Chapter 9

Changes in Ecosystem Services and Their Drivers across the Scenarios

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APPENDIXES

BOXES

FIGURES

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*This appears in Appendix A at the end of this volume.

TABLES

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Main Messages

The demand for provisioning services, such as food, fiber, and water, strongly increases in all four scenarios (*with medium to high certainty*). This is due to expected increases in population, economic growth, and changing consumption patterns. Increasing demand for provisioning services leads (*with high certainty*) to further stress on the ecosystems that provide these services. By 2050, global population increases (*with medium to high certainty*) to 8.1–9.6 billion, depending on the scenario. At the same time, per capita GDP expands by a factor of 1.9–4.4, again depending on the scenario (*low to medium certainty*). Increasing income fuels increasing per capita use of most resources in most parts of the world. The combination of increasing population and per capita consumption increases the demand (*with high certainty*) for ecosystem services, including water and food. Demand is dampened somewhat by increasing efficiency in the use of resources.

Trade-offs between ecosystem services continue and perhaps intensify. The gains in provisioning services, such as food supply and water, will come partly at the expense of losses of other services. Providing additional food to match increased demand will lead (*with low to medium certainty*) to further expansion of agricultural land, and this in turn will lead to the loss of natural forest and grassland, as well as the loss of ecosystem services associated with this land (genetic resources, wood production, habitat for fauna and flora). Water use will increase in poorer countries (*with high certainty*), and this is likely to be accompanied by a deterioration of water quality and the loss of the ecosystem services provided by clean freshwater systems (genetic resources, fish production, habitat for aquatic and riparian flora and fauna).

Overall, the largest decrease in the quality of ecosystems and the provision of ecosystem services (*with medium certainty*) occurs under the Order from Strength scenario. This is driven by a relatively large increase in population, a reactive attitude toward ecological management, the low level of technological development, and restrictions on trade.

The scenarios indicate (*with medium certainty*) certain ''hot spot regions'' of particularly rapid changes in ecosystem services, including sub-Saharan Africa, the Middle East and Northern Africa, and South Asia. To meet its needs for development, sub-Saharan Africa is likely to rapidly expand its withdrawal of water, which will require an unprecedented investment in new water infrastructure. Under some scenarios (*medium certainty*), this rapid increase in withdrawals will cause a similarly rapid increase in untreated return flows to the freshwater systems, which could endanger public health and aquatic ecosystems. Sub-Saharan Africa could experience not only accelerating intensification of agriculture but also extensification through expansion of agricultural land into natural areas. Further intensification could lead to a higher level of contamination of surface and groundwaters. Extensification will come at the expense of a large fraction of sub-Saharan Africa's natural forest and grasslands (*medium certainty*), as well as the ecosystem services they provide.

In all scenarios, rising income in the Middle East and Northern African countries leads to greater meat demand, which could lead to a still higher level of dependence on food imports (*low to medium certainty*). There is a *medium certainty* that rising incomes put further pressures on limited water resources in the hot-spot regions, which will either stimulate innovative approaches to water conservation or could limit development. In South Asia, deforestation continues in all scenarios, despite increasingly intensive industrial-type agriculture. Here, rapidly increasing water withdrawals and return flows further intensify water stress. There may be regions (*with low certainty*) where the pressure on ecosystems causes breakdowns in these ecosystems, and these breakdowns could interfere with the well-being of the population and its further economic development.

The four scenarios describe contrasting pathways for the development of human society and ecosystems. At the same time, similar outcomes for ecosystem services can be achieved through multiple pathways. For example, food demand across scenarios can be fulfilled either through expansion in cropping area or through an increase in crop yields. Similarly, comparable rates of land use change can result from different combinations of growth rates of population, economic activity, and technology developments.

There are several conclusions regarding specific drivers and ecosystem services:

- **Vast changes are expected in world freshwater resources and hence in the ecosystem services provided by freshwater systems.** A deterioration of the services provided by freshwater resources (aquatic habitat; fish production; water supply for households, industry, and agriculture) is expected under the two scenarios that are reactive to environmental problems (Global Orchestration and Order from Strength). A less severe decline is expected under the two scenarios that are proactive about environmental issues (TechnoGarden and Adapting Mosaic) (*medium certainty*). Water withdrawals are expected to increase greatly outside wealthy countries (as a result of economic and population development) but will continue to decline in other regions (as a result of saturation of per capita demands, efficiency improvements, and stabilizing population) (*medium certainty*).

  The extent of the increases outside the rich countries is scenario-dependent. In sub-Saharan Africa, domestic water use greatly increases in all scenarios, and this implies (*with low to medium certainty*) an increased access to fresh water. However, these estimates do not factor in the technical and economic feasibility of increasing domestic water withdrawals. Under the Global Orchestration and Order from Strength scenarios, massive increases in water withdrawals are expected to lead to an increase in untreated wastewater discharges (in poorer countries), causing a deterioration of freshwater quality. Climate change leads to both increasing and declining river runoff, depending on the region. The combination of huge increases in water withdrawals, decreasing water quality, and decreasing runoff in some areas leads to an intensification of water stress over wide areas.

- **Land use change is a major driver of changes in the provision of ecosystem services up to 2050 (*medium to high certainty*).** The scenarios indicate (*low to medium certainty*) that 10–20% of current grassland and forestland may be lost between now and 2050, mainly due to the further expansion of agriculture (and secondarily, because of the expansion of cities and infrastructure). This expansion mainly occurs in low-income and arid regions, while in the high-income regions, agricultural area declines. The provisioning services associated with affected biomes (genetic resources, wood production, habitat for terrestrial biota and fauna) will also be reduced. The degree to which natural land is lost differs among the scenarios. The Order from Strength scenario has the greatest implications from land use changes, with large increases in both crop and grazing areas. TechnoGarden and Adapting Mosaic, in contrast, are the most land-conserving scenarios because of increasingly efficient agricultural production, lower meat consumption, and lower population increases. Existing wetlands and the services they provide (such as water purification) are faced with increasing risk in some areas due to reduced runoff or intensified land use in all scenarios.

- **After 2050, climate change and its impacts (such as sea level rise) have an increasing effect on the provision of ecosystem services (*medium certainty*).** Under the four MA scenarios, global temperature is expected to increase significantly: 1.5–2.0° Celsius above pre-industrial in 2050, and 2.0–3.5° Celsius in 2100, depending on the scenario and using median estimates for climate change variables (*medium certainty*). This is in the low to middle range of the scenarios developed for the IPCC Third Assessment Report (2.0–6.4° Celsius). The main reasons for this are that the MA range does not include the effect of the uncertainty in climate sensitivity and the MA set includes one scenario that assumes climate policy, in contrast to the climate policy–free IPCC scenarios. There is an increase in global average precipitation (*medium certainty*), but some areas will become more arid while others will become moister. Climate change will directly alter ecosystem services, for example, by causing changes in the productivity and growing zones of cultivated and noncultivated vegetation. Climate change also alters the frequency of extreme events, with associated risks to ecosystem services. Finally, it will indirectly affect ecosystem services in many ways, such as by causing sea level to rise, which threatens mangroves and other vegetation that now protect shorelines.

- **Food security remains out of reach for many people, and child malnutrition cannot be eradicated by 2050 (*with low to medium certainty*), even though the supply of food increases under all four scenarios (*medium to high certainty*) and diets in poorer countries become more diversified (*low to medium certainty*).** On a global basis, food supply increases significantly in all four scenarios. On a per capita basis, however, basic staple production stagnates or declines for all scenarios in the Middle East and North Africa and increases very little in sub-Saharan Africa (*low to medium certainty*). Resulting shortfalls in these regions are expected to be covered through increased net food imports (*medium certainty*). Even though cereal production in 2050 will be 50% larger and the per capita availability of food increases, child malnutrition is not eradicated (*low to medium certainty*). Moreover, higher grain prices under the Order from Strength and Adapting Mosaic scenarios indicate a tightening of world food supplies. Order from Strength leads to the highest estimated number of malnourished children in 2050—181 million, compared with 166 million children today. Also in Adapting Mosaic, we estimate (*with low certainty*) that by 2050 some 116 million children might still be malnourished. The large number of malnourished children arises because of inadequate investments in food production and its supporting infrastructure and high population growth. Larger investments in health and education and enhanced community development could reduce the number of malnourished children (*with high certainty*).

- **Demand for fish as food will expand, and the result will be an increasing risk of the major long-lasting decline of regional marine fisheries (*low to medium certainty*).** The demand for fish from both freshwater and marine sources as well as from aquaculture will increase across all scenarios because of increasing human population, income growth, and increasing preferences for fish. Increasing demand will raise the pressure on marine fisheries, which may already be near their maximum sustainable yield, and could cause a long-term decline in their productivity (*low to medium certainty*). The production of fish via aquaculture will add to the risk of decline of marine fisheries if aquaculture continues to depend on marine fish as a feed source.

- **The future contribution of terrestrial ecosystems to the regulation of climate is uncertain.** Deforestation is expected to reduce the carbon sink, most strongly under the Order from Strength scenario (*with medium certainty*). Carbon release or uptake by ecosystems affects the CO_2 and CH_4 content of the atmosphere at the global scale and thereby affects global climate. Currently, the biosphere is a net sink of carbon, absorbing about 1 to 2 gigatons of carbon per year, or approximately 20% of fossil fuel emissions. It is very likely that the future of this service will be greatly affected by expected land use change. In addition, a higher atmospheric CO_2 concentration is expected to enhance net productivity, but this does not necessarily lead to an increase in the carbon sink. The limited understanding of soil respiration processes generates uncertainty about the future of the carbon sink. There is a medium certainty that climate change will increase terrestrial fluxes of CO_2 and CH_4 in some regions (in Arctic tundras, for example). Among the four scenarios, the greatest reduction of the terrestrial biosphere's carbon sink will occur (*with low certainty*) under the Order from Strength scenario because of its high level of deforestation.

