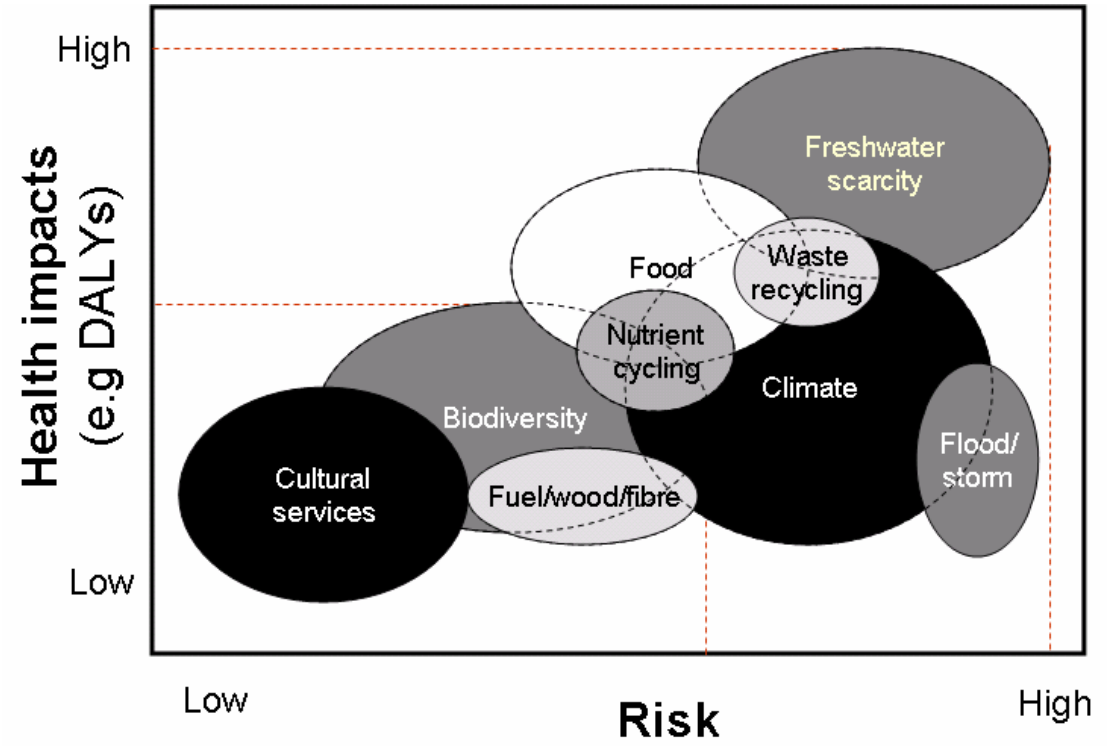

Figure 5. A simple risk assessment of health impacts and different types of environmental change

Concluding remarks

The Millennium Ecosystem Assessment differs form assessments like the IPCC in that it comprehensively looks at multiple drivers and multiple impacts. It more strongly bridges between the natural and social sciences and tries to understand the systemic interactions between ecosystems, ecosystem services and human well-being. One of the main findings is that a lot of the science needed to do this is still immature. The Millennium Assessment will therefore probably not provide ultimate answers to the entire user needs but will, at least, provide a foundation for further integrative research.

The Earth Systems Science Partnership of all the global-change research programmes is already picking up this challenge by developing a joint project on global environmental change and human health. Here frameworks for improved vulnerability and adaptation assessments will be developed together with a better understanding of all the environment–health relations. The objective is to understand better the multi-faceted and complex linkages between global change (including climate change, land- and sea-use changes, global biodiversity loss and changes, global socio-economic changes) and human health. This project is also strongly supported by the World Health Organization. In the coming decade much advancement in understanding will surely be made in this research area. When available, decision-makers and the broader public will surely gain from these achievements.

References

Alcamo, J., Amann, M., Hettelingh, J.-P., et al., 1987. Acidification in Europe: a simulation model for evaluating control strategies. *Ambio*, 16 (5), 232-245.

Biggs, R., Bohensky, E., Desanker, P.V., et al., 2004. *Nature supporting people: the southern African Millennium Ecosystem Assessment*. Council for Scientific and Industrial Research, Pretoria.

Brundtland, G.H. (ed.) 1987. *Our common future*. Oxford University Press, Oxford.

Carson, R., 1962. *Silent spring*. The Riverside Press, Cambridge.

McCarthy, J.J., Canziani, O.F., Leary, N., et al. (eds.), 2001. *Climate change 2001: impacts, adaptation and vulnerability*. Cambridge University Press, Cambridge. [http://www.grida.no/climate/ipcc_tar/wg2/index.htm]

McG. Tegart, W.J., Sheldon, G.W. and Griffiths, D.C. (eds.), 1990. *Climate change: the IPCC impacts assessment*. Australian Government Publishing Service, Canberra.

Meadows, D.H., Meadows, D.L., Randers, J., et al., 1972. *The limits to growth: a report for the Club of Rome's project on the predicament of mankind*. Universe Books, New York.

Millennium Ecosystem Assessment, 2003. *Ecosystems and human well-being: a framework for assessment*. Island Press, Washington. [http://pdf.wri.org/ecosystems_human_wellbeing.pdf]

World Bank, 2002. *World development report 2003: sustainable development in a dynamic world: transforming institutions, growth, and quality of life*. Oxford University Press, New York. [http://econ.worldbank.org/wdr/wdr2003/text-17926/]