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

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

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

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

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

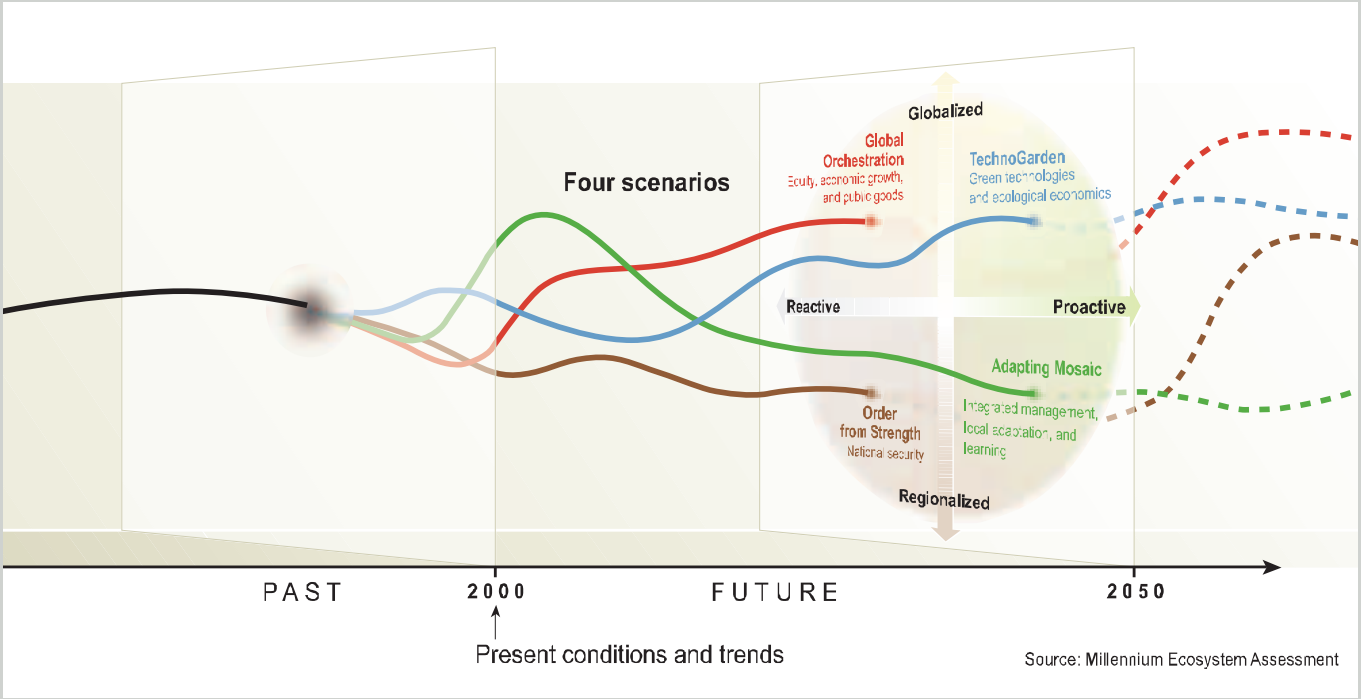
Box 3.1 Scenario exercises

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

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

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

Box 3.2 Health dimensions of the four MA scenarios



Millennium Ecosystem Assessment Scenarios

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

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

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

Global Orchestration

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

Continues on page 32

Box 3.2 (continued)

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

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

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

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

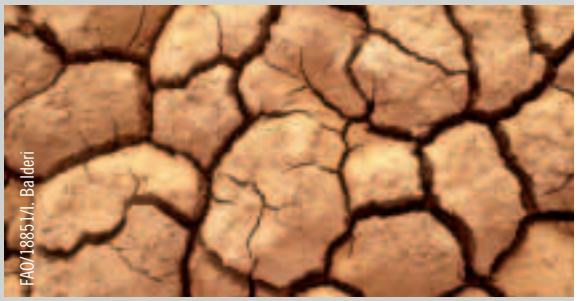
This scenario has the lowest investment in human capital. Poor countries face major obstacles in improving the health status of their citizens. Institutions critical to good governance remain particularly weak, exacerbating health gaps. Social and political institutions are overwhelmed by powerful lobby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

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

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

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

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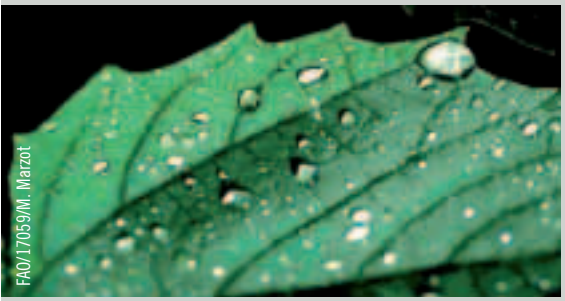
population; social, political and economic instability in many regions contributes to temporary and fluctuating population declines and increases. It is also possible, though of low probability, that a more chronic disease could cross from a non-domesticated animal species into humans. As with HIV, this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