9.1 Introduction

The capacity of ecosystems to provide services is determined by many different direct and indirect driving forces operating at the local to global level. (See Chapters 1 and 7.) Changes in driving forces will catalyze changes in the provision of ecosystem goods and services. In this chapter, we estimate the future changes in ecosystem services according to changes in driving forces described in the MA scenarios. The expectations about the future of ecosystem services are consistent with the storylines presented in Chapters 5 and 8.

We present estimates of changing ecosystem services in the form of both qualitative and quantitative information. The qualitative information is based on our interpretation of the storylines presented in Chapters 5 and 8, while the quantitative information is based on a modeling analysis, also related to the storylines, as explained below.

Qualitative expectations for future ecosystem services are summarized in Table 9.1 for provisional and regulating services. Since it is not feasible to present these expectations in natural units, such as tons of grain or cubic meters of potable water, we use a simple, three-level indicator system: zero if the ecosystem service changes little between 2000 and 2050, +1 if it is in better condition in 2050 than in 2000, and −1 if it is in worse condition. These qualitative expectations were not calculated from computer models but are based on our assessment and judgment of the storylines presented in Chapters 5 and 8. But these judgments are analogous to the model results in some ways. Model results and qualitative expectations were both constructed to be consistent with the logic and rationale of the storylines. They both have substantial uncertainties. By explicitly comparing outcomes for ecosystem services using both qualitative and quantitative approaches, we gain some perspective on the uncertainties.

The storylines also imply certain conclusions about the vulnerability of ecosystems. An ecosystem is vulnerable if it is sensitive to anthropogenic or non-anthropogenic disturbances. If society is highly dependent on a service provided by a threatened or sensitive ecosystem, then society too is vulnerable.

The quantitative conjectures come from a modeling exercise described in Chapter 6 and are reported in the text and the figures of this chapter. The exercise had the following basic steps. First, from the storylines we derive a set of

Table 9.1. Qualitative Expectations for Provisioning and Regulating Ecosystem Services in MA Scenarios. Ecosystem services are defined in the MA conceptual framework volume (MA 2003: 56–59). "Industrial Countries" stands for nations that are relatively developed and wealthy in 2000; "Developing Countries" stands for nations that are relatively undeveloped and poor in 2000. Note that any particular nation could switch categories between 2000 and 2050. Scores pertain to the endpoint, 2050. A score of +1 means that the ecosystem service is in better condition than in 2000. A score of zero means that the ecosystem service is in about the same condition as in 2000. A score of −1 means that the ecosystem service is in worse condition than in 2000.

Vulnerability of an ecosystem service is defined as the sensitivity of the service to external disturbances multiplied by the sensitivity of the socioecological system to changes in the ecosystem service. If society is highly dependent on an ecosystem service that is sensitive to disturbance, then the ecosystem service has high vulnerability. If society is not dependent on an ecosystem service, or if the ecosystem service is not sensitive to disturbance, then the ecosystem service has low vulnerability.

	Global Orchestration		Order from Strength		Adapting Mosaic		TechnoGarden	
Ecosystem Service	**Industrial Countries**	**Developing Countries**	**Industrial Countries**	**Developing Countries**	**Industrial Countries**	**Developing Countries**	**Industrial Countries**	**Developing Countries**
Provisioning services								
Food (extent to which demand is met)	+1	+1	0	−1	0	−1	+1	+1
Fuel	+1	+1	+1	+1	+1	+1	+1	+1
Genetic resources	0	0	−1	−1	+1	+1	0	+1
Biochemical discoveries	−1	+1	−1	−1	0	0	+1	+1
Ornamental resources	0	0	0	−1	+1	+1	0	0
Fresh water	+1	+1	0	−1	+1	−1	+1	0
Comments on vulnerability of provisioning services	increased vulnerability of ecosystem services to stochastic shocks; breakdowns have greater impact on the poor		in industrial countries, ecosystem services are vulnerable due to small patch effects and climate change; in developing countries, ecosystem services are vulnerable due to these factors as well as overexploitation, degradation of ecosystems, and lower trade		vulnerability of ecosystem services is reduced, especially in developing countries; smoother adaptation of ecosystem services to changing environmental drivers		vulnerability of ecosystem services is increased by maximization of efficiencies; generally high performance of ecosystem services but frequent massive interruptions due to environmental changes and shocks; tendency to increase provisioning services due to investment in technology	

Regulating services								
Air quality maintenance	0	0	0	−1	0	0	+1	+1
Climate regulation	0	0	−1	−1	0	0	+1	+1
Water regulation	0	−1	−1	−1	+1	+1	0	+1
Erosion control	0	−1	−1	−1	+1	+1	0	+1
Water purification	0	−1	−1	−1	+1	+1	0	+1
Regulation of human disease	0	+1	0	−1	0	+1	+1	+1
Biological control	0	−1	−1	−1	+1	+1	0	0
Pollination	−1	−1	−1	−1	0	0	−1	−1
Storm protection	0	−1	0	−1	+1	+1	+1	0
Comments on vulnerability of regulating services	improvements in targeted problem areas, but increased vulnerability of ecosystem services to stochastic shocks, especially in developing countries; indirect effects and cross-sector interactions are the root of increasing problems; low attention to underlying processes, so regulating services should generally diminish; some improvements for ecosystem services that have clear direct effects on people		increased vulnerability of ecosystem services to stochastic shocks leads to severe breakdowns of ecosystem support to people, especially in developing countries; wealth allows some adaptation in industrial countries		vulnerability is reduced in water management and some aspects of ecosystem management, but shows little change for large-scale commons (atmosphere, global fisheries)		improvements are achieved through increased efficiency, but the engineered ecosystems are increasingly vulnerable to shocks and require frequent technological fixes; more focus on underlying processes, but emphasis on efficiency creates new problems that require new fixes	

quantitative assumptions for the indirect drivers of ecosystem changes (such as population and economic growth). Second, we use information about indirect drivers to derive assumptions about the direct drivers of ecosystem change (such as energy use and irrigated area). In some cases (land cover change, for instance), models are used to derive these direct drivers. Next, the direct drivers are input to a suite of numerical simulation models. These models generate first estimates of temporal and spatial changes in a wide range of ecosystem services. As noted in Chapter 6, an important point is that these models can only cover a small part of the attributes and processes having to do with ecosystem services. For example, while the quantitative models address many provisioning and regulating ecosystem services, we do not have quantitative models for estimating future provision of supporting and cultural services. We try to fill in some of the missing information with the qualitative expectations.

This chapter starts with a discussion of the assumed changes in indirect and direct drivers and then describes estimates for each of the provisioning and regulating ecosystem services in turn. This is followed by brief sections describing qualitative estimates of supporting and cultural services. We focus on results for 2050, which is a compromise between the shorter time horizon of a typical agricultural or urban prospective study and the longer time horizon of climate impact studies. The year 2050 also gives us a long-term perspective on the ecological consequences of current actions and policies. Nevertheless, where appropriate we also provide information about the year 2100 and temporal trends throughout the twenty-first century.

9.2 Indirect Drivers of Ecosystem Services

Drivers of ecosystem services, as the term is used in the MA, are human-induced factors that directly or indirectly cause a change in an ecosystem. The difference between indirect and direct drivers is that the latter unequivocally influence ecosystem processes, while the former operate more diffusely, often by altering one of the more direct drivers.

Chapter 7 discusses the role of the different drivers of change in ecosystem services, their historic changes, and the range of possible changes in the future. In this chapter, we estimate their changes under each of the storylines. Models were used to provide quantitative estimates for most of the relevant drivers. (See Table 9.2.) For other drivers, qualitative judgment was used.

The key indirect driving forces of the MA scenarios are population, income, technological development, and changes in human behavior. The future trends of these driving forces are quite different, as implied by the story-lines of the four scenarios.

9.2.1 Population

9.2.1.1 Methodology and Assumptions

Change in population is important because it will influence the number and kind of consumers of ecosystem services. Furthermore, it will directly affect the amount of energy used, the magnitude of air and water pollutant emissions, the amount of land required, and the other direct drivers of ecosystem change. Population scenarios are developed on a regular basis by demographers at the United Nations and the International Institute for Applied Systems Analysis (IIASA; Lutz et al. 2001). Both groups also try to express the uncertainties of the population projections, by giving either more than one scenario (the United Nations) or probabilistic projections (IIASA).

Table 9.2. Driving Forces and Their Degree of Quantification

Quantified Drivers	Unquantified Drivers
Indirect	**Indirect**
Population growth	Sociopolitical
Economic activities	Culture and religion
Technology change	
Direct	**Direct**
Energy use	Species introduction/removal
Emissions of air pollutants (sulfur, nitrogen)	
Emissions of GHG and climate change	
Land use/cover change	
Harvest and resource consumption	
External inputs (irrigation, fertilizer use)	

By 2050, most projections are in the range of 7–11 billion people. After 2050, this range widens significantly, with some scenarios showing increasing population levels while others show decreasing levels. In recent years there have been several downward revisions of population projections. Thus the population projections of the MA scenarios, as discussed here, have a lower range than those used in earlier global environmental assessment studies (such as the Intergovernmental Panel on Climate Change and the Global Environmental Outlook of the U.N. Environment Programme). The four population projections used here have been based on the IIASA 2001 probabilistic projections for the world (Lutz et al. 2001), but they are designed to be consistent with the four MA storylines. (See Table 9.3.) The IIASA projections are generally consistent with those from the other major institutions that produce global population scenarios (United Nations, World Bank, and U.S. Census Bureau).

The first step in deriving the projections was to make qualitative judgments about trends in the components of population change (fertility, mortality, and migration) in 13 world regions for each of the MA storylines. Next, the qualitative judgments were converted into quantitative assumptions based on conditional probabilistic projections. Using this approach, the high, medium, and low categories in Table 9.3 were mapped to three evenly divided quantiles of the unconditional probability distributions, as defined in the IIASA projections, for each component of population change. Single, deterministic scenarios for fertility, mortality, and migration in each of 13 regions were derived for

Table 9.3. Assumptions about Fertility, Mortality, and Migration for Population Projections in MA Scenarios. In the IIASA projections, migration is assumed to be zero beyond 2070, so all scenarios have zero migration in the long run.

Variable	Global Orchestration	Order from Strength	Adapting Mosaic	TechnoGarden
Fertility	HF: low LF: low VLF: medium	HF: high LF: high VLF: low	HF: high/ medium LF: high/ medium VLF: low	HF: medium LF: medium VLF: medium
Mortality	D: low I: low	D: high I: high	D: high/ medium I: high/ medium	D: medium I: medium
Migration	high	low	low	medium

Key: I = industrial country regions; D = developing-country regions; HF = high fertility regions (TFR>2.1 in year 2000); LF = low fertility regions (1.7<TFR<2.1); VLF = very low fertility regions (TFR<1.7). (Total fertility rate is the number of children that a woman would have at the end of her fertile period if current age-specific fertility rates prevailed.)

each storyline, defined by the medians of the conditional distributions for these variables. Population projections for each MA scenario were then produced based on the deterministic scenarios for each component of population change. Regional population projections were then downscaled to the country level to facilitate impact assessments and to allow modeling groups to reaggregate the country level results to their own regional definitions. (More information on the methodology for deriving population projections is given in Chapter 6.)

Table 9.3 lists the qualitative assumptions about fertility, mortality, and migration for each storyline. These assumptions are expressed qualitatively as high, medium, or low and in relative rather than absolute terms. That is, a high fertility assumption for a given region means that fertility is assumed to be high relative to the median of the probability distribution for future fertility in the IIASA projections. Since the storylines describe events unfolding through 2050, the demographic assumptions specified here apply through 2050 as well. For the period 2050–2100, assumptions were presumed to remain the same in order to gauge the consequences of trends through 2050 for the longer term. This is not intended to reflect any judgment regarding the plausibility of trends beyond 2050.

Trends in fertility and mortality in currently high-fertility countries were based on demographic transition reasoning. In Global Orchestration, higher investments in human capital (especially education and health) and greater economic growth rates are assumed to be associated with a relatively fast transition, implying lower fertility and mortality than in a central estimate. In Order from Strength, lower investments in human capital and slower economic growth lead to a slower transition (that is, higher fertility and mortality). TechnoGarden, with more moderate investments and economic growth assumptions, is assumed to undergo a moderate pace of change in both fertility and mortality. The Adapting Mosaic storyline begins similarly to Order from Strength but diverges later because large investments in education pay off in an acceleration of economic growth and technological development in all regions. Demographic trends in Adapting Mosaic are therefore specified to follow Order from Strength for 10 years and then to diverge to "medium assumptions" of mortality and fertility by midcentury.

The determinants of long-term fertility change are poorly known in countries that have completed the demographic transition to low fertility, and therefore there is little basis for preferring one set of assumptions over another for a given storyline. In the face of this uncertainty, the overarching rationale for specifying trends for given storylines was chosen to be the scope of convergence in fertility across low fertility countries. Since Order from Strength describes a regionalized, divergent world, and Global Orchestration a globalizing, convergent world, these characteristics were applied to future fertility. Thus the low fertility countries were divided into two groups (one with "very low fertility" and one with "low fertility," see note to Table 9.3), and fertility assumptions were adopted such that fertility in these two groups would tend to converge in the Global Orchestration scenario to around 1.6 and diverge in the Order from Strength scenario to span a range from 1.3 to 2.2. In Adapting Mosaic, fertility initially follows the Order from Strength assumptions, then diverges toward medium levels. In TechnoGarden, medium fertility is assumed.

Mortality in wealthy country regions is assumed to be lowest in the Global Orchestration scenario, consistent with its high economic growth rates, relatively rapid technological progress (assumed to occur in the health sector as well), and reductions in inequality within the region. In contrast, Order from Strength, which assumes growing inequality within wealthy countries and even the potential for reemergence of some diseases, is assumed to have the highest mortality. TechnoGarden assumes a medium pace of mortality change, and Adapting Mosaic follows the Order from Strength assumptions for 10 years before diverging to medium levels in 2050.

Net migration rates are assumed to be low in the regionally oriented scenarios (Adapting Mosaic and Order from Strength), consistent with higher barriers between regions. In Global Orchestration, permeable borders and high rates of exchange of capital, technology, and ideas are assumed to be associated with high migration. TechnoGarden assumes a more moderate migration level.

9.2.1.2 Comparison of Population Size among Scenarios

Table 9.4 shows the results for global population size through 2100 for each of the four scenarios. The range between the lowest and the highest scenario is 8.1–9.6 billion in 2050 and 6.8–10.5 billion in 2100. These ranges cover 50–60% of the full uncertainty distribution for population size in the IIASA projections. The primary reason that these scenarios do not fall closer to the extremes of the full uncertainty distribution is that they correlate fertility and mortality: Order from Strength generally assumes high fertility and

Table 9.4. Population by Region in 1995 and Assumptions in MA Scenarios (IIASA)

Region	Population in 1995	Global Orchestration			Order from Strength			Adapting Mosaic			TechnoGarden		
		2020	2050	2100	2020	2050	2100	2020	2050	2100	2020	2050	2100
					(million)								
Former Soviet Union	285	290	282	245	287	257	216	288	273	246	292	281	252
Latin America	477	637	742	681	710	944	1,309	708	933	1,155	672	831	950
Middle East and North Africa	312	478	603	597	539	774	972	537	765	924	509	692	788
OECD	1,020	1,136	1,255	1,153	1,076	998	856	1,079	1,068	978	1,117	1,154	1,077
Asia	3,049	3,861	4,104	3,006	4,210	5,023	5,173	4,201	4,992	4,753	4,039	4,535	3,992
Sub-Saharan Africa	558	858	1,109	1,132	956	1,570	1,988	951	1,492	1,775	907	1,329	1,516
World	**5,701**	**7,260**	**8,095**	**6,814**	**7,777**	**9,567**	**10,514**	**7,764**	**9,522**	**9,830**	**7,537**	**8,821**	**8,575**

high mortality, and Global Orchestration generally assumes low fertility and low mortality. Both of these pairs of assumptions lead to more moderate population size outcomes.

Adapting Mosaic is nearly identical to Order from Strength at the global level over most of the century, even though it is designed to follow Order from Strength only for 10 years and then diverge from it. This is because the effects of deviations in fertility in the Adapting Mosaic scenario do not become apparent in population size for many decades due to population momentum and because both fertility and mortality trends diverge. Thus, although fertility declines in Adapting Mosaic relative to Order from Strength after 2010, tending (eventually) toward a smaller population size, mortality declines relative to Order from Strength as well, tending toward a larger population size. The net result is little difference, especially in the short to medium term.

The relationship across scenarios differs by region. While in poorer-country regions the ranking is the same as in the global results (that is, Global Orchestration produces the lowest population size, and Order from Strength the highest), this ranking is reversed in many of the wealthy-country regions (Western Europe, Eastern Europe, Soviet Europe, and Pacific OECD). The main reason is that Order from Strength is assumed to have divergent fertility trends coupled with low migration among the wealthy regions.

Thus the regions with currently very low fertility rates (less than 1.5 births per woman) are projected to see little change in fertility levels in the future, maintaining the fertility difference between these regions and North America and China, where fertility remains around replacement level of about 2 births per woman. These assumptions, in the absence of countervailing increases in net migration into the region, produce substantial population declines in the very low fertility regions. For example, in Western Europe population declines by nearly 20% by 2050 and by more than 50% by 2100. Declines are even greater in other European regions. By contrast, in the Global Orchestration scenario, fertility rates are assumed to converge across wealthy countries, leading to increases in the regions where fertility is currently very low. In addition, migration into the region is assumed to be high in this scenario. The combined effect is to make Global Orchestration the highest population scenario for the richer-country regions.

The range of outcomes for one region, North America, is particularly small over all four scenarios, despite widely differing sets of assumptions about input variables. The reason is that assumptions about the different components of population change, as dictated by the storylines, tend to offset each other. When fertility is assumed to be low, mortality is low as well, and migration (which has a substantial influence on population growth in this region) is high. A similar situation holds, in reverse, when fertility is high. Thus the range of population size outcomes is only 426–439 million in 2050 and 420–540 million in 2100.

In sub-Saharan Africa, the HIV/AIDS epidemic takes a heavy toll in all scenarios. Life expectancy for the region as a whole is assumed to decrease and not to return to current levels for 15–25 years, depending on the scenario. In individual countries where HIV prevalence rates are highest, population is projected to decline. Yet the population of the region as a whole is projected to grow in all scenarios, driven by the large countries of the region whose HIV/AIDS prevalence rates are estimated to be relatively low and either past or near their peaks (UN 2003), by the momentum inherent in the young age structure of the region, and by relatively high fertility.

9.2.1.3 Comparison of Aging among Scenarios

The age distribution of the population will have an important influence on future consumption patterns as well as on the vulnerability and adaptive capacity of society. This is reflected, for example, in a computation of the number of malnourished children later in this chapter.