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

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

Technological improvements in the development of alternative energy sources facilitate greater availability of energy at relatively low prices. Cost-effective seawater desalinization makes possible the broader irrigation of deserts that currently are sparsely populated and higher crop yields, improving food production capacity. Global nutrition improves substantially, driving virtuous cycles of consequent social and economic improvements, especially among poor tropical populations. Medical breakthroughs extend life expectancy and improve the quality of the later years of life. Technological, surgical, genetic, pharmacological, nutraceutical and other scientific advances increase human carrying-capacity on a global scale. Heat-stable, single-dose oral vaccines that confer lifetime immunity to multiple diseases are developed. Water pollution and indoor air pollution are eliminated almost entirely. Societies could use new technologies for greater expression, strengthening social, family and human capital.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This utopian scenario could unravel, however, if institutional improvements fail to match the pace of technological advance. In that event, public health could be undermined in many regions and many forms of inequality could increase, even in a scenario yielding an absolute increase in the production of ecosystem services. Virtual reality could be misused to pacify and condition people in ways that reduce freedom. Devastating engineered diseases could be released accidentally or deliberately. Cheap robots could reduce danger, drudgery and servitude but also increase unemployment and human exploitation. Family and social ties could loosen if children bond to virtual nurses rather than flesh-and-blood playmates. Audiences desensitized by excessive diets of virtual violence and pornography could challenge civil society norms if whetted appetites demand ever-increasing doses.

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

Adapting Mosaic

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

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

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

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

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

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

3.1 Critical drivers and other factors affecting future changes to health

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

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

3.1.1 *Direct drivers*

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

3.1.2 *Indirect drivers*

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

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

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


UNEP/TopFoto.co.uk

Suburban housing development replaces natural tropical forest.

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

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

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

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

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

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


A. Waak/PAHO

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

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

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

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

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

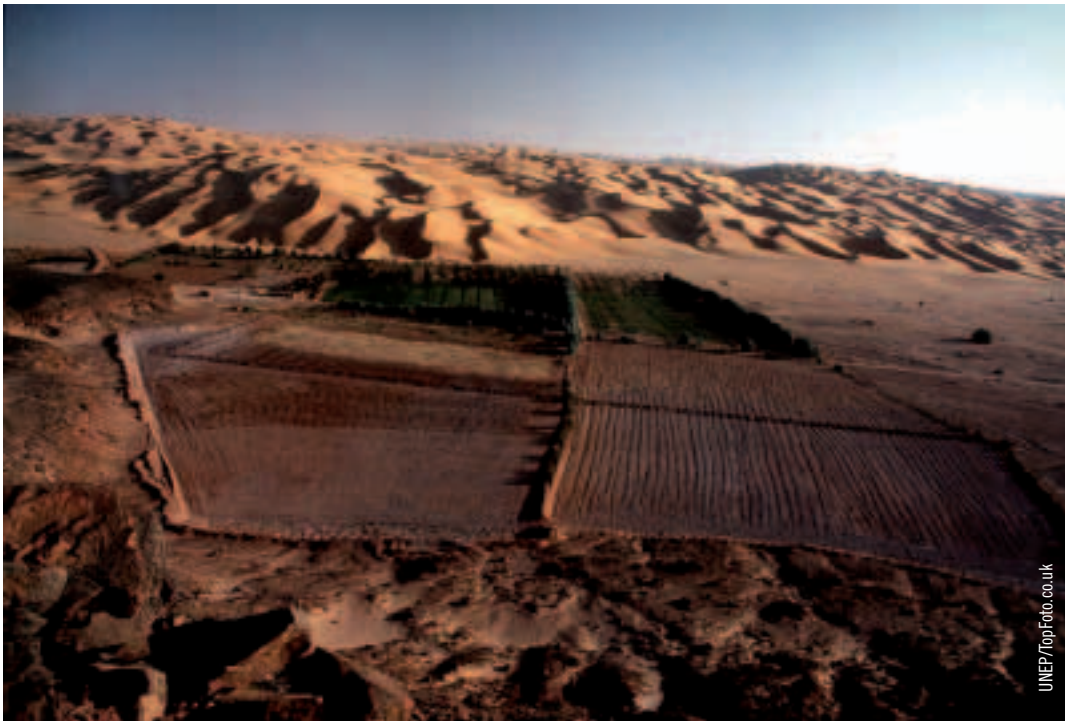
3.3 Possible thresholds, regime shifts or irreversible changes

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

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

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

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



Experiment in agriculture in deserts and drylands.