In all scenarios, substantial aging of the population occurs. The least amount of aging occurs in Order from Strength, due to its high fertility and mortality assumptions in poorer countries, but even in this case the proportion of the population above age 65 more than doubles from about 7 to 17% by 2100. In Global Orchestration, the proportion above age 65 triples by 2050 (to 22%) and increases by a factor of six (to 42%) by 2100. This result is driven by low fertility assumptions in poorer-country regions, along with low mortality assumptions for all regions.

Within these general trends at the global level, results vary by region. In all richer-country regions, the proportion over 65 doubles to at least 30% by 2100 in nearly all scenarios (the only exception is the Order from Strength scenario in North America). In contrast, while aging is extraordinarily fast in poorer regions in most scenarios—the proportion over 65 increases, for example, from 5% currently to over 40% by the end of the century in Global Orchestration—in Order from Strength the older age group never accounts for more than 20% of the population in any of these regions. In fact in sub-Saharan Africa, where fertility and mortality are the highest, little aging occurs over the first half of the century in any scenario. And even by the end of the century, the proportion of the population there over 65 years of age reaches only 22% in the most extreme outcome (the Global Orchestration scenario).

9.2.2 Economic Development

9.2.2.1 Methodology and Assumptions

Economic development as a driver of the use of ecosystem services comprises many dimensions—including income levels, economic structure, consumption, and income distribution. Often, however, levels of per capita income (GDP or GNP) are used as a measure of the degree of economic development. In fact, per capita income is typically the only development indicator used in the literature for long-term scenarios.

Assumptions about economic development influence the future of ecosystem services by affecting the direct drivers of ecosystem changes such as energy use and food consumption and the indirect drivers such as technological progress. The relationship between income development and direct drivers differs greatly among ecosystem services. For several services, model calculations assume that the higher the income, the greater the per capita consumption of commodities, up to some saturation level (for example, energy consumption per sector or domestic water use). For other services, high income may lead to a decrease in consumption because of a change in consumption patterns (fuelwood consumption, say).

Income levels are best measured in local currencies for many analyses with a national focus. However, for international comparison they need to be converted into a common unit. Historically, most scenario analyses have used conversion into U.S. dollars based on market exchange rates. An alternative measure is based on ‘‘purchasing power parity’’. PPP values show the ratio of the prices in national currencies of the same good or service in different countries and reflect the fact that many products have lower prices in low-income countries. Although PPP comparisons are considered to be a better indicator of relative wealth, the measurement is somewhat more problematic. PPP values can be determined by measuring price levels of a representative set of goods and services in different countries; it is not, however, straightforward to define such a set across a range of very different economies, also taking into account differences in quality. Hence the advantages and disadvantages of both approaches are being intensively debated.

An important aspect of this debate has been the recent discussion about MER-based income projections underlying the scenarios of IPCC’s Special Report on Emission Scenarios (Nakićenović et al. 2000). While most scenarios in SRES indeed use MER numbers, some of them have reported PPP values too, assuming real exchange rates to change dynamically with increasing degree of development. In the view of the SRES researchers, changing the metric of monetary income levels does not change the underlying real activity levels that are relevant for ecological impacts. They argue that the use of different income measures implies a different relationship between income and these physical indicators, implying that it does not matter whether PPP or MER values are used (that is, all effects are cancelled out).

Castles and Henderson (2003), however, questioned the use of MER-based income projections in the SRES. They argued that underestimation of real income in developing countries (by using MER numbers) led SRES modeling teams to overestimate activity growth rates in the next 100 years (and therefore the growth of greenhouse gas emissions) (see also Economist 2003; Maddison 2004). In response, the SRES researchers indicated that the IPCC growth projections are consistent with historic growth trajectories and that using alternative metrics for growth will not fundamentally change the scenarios (Nakićenović et al. 2003).

Several researchers explored the issue more quantitatively. Manne and Richels (2003) found some differences between using PPP and MER estimates as a result of counteracting influences in their model. Differences found by McKibbin et al. (2004) were larger, but they too concluded that possible impacts are within the range of other uncertainties impacting emissions. Finally, Holtsmark and Alfsen (2004) showed that, in their model, consistent replacement of the metric of monetary proxies (PPP for MER) throughout (for income levels but also for underlying technology relationships) led to a full cancellation of the impact. Using PPP values might give rise to lower growth rates for developing countries, but also to a different relationship between income and demand for energy. On the basis of these studies, it seems that although impacts on economic growth projections are uncertain, using PPP-based values instead of MER-based ones would at most only mildly change future estimates of resource consumption.

In the MA, we use income levels mostly as a proxy to derive activity levels measured in physical units in different models. The final results in terms of demand for ecological services have been checked against historic trends and among different regions and were found to be consistent and convincing. It should be noted that the income numbers themselves (expressed in MER-based values) should be used with some reservation in light of the debate just described—and should certainly not be directly interpreted as to express real differences in economic welfare among different regions. In a more qualitative way, however, they do express the storylines of the different scenarios.

Historically, global GDP has increased by a factor of 20 over the last 110 years, or at a rate of about 2.7% per year. Per capita GDP growth was 1.5% per year (Maddison 1995). There has been, however, a substantial variation in the rates of economic growth over time and across countries. For the OECD region, economic growth has accelerated to over 1% per year since about 1870. For most developing countries, comparable conditions for economic growth existed only in the second half of the twentieth century. It is important not to conceptualize economic development as a quasi-autonomous, linear development path. Numerous socioinstitutional preconditions have to be met before any "takeoff" into accelerated rates of productivity and economic growth can materialize.

Different strategies to create such conditions have been successful (Freeman 1990; Chenery et al. 1986). Once these preconditions are met, it is not uncommon for countries to experience an "acceleration phase" in which they catch up relatively quickly to wealthier countries. The most obvious examples have been Japan, South Korea, and China (all experienced economic growth rates over 6% over a period of at least 20 years). At the same time, income gaps in both absolute and relative terms have not disappeared from the world. For instance, per capita GDP growth in Africa has been below OECD levels since 1950, and even negative in several periods since 1980. Since 1990, other important economic trends have been the serious economic setbacks in Eastern Europe and the former Soviet Union after the transition to market economies and the more recent slow recovery of economies in Latin America.

Most economic growth scenarios found in literature only encompass periods of 10–20 years (e.g., World Bank 2002). An important exception have been the economic scenarios developed as a basis for building energy and environmental scenarios, such as those reviewed in Alcamo et al. (1995) and Nakićenović et al. (2000). Typically, such scenarios show annual economic growth rates (GDP per capita measured at MER) between 0.8 and 2.8% over the 1990–2100 period. In most cases, economic growth slows down in the second half of the century as a result of (assumed) demographic trends (aging of the population), saturation of consumption, and slower reduction in technological change. Moreover, most scenarios assume that incomes in different regions will converge in relative terms (that is, higher growth rates are assumed in poorer countries than in OECD ones).

The MA scenarios for income cover a range of economic growth rates consistent with the scenario storylines described earlier in this volume. Table 9.5 shows the qualitative asassumptions for economic variables fitting to these storylines. Using these assumptions together with the World Bank's economic prospects to 2015 (World Bank 2002) and IPCC's SRES scenarios (Nakićenović et al. 2000) as starting points, we have selected economic growth rates for each scenario. Compared with the SRES scenarios, this means that growth rates in developing regions (in particular, Africa and West Asia) have been slowed down somewhat and now bracket the World Bank prospect. As a result, the degree of convergence in the scenarios is also somewhat lower. For the period after 2015, the more detailed IMAGE implementation of the SRES scenarios were used. The SRES scenarios were scaled down earlier to the level of 17 regions (see IMAGE-team 2001) using the macroeconomic model "WorldScan," following a procedure described by Bollen (2004).[1] Assumptions range from high economic growth for Global Orchestration and low economic growth for Order from Strength, with TechnoGarden and Adapting Mosaic falling between (and partly branching off of these).

9.2.2.2 Comparison of Economic Development among Scenarios

In Global Orchestration, economic growth is assumed to be above historic averages for several regions, due to a combination of trade liberalization, economic cooperation, and rapid spread of new technologies. Among the scenarios, Global Orchestration also assumes the highest rates of investment in education and health care. The wealthier countries have a per capita growth rate of about 2.4% per year in the 2000–25 period, slowing down to around 1.8% per year afterwards. (See Table 9.6.) The Asian economies return to rapid growth rates during most of this period (with growth rates of 5–6% per year). The Latin American region overcomes its debt and balance-of-trade problems and finds itself back on track with strong economic growth. Africa carries out institutional reforms that enable strong economic growth after 2025, when it finally exploits its rich natural and human resources. After 2025, Africa achieves growth rates that are only slightly below the Asian economies in the 1980s and 1990s. As poorer countries grow much faster than others, the income gap between richer and poorer regions closes in relative terms—but hardly in absolute terms. (See Table 9.7.) In all scenarios, growth rates for the countries of the former Soviet Union are relatively high because the region uses its highly skilled labor force to recover from the economic downturn of the 1990s.

Economic development in TechnoGarden follows a similar pattern to Global Orchestration, but with lower growth rates from 2000 to 2050. By the end of the period, however, earlier investments in technology pay off with higher economic growth rates similar to Global Orchestration. Investments in human resources are likely to be lower than under Global Orchestration, partly as a result of the emphasis of TechnoGarden on technology investments.

Under the Order from Strength scenario, global economic growth is sluggish (staying below historic rates) because of the low level of international trade (except for food staples) and limited exchange of technology. The high-income countries manage to maintain a growth rate of per capita GDP of 1.9% per year during the first half of the century, but this drops to 1.2% during the second half. The income gap between rich and poor regions widens between 2000 and 2025. Despite the sluggish economy, average GDP per person increases by a factor of two between now and 2050. Investments in education and health care outside of current high-income regions will be low because of the lack of financial capital.

Table 9.5. Qualitative Assumptions on Economic Growth in MA Scenarios. The terms low, medium, and high are relative to the normal development pathways that are assumed for these regions.

Variable	Global Orchestration	Order from Strength	Adapting Mosaic	TechnoGarden
Average income growth	high	industrial countries: medium developing countries: low	begins like Order from Strength, then increases in tempo	somewhat lower than Global Orchestration, but catching up
Income distribution	income distribution becomes more equal	income distribution remains similar to today	begins like Order from Strength, then becomes more equal	similar to Global Orchestration

Table 9.6. Annual Growth Rates of GDP per Capita, 1971–2000, and Assumptions in MA Scenarios

	Historic	Global Orchestration			Order from Strength			Adapting Mosaic			TechnoGarden		
Region	1971–2000	1995–2020	2020–50	2050–2100	1995–2020	2020–50	2050–2100	1995–2020	2020–50	2050–2100	1995–2020	2020–50	2050–2100
						(percent per year)							
Former Soviet Union	0.4	3.5	4.9	3.1	2.2	2.6	2.7	2.6	4.0	3.1	2.9	4.5	3.1
Latin America	1.2	2.8	4.3	2.2	1.8	2.3	1.8	2.0	3.0	2.2	2.4	3.9	2.2
Middle East and North Africa	0.7	2.0	3.4	2.5	1.5	1.8	1.9	1.6	2.4	2.4	1.7	3.3	2.5
OECD	2.1	2.45	1.9	1.3	2.1	1.3	0.9	2.0	1.6	1.2	2.2	1.7	1.4
Asia	5.0	5.06	5.3	3.1	3.2	2.4	2.1	3.8	4.1	2.5	4.2	4.7	3.1
Sub-Saharan Africa	−0.4	1.69	4.0	4.1	1.0	2.1	2.1	1.2	2.9	3.3	1.4	3.8	4.1
World	**1.4**	**2.38**	**3.0**	**2.3**	**1.4**	**1.0**	**1.3**	**1.5**	**1.9**	**1.9**	**1.9**	**2.5**	**2.3**

Table 9.7. Annual GDP per Capita by Region in 1995 and Assumptions in MA Scenarios

	GDP, 1995	Global Orchestration			Order from Strength			Adapting Mosaic			TechnoGarden		
Region	1995	2020	2050	2100	2020	2050	2100	2020	2050	2100	2020	2050	2100
						(dollars per capita)							
Former Soviet Union	1,630	3,853	16,223	76,107	2,837	6,198	23,708	3,093	10,109	46,010	3,365	12,560	58,898
Latin America	4,337	8,660	30,427	92,226	6,747	13,293	31,952	7,229	17,489	52,575	7,769	24,682	74,738
Middle East and North Africa	2,068	3,363	9,223	31,630	3,010	5,070	13,214	3,085	6,337	20,711	3,186	8,353	28,757
OECD	22,657	41,496	73,607	143,151	37,752	55,734	85,678	37,188	59,114	106,588	39,235	65,876	128,822
Asia	784	2,694	12,600	57,296	1,733	3,564	9,913	1,972	6,612	22,961	2,212	8,781	40,947
Sub-Saharan Africa	637	969	3,117	23,035	820	1,540	4,492	860	1,997	10,169	910	2,787	20,629
World	**5,102**	**9,190**	**22,282**	**68,081**	**7,204**	**9,838**	**18,377**	**7,338**	**12,932**	**32,808**	**8,162**	**16,941**	**51,546**

The Adapting Mosaic scenario initially follows the pattern of the Order from Strength scenario, but because of large investments in education and health care, economic growth rates increase over time and approach those of the TechnoGarden scenario in the last half of the century.

9.2.3 Technological Change

9.2.3.1 Methodology and Assumptions

The rate of technological change is an indirect driver of changes in ecosystem services because it affects the efficiency by which ecosystem services are produced or used. Most relevant in this context are the factors related to energy, water, and agriculture. A higher rate of improvement of crop yields, for instance, could lead to a lower demand for cropland (to produce the same amount of food), reducing the need to convert forest or grassland. Technological change, however, can also lead to increased pressure on ecosystem services because technological advancements often require large amounts of goods and materials themselves and can cause new ecological risks. (For example, the application of chemical fertilizers for increasing crop yield can also lead to nitrogen contamination of surface water and groundwater.)

Technological change is a complex and dynamic process. It is linked to the economic and cultural environment beyond individual "innovating firms," as described by Rostow (1990) and Grübler (1998). Innovations are highly context-specific in that they emerge from local capabilities and needs and evolve from existing designs. Numerous examples illustrate the messiness and complexity of the innovation process (e.g., Grübler 1998; Rosenberg 1994). Nevertheless, some generalizations can be applied to the concepts of innovation and technological change (see Nakićenović et al. 2000): Innovation draws on underlying scientific or other knowledge. Many innovations depend on knowledge obtained through experience. The social and economic environment should encourage a situation in which innovators are willing and able to take some risks. Technology change may be both supply- and demand-driven. And technological diffusion is an integral part of technology change (and can thus be slowed down by protectionist measures).

It is notable that technology development is typically driven by factors unrelated to ecosystem services. For example, efforts to improve crop yield depend on factors such as the profitability of farmland and general investments in education and research. The same holds for the development of new energy technologies such as solar and wind power, which are influenced by trends in fossil fuel prices and environmental policies. Michaelis (1997), for instance, showed the strong relationship between fuel prices and the rate of energy efficiency improvement.

9.2.3.2 Comparison of Technological Change among Scenarios

In order to maintain consistency across the MA scenarios, it is necessary to assume some general trends in technological change over the scenario period and to apply these general trends to all scenario variables that are strongly influenced by technological change. This section presents the general assumptions made about technological development used to select future trends in improvement in irrigation efficiencies, crop yield improvements, improvements of water use efficiency, improvement of energy use efficiency, costs reductions of new energy technologies, and the rate of emission control technologies.

The assumed overall trend in "technological efficiency" for the four MA scenarios is given in Figure 9.1. We assume the highest rates of technological development under Global Orchestration because this scenario has several features that are favorable to technology development (see Table 9.8): high economic growth rates, which in principle are consistent with new capital investments; large investments in education; low trade barriers, leading to relatively rapid dispersal of knowledge and technologies; and an accent on entrepreneurship, possibly providing a stimulus to human ingenuity. It should be noted, however, that it is also assumed that the technology development under Global Orchestration will not necessarily be environmentally friendly. Fossil fuel–based technologies could develop at the same rate as, for instance, solar or wind power. In the example for irrigation efficiency, we assume that careful market-oriented reform under Global Orchestration in the water sector (with coordinated government action) could lead to greater water management investments in efficiency-enhancing water and agricultural technology, particularly in Asia and sub-Saharan Africa.

Under TechnoGarden, a somewhat lower rate of technology development is expected than under Global Orchestration, given the fact that several of the factors just mentioned are less dominant. A central tenet of this scenario is that technology development is directed to reduce (or at least mitigate) existing ecological problems. That implies relatively high technological growth rates for environmental technologies, but lower rates of development for technologies in general. Later in the century, the technology rate improvement could start to catch up with Global Orchestration (as it is less close to the frontier). For the example of irrigation efficiency, under the TechnoGarden scenario technological innovations could help boost irrigation efficiency levels across the world to previously unseen levels. Gradual introduction of water price increases in some agricultural areas induce farmers in these regions to use water more efficiently. As a result, high efficiency levels are reached, particularly in regions where little or no further improvement had been expected, like the OECD and the Middle East and Northern Africa.

Under Adapting Mosaic, regionalization and higher barriers could be expected to slow economic growth and the dispersion of technologies and to slow down overall technological development (2000–25). Increased (decentralized) learning could at the same time build up a new basis from which technologies can be developed. Therefore, technologies under this scenario develop slowly at first but speed up later in the century compared with the other scenarios. For the example of irrigation efficiency, local adaptations—including expansion of water harvesting and other water conservation technologies as well as the increased application of agro-ecological approaches—could help boost efficiency levels in some regions and countries. Efficiency increases are achieved but remain scattered in areas and regions within countries, and the global and regional impacts are smaller than under the TechnoGarden and Global Orchestration scenarios.

Finally, under the Order from Strength scenario, technology development will be relatively slow throughout the whole period, especially in low-income countries. The main reasons include the lack of international cooperation and the low potential for investment. This is reflected in the assumptions made for irrigation efficiency. Government budgetary problems are assumed to worsen, resulting in dramatic government cuts in irrigation system expenditures. Water users strongly oppose price increases, and a high degree of conflicts hinder local agreements among water users for cost-sharing arrangements. Rapidly deteriorating infrastructure and poor management reduce system- and basin-level water use efficiency under this scenario. As a result, efficiency levels are assumed to decline in both wealthy countries and in poorer countries where efficiencies are already quite low.

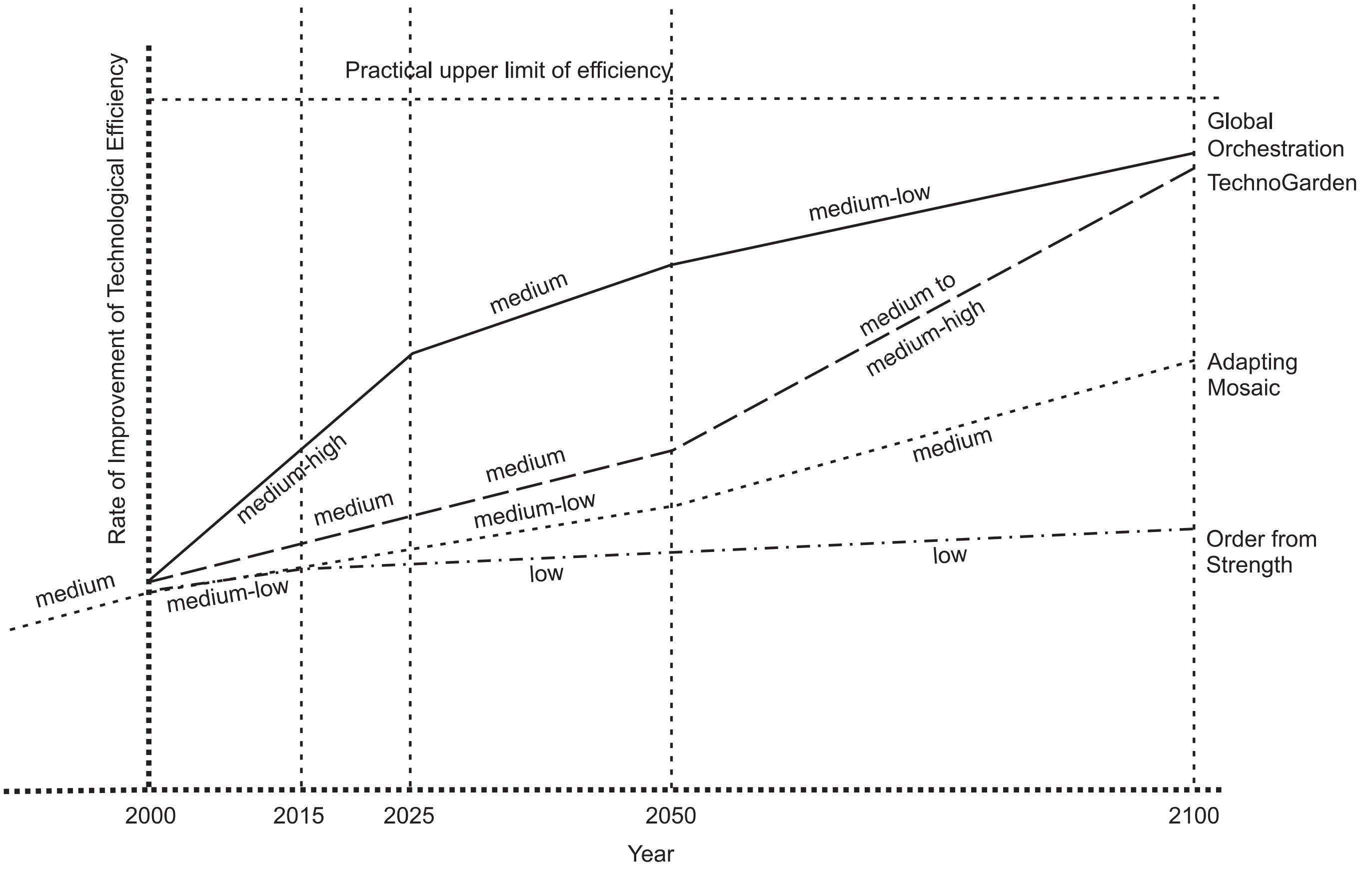

Figure 9.1. Global Trends of Technological Efficiencies in MA Scenarios. Depicted are the qualitative assumptions made for changes in technological efficiency under the four MA scenarios. Technological Efficiency refers, for example, to the conversion efficiency of power plants, or the yield of all crops per hectare. As a reference point for the scenarios, we designate the current rate of improvement of all technologies as "medium." Therefore, a "high" scenario implies an acceleration, and a "low" scenario implies a slowing of the current rate of improvement. These qualitative assumptions are used for setting technology-related parameters in the models used for quantifying the scenarios (e.g., the rate of increase of crop yield due to technological improvements in crops). For the TechnoGarden scenario, a faster rate of improvement than shown in the curve was assigned to the technologies directly related to pollution control such as air pollution filtering devices. This is consistent with the storyline of the scenario which specifies that the environmental orientation of TechnoGarden leads to a faster improvement in pollution control technologies than under the Global Orchestration scenario, but a slower improvement in all other technologies.

Table 9.8. Qualitative Assumptions for Technology Development in MA Scenarios

Variable	Global Orchestration	Order from Strength	Adapting Mosaic	TechnoGarden
Investments into new produced assets	high	industrial countries: medium; developing countries: low	begins like Order from Strength, then increases in tempo	high
Investments into human capital	high	industrial countries: medium; developing countries: low	begins like Order from Strength, then increases in tempo	medium
International relationships (stimulating technology transfer)	high	low (medium among cultural groups)	low-medium	high
Overall trend	high	low	medium-low	medium for technology in general; high for environmental technology

9.2.4 Social, Cultural, and Political Drivers

9.2.4.1 Methodology and Assumptions

Social, cultural, and political drivers are important indirect drivers of ecosystem services. Assumptions about these drivers influence the trends of the direct drivers of ecosystem services, such as the trends in producing energy or consuming food. Here we briefly review the trends of these important indirect drivers, as they are implied by the storylines in Chapter 8, and give some examples of their impact on the direct drivers of ecosystem services. (See Table 9.9.)

9.2.4.2 Comparison of Social, Cultural, and Political Drivers among Scenarios

Although it is difficult to represent social and cultural factors in global scenarios, we have two preliminary examples of including the influence of these factors on resource consumption.

The scenarios differ in people's attitude toward international cooperation, and this leads to other assumptions for drivers of ecosystem change in the scenarios. A positive attitude toward international cooperation is assumed to lead to a higher level of international trade in Global Orchestration and TechnoGarden. Conversely, a more negative attitude in Adapting Mosaic and Order from Strength is assumed to inhibit the formulation of international environmental policies, and, in particular, climate policies. Hence, these two scenarios assume a low level of controls of greenhouse gas emissions.

The scenarios also differ in people's attitudes toward environmental policies, and this leads to other assumptions for drivers of ecosystem change. The projected attitudes toward environmental policies also lead to assumptions about other variables. For instance, a generally reactive attitude with regard to environmental policies is assumed in Global Orchestration. This is consistent with the scenario's optimistic view on the robustness of ecosystems and the abilities of humans to deal with environmental problems when they are observed, combined with a strong focus on improving human well-being by means of social policies and economic development. This was interpreted to mean that there will be no incentive in the future to reduce the amount of meat consumed per person (despite the connection between meat consumption, livestock grazing, deforestation, and soil degradation). Similarly, under Global Orchestration it was assumed that society is not likely to subsidize use of renewable energy for environmental protection reasons. Figure 9.2 shows that Global Orchestration gets a much lower share of energy use from renewable energy than the two scenarios that emphasize proactive ecological policies, TechnoGarden and Adapting Mosaic.

Table 9.9. Assumed Changes for Selected Indirect Drivers in MA Scenarios

Variable	Global Orchestration	Order from Strength	Adapting Mosaic	Techno-Garden
International cooperation	strong	weak—international competition	Weak—focus on local environment	strong
Attitude toward environmental policies	reactive	reactive	proactive—learning	proactive

9.2.5 Energy Use and Production

9.2.5.1 Methodology and Assumptions

Energy use has many indirect effects on ecosystem services. The use of fossil fuel determines the rate of air pollutant emissions and therefore the load-on quality of the atmosphere. The level of biofuel use affects the type and distribution of land cover and the services provided by forest and other land cover types, while the magnitude of thermal-generated electricity will influence water withdrawals. Energy production is also one of the principal sources of greenhouse gas emissions, which are the main determinants of climate change, which itself is a direct driver of changes in ecosystem services.

The amount of energy used in the different scenarios is influenced by the demand for energy services (driven mostly by economic and population growth) and by continuing improvements in the efficiency of energy use.

Wide-ranging ''reference'' and storyline-based energy scenarios have recently been published, including the regularly updated scenarios of the International Energy Agency (IEA 2002), the U.S. Department of Energy (DOE 2004), the Shell Oil Company, the IPCC SRES scenarios (Nakićenović et al. 2000), and the World Energy Assessment (WEA 2000). Nakićenović et al. (2000) provide an extensive overview of the energy scenarios found in the literature. Almost all scenarios show substantial increases in energy use in the period from 2000 to 2050. While new energy carriers (such as renewables) increase their market share, energy use continues to be dominated by fossil fuel use in nearly all scenarios. After 2050, some scenarios indicate stabilizing or even decreasing energy use, while others show continuous growth. In the compilation of the MA scenarios, we have combined assumptions of the IPCC SRES scenarios with the drivers discussed earlier. (See Table 9.10.)

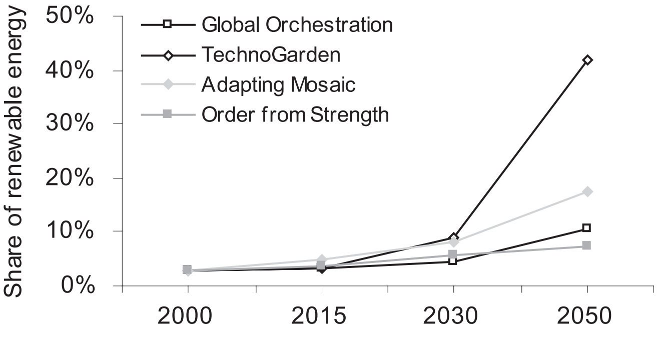

Figure 9.2. Share of Renewable Energy in Total Primary Energy Consumption in MA Scenarios. Renewable Energy is defined here as solar, wind hydropower, and the use of modern biofuels. (IMAGE 2.2)

Table 9.10. Main Assumptions about Energy in MA Scenarios

Variable	Global Orchestration	Order from Strength	Adapting Mosaic	TechnoGarden
Energy demand	lifestyle assumptions and energy efficiency investments based on current North American values	regionalized assumptions	regionalized assumptions	lifestyle assumptions and energy efficiency investments based on current Japanese and West European values
Energy supply	market liberalization; selects least-cost options; rapid technology change	focus on domestic energy resources	some preference for clean energy resources	preference for renewable energy resources and rapid technology change
Climate policy	no	no	no	yes, aims at stabilization of CO_2-equivalent concentration at 550 ppmv

9.2.5.2 Comparison of Energy Use and Production among Scenarios

The dominant themes in the Global Orchestration scenario are a rapid increase in energy demand (driven by strong economic growth), a minimization of energy costs, and provision of a reliable energy production system. Environmental considerations receive little attention, as society believes the environmental impacts of energy production to be either small or manageable by future technological change (if signals of severe environmental deterioration become apparent). Based on these considerations, we have assumed that there is no attempt to control greenhouse gas emissions in the first decades of the scenario period. At the same time, technology development in the energy sector is relatively fast, which leads to indirect reductions in emissions of greenhouse and other pollutant gases.

Since the effects of climate change are apparent later in Global Orchestration, we assume that society responds by adapting to impacts rather than reducing emissions (since by that time a certain degree of climate change will be unavoidable). As a result of these assumptions, fossil fuel use expands rapidly, in particular the use of gaseous fuels (for households and electricity production) and liquid fuels (in the transport sector, possibly replaced by hydrogen). Total energy use increases up to 1,200 exajoules by 2050 (compared with a current level of 400 exajoules) and levels off toward the end of the century. (See Figure 9.3 in Appendix A.) Trends are very similar to IPCC's A1b scenario (Nakićenović et al. 2000), while consumption levels are somewhat lower due to lower population and economic growth. In the second half of the century, new (non-fossil) fuel options rapidly penetrate the market.

The TechnoGarden scenario assumes that society will be convinced that environmental degradation decreases human well-being and therefore supports long-term reductions of greenhouse and other air pollutant emissions. To mitigate climate change, the international community adopts a goal of limiting global mean temperature increase to 2° Celsius by 2100 over preindustrial levels (similar to the current target for climate policy in the EU and several European countries). Assuming medium values for the relevant parameters in a simple climate model, the attainment of this temperature goal implies that global emissions must fall below half the current emissions before 2100. Since emissions stem mostly from energy use, this requires a reduction in the use of fossil fuels, which is brought about by energy efficiency, increasing use of ''zero-carbon'' energy sources (modern biofuels and solar and wind energy, as examples), and more low-carbon fuels (principally natural gas). As a result, total energy use reaches a level of 510 exajoules in 2050 and slowly increases thereafter, despite relatively high economic growth rates. This energy scenario is similar to others that aim to achieve comparable climate goals, such as those that aim to stabilize carbon dioxide at 450 parts per million by volume or total greenhouse gas concentration at 550 parts per million CO_2-equivalent (Morita et al. 2001; van Vuuren and de Vries 2001).

A central theme of Order from Strength is securing reliable energy supplies, and this leads to a focus on developing domestic energy sources. Slow diffusion of new technologies and increased barriers for global energy trade (particularly important for natural gas and oil) also contribute to a continued intensive use of domestic fossil fuels. For China and India, this implies a continued reliance on coal. Total energy use increases almost linearly throughout the century, reaching about 800 exajoules in 2050. This is much lower than Global Orchestration because the Order from Strength scenario has lower economic growth, particularly in poorer countries. Energy use is higher than in TechnoGarden because Order from Strength assumes slower improvements in the efficiency of energy use. This scenario is similar in character to IPCC's A2 scenario.

Adapting Mosaic is similar to Order from Strength in that it has lower economic growth rates than Global Orchestration and lacks global climate policies. Global energy use in 2050 (880 exajoules) is between Global Orchestration and TechnoGarden. However, it differs from the Order from Strength scenario in that there is great concern about environmental degradation. Thus, local approaches are adopted for improving efficiency of energy use and for exploiting environmentally friendly fuels. As a result, total energy use stabilizes soon after mid-century, and non-fossil fuels play an increasing role in the energy economy.

9.2.6 Summing Up Trends in Indirect Drivers

Figure 9.4 provides a graphical overview of the global trends for several crucial indirect drivers. As concluded by

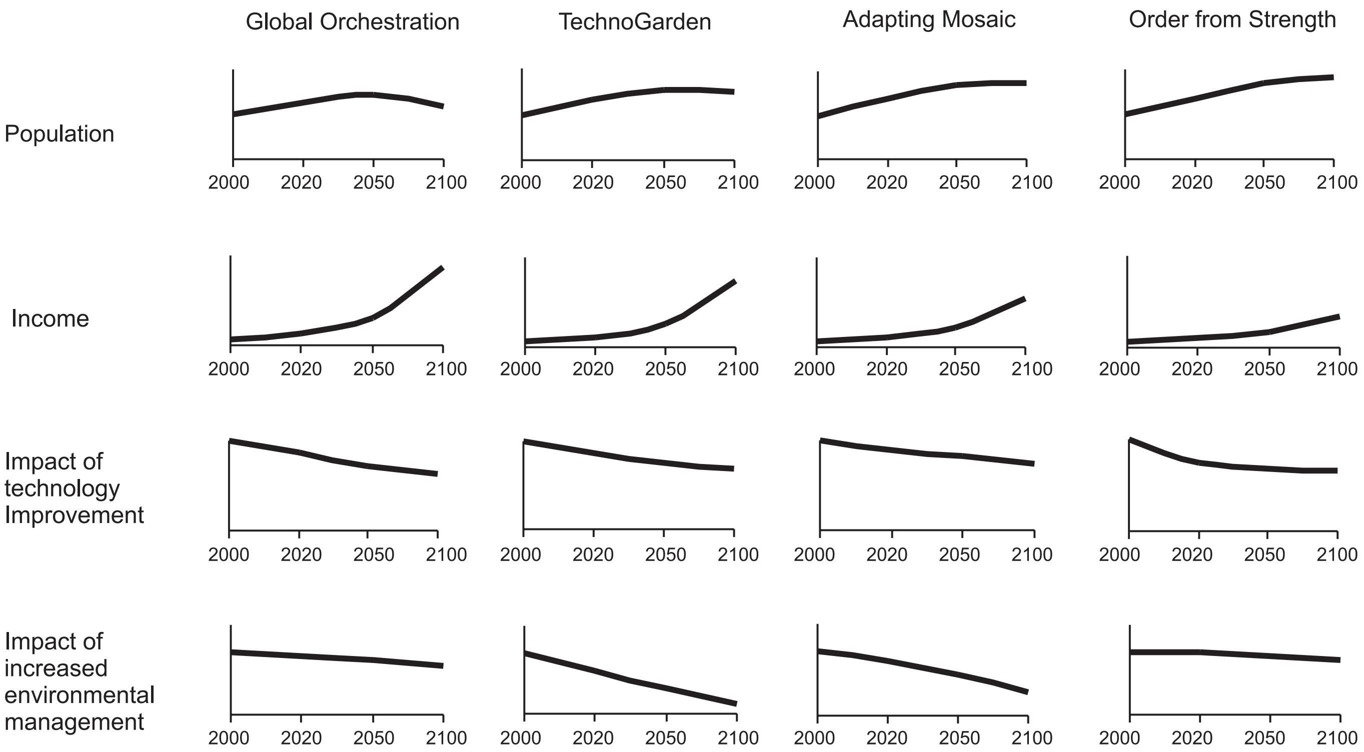

Figure 9.4. Impact of Trend in Crucial Indirect Drivers on Pressures on Ecosystems in MA Scenarios. Population and activity growth lead to increased pressures; technology improvement and increased impact of increased environmental management to fewer pressures.

Nakićenović et al. (2000), it is not advisable to assume that future indirect drivers, such as population and economic growth, will be independent of one another. Their coupling can be taken into account in scenario storylines and, where possible, in the models used to produce quantitative scenarios. In the MA scenario we have, for example, assumed that there is a higher probability of high population growth in poorer countries under low economic growth scenarios (due to a slowdown of the demographic transition). We have also assumed that there is a higher likelihood of faster technological development under higher economic growth (because of higher investments in research and education).

We note here that some assumed relationships between indirect drivers tend to create compensating effects in the scenarios. For example, since we combine the assumption of highest population growth with the lowest economic growth, and the lowest population growth with the highest economic growth, we compute a narrower range of demands for goods and services among the scenarios than the range of assumptions of population growth and economic growth.

9.3 Direct Drivers of Ecosystem Services

Direct drivers are mainly physical, biological, or chemical processes that tend to directly influence changes in ecosystem goods and services. In some cases it is difficult to distinguish between drivers and ecosystem services. An example is the case of the ecosystem service "food provisioning," which itself is a prime determinant of the direct driver "land use change" (discussed here as a direct driver). The direct drivers discussed here are:

- greenhouse gas emissions,
- air pollution emissions,
- risk of acidification and excess nitrogen emissions,
- climate change,
- sea level rise,
- land use and land cover change,
- use of nitrogen fertilizers and nitrogen loading to rivers and coastal marine systems, and
- disruption of landscape by mining and fossil fuel extraction.

9.3.1 Greenhouse Gas Emissions

9.3.1.1 Methodology and Assumptions

Greenhouse gas emissions determine to a large degree both the rate and intensity of future climate change. The main sources of these emissions are energy use, agricultural activity, industrial processes, and deforestation. The most important greenhouse gas (in terms of the contribution to increased forcing) is CO_2. Emissions of methane and nitrous oxide, stemming mainly from agricultural sources, account for about one fifth of total greenhouse gas emissions (in units of equivalent carbon dioxide).

In recent years, several long-term greenhouse gas scenarios have been published. Alcamo and Nakićenović (1998) and Nakićenović et al. (2000) published extensive overviews of available scenarios in the literature, showing that the range covered by the IPCC SRES scenarios reasonably coincides with the range drawn up by "non-intervention'' scenarios in the literature (that is, scenarios that do not assume specific policies to reduce greenhouse gas emissions or stimulate additional uptake of CO_2 by the atmosphere). Using the SRES scenarios or other reference scenarios as departure points, researchers have developed scenarios that incorporate climate policies (examples include Alcamo and Kreileman 1996; Hyman et al. 2003; Manne and Richels 2001; Morita et al. 2001; Reilly et al. 1999; van Vuuren et al. 2003).

The greenhouse gas trends for the MA scenarios (see Table 9.11) can be derived almost directly from the energy and land use trends discussed elsewhere in this chapter. Their range coincides well with those found in the literature, in particular the IPCC scenarios and, in the case of the TechnoGarden scenario, the derived climate policy scenarios. Obviously, the range presented is not exhaustive—for instance, lower greenhouse emission pathways are possible, but at relatively high costs.

9.3.1.2 Comparison of Greenhouse Gas Emissions among Scenarios

Under Global Orchestration, greenhouse gas emissions peak at mid- century just above 25 Gt C-eq, compared with around 10 Gt C-eq in 2000.[2] Emissions decline afterwards because total energy use stabilizes and a greater percentage of low carbon fuels are used. (See Figure 9.5 in Appendix A.) CO_2 emissions are projected to grow somewhat faster than those of other important greenhouse gases such as CH_4 and N_2O, since the drivers of CO_2 (energy production) grow somewhat faster than the drivers of the other gases (agricultural variables).

The share of emissions coming from the OECD and former Soviet Union regions declines from 48% to 30% as a result of larger economic and population growth in the other regions. In terms of emissions, Global Orchestration is comparable to IPCC-SRES A1b scenario or other scenarios with relatively high emissions.

The strong climate policies in TechnoGarden limit the increase in fossil fuel consumption in that scenario. Hence emissions grow much more slowly; they peak around 2020 at 12 GtC-eq and decline by 2050 to 30% below their level in 2000. Several studies indicate that technical options exist for such emission reductions (IPCC 2001). The economic costs of these emission controls are much more uncertain and generally range from 1% to 4% of world GDP (IPCC 2001). Here, we use an implementation of a multigas reduction strategy calculated by IMAGE that aims to limit global temperature increase to 2° Celsius above preindustrial levels. In the OECD and former Soviet Union regions, emissions decline by 2050 to about 30% of emissions in 2000. In Asia and Latin America, emissions return to their 2000 values around 2050. For Africa and the MENA regions, emissions growth (coming from low levels in 2000) is reduced. The difference between the regions is caused by the much faster increase in population and economic activities in developing regions. The emissions under this scenario are representative of low emissions scenarios found in the literature.

The trend in emissions under Order from Strength follows the linear increase in total global energy use of this scenario. Emissions almost double between 2000 and 2050, and again between 2050 and 2100. Up to 2050 the emissions of all greenhouse gases increase, whereas afterwards the only significant increase is from CO_2 emissions. Order from Strength is the only scenario where continuing deforestation implies that land use change will remain an important source of CO_2 emissions. Quantitatively, the emissions in this scenario are similar to IPCC's A2 scenario (which implies that it compares well to relatively high emission scenarios in the second half of the century).

Emissions under Adapting Mosaic grow steadily to a level of 18 Gt C-eq around mid-century. After 2050, emissions gradually decline to a level slightly above 16 Gt C-eq as energy growth slows and more low-carbon fuels are used. This emission path is comparable to that of the IPCC-B2 scenario. The scenario is representative of the medium range of scenarios found in the literature.

9.3.2 Air Pollution Emissions

9.3.2.1 Methodology and Assumptions

A large number of activities contribute to air pollution. Burning of fossil fuels and biomass contribute to air pollutants such as sulfur dioxide, carbon monoxide, nitrogen oxides, particulate matter, volatile organic compounds, and some heavy metals. In addition, industrial activities and agriculture also contribute to air pollution. In our assessment, we concentrate on sulfur dioxide and nitrogen oxides. Emissions

Table 9.11. Kyoto Greenhouse Gas Emissions in 1995 and Assumptions in MA Scenarios (IMAGE 2.2)

Greenhouse Gas	Emissions in 1995	Global Orchestration	Order from Strength	Adapting Mosaic	Techno-Garden
		(emissions in GtC-equivalent[a])			
CO_2	7.3	20.1	15.4	13.3	4.7
CH_4	1.8	3.7	3.3	3.2	1.6
N_2O	0.7	1.1	1.1	0.9	0.6
Other GHG	0.0	0.7	0.5	0.6	0.2
		(percent)			
OECD and former Soviet Union as share of total emissions	48	30	34	29	22

[a] GtC-equivalent emissions are the contribution of different greenhouse gases expressed in tons of carbon based on 100-year global warming potentials.

of these compounds lead to problems both near and far from their source. In the vicinity of pollution sources, high emissions (in particular, when combined with unfavorable meteorological conditions) can lead to the buildup of high concentrations of SO_2 , ozone, and other gases and pose a threat to human health. The local level of SO_2 and ozone can be high enough to cause long-term damage to vegetation. SO_2 and NO_x emissions are also transported hundreds of kilometers from their source and are then deposited via precipitation and diffusion to vegetation and soils, where they cause acidification of soils and freshwater systems (as well as direct impacts on vegetation). Because of their important role in many key air pollution-related problems, SO_2 and NO_x are good indicators of air pollution.

Trends of SO_2 and NO_x emissions are somewhat different. SO_2 emissions are relatively easy to control, either by filtering them from smokestacks or reducing the sulfur content of fuels. As a result, SO_2 emissions trends tend to follow a pattern that is sometimes referred to as the Environmental Kuznets Curve. First, emissions increase with growing energy use, but they eventually decrease as impacts of emissions increase and society demands control of air pollution. SO_2 emissions are currently decreasing in most OECD countries, but some researchers claim that emissions may again increase with economic growth once the cheaper measures for abating SO_2 emissions are exploited. Measures for reducing NO_x emissions are usually more expensive. As a result, NO_x emissions have been less controlled than SO_2 emissions and only in high-income countries.

9.3.2.2 Comparison of Sulfur Dioxide Emissions among Scenarios

Most published scenarios of global SO_2 emissions follow the historical trends, showing declines in emissions in most high-income countries and initially increasing emissions followed by a decline in low-income countries (see, e.g., Mayerhofer et al. 2002; Bouwman et al. 2002). For $NO_{x,}$ in general a similar pattern is noted, but later in time and with less stringent reduction in emissions.

Based on the storylines of the MA scenarios (see Table 9.12), both the AIM and IMAGE modeling groups independently made assumptions on the development of the major drivers of emissions and emission control policies. Both results are discussed in order to capture some of the uncertainty of estimates. (If only one result is quoted, then it refers to AIM model results.) While the scenarios have been worked out at the regional scale, we concentrate here on the global results.

Under Global Orchestration, the elaboration of both models shows an initial increase followed by declining emissions, which is a result of decreasing emissions in high-income countries and initially increasing emissions in low-income regions. The rate of decline after 2020, however, is uncertain. As a result, estimates for 2050 emissions differ between near-current emission levels (IMAGE) to a 45% drop worldwide in AIM (compared with 2000). (See Figure 9.6.) The regional results (shown for AIM in Figure 9.7), show that the reductions are much stronger in the OECD and former Soviet regions, assuming a continuation of current controls of SO_2 emissions and a major shift to lower sulfur fuels. Sulfur dioxide emissions in most other regions initially grow, but by 2050 drop considerably. (See Figure 9.7.) In sub-Saharan Africa, in contrast, emissions more than double because the economic level is still not high enough to support sulfur emission controls.

Under TechnoGarden, both stricter environmental policies and the benefits of climate policies contribute to reducing sulphur emissions (high carbon fuels often also contain high sulphur levels). The two models agree on very substantial drops in global sulphur emissions. Emission reductions in this scenario outside the OECD and former Soviet region can also be impressive, such as for the MENA and for Latin America. This is partly caused by the fact that the assumed climate policies in TechnoGarden are effective in all regions (possibly financed through emission trading schemes). In sub-Saharan Africa, emissions still grow significantly, resulting mainly from the low 2000 values.

For Adapting Mosaic, there is quite some difference between the AIM and IMAGE 2020 values, but in 2050 reductions are in both cases 30–40%. Differences between the models are mainly caused by different expectations of when air pollution control policies will become important. In this scenario, trends can differ widely in different regions. Reductions are strong in the OECD, Latin America, and former Soviet region, but other regions show stable emissions or even an increase.

Finally, elaboration of Order from Strength indicates that this scenario has the highest emissions of the four MA scenarios—in fact, showing a net increase of emissions in 2050. In this scenario, emissions reductions in OECD, Latin America, and former Soviet regions are offset with strong emission increases in sub-Saharan Africa and Asia.

Table 9.12. Main Assumptions about Air Pollution Emissions in MA Scenarios (IMAGE 2.2)

Variable	Global Orchestration	Order from Strength	Adapting Mosaic	TechnoGarden
SO_2 policies and NO_x policies	environmental Kuznets type, thus decreasing after sufficient income	environmental Kuznets type; low income growth slows down policies	proactive going beyond environmental Kuznets type; reduced income growth slows policies somewhat	proactive going beyond environmental Kuznets type
Characteristic driving force	strong increases in energy use and transport	coal dominant energy carrier in Asia	most drivers have medium values	climate policies have large co-benefits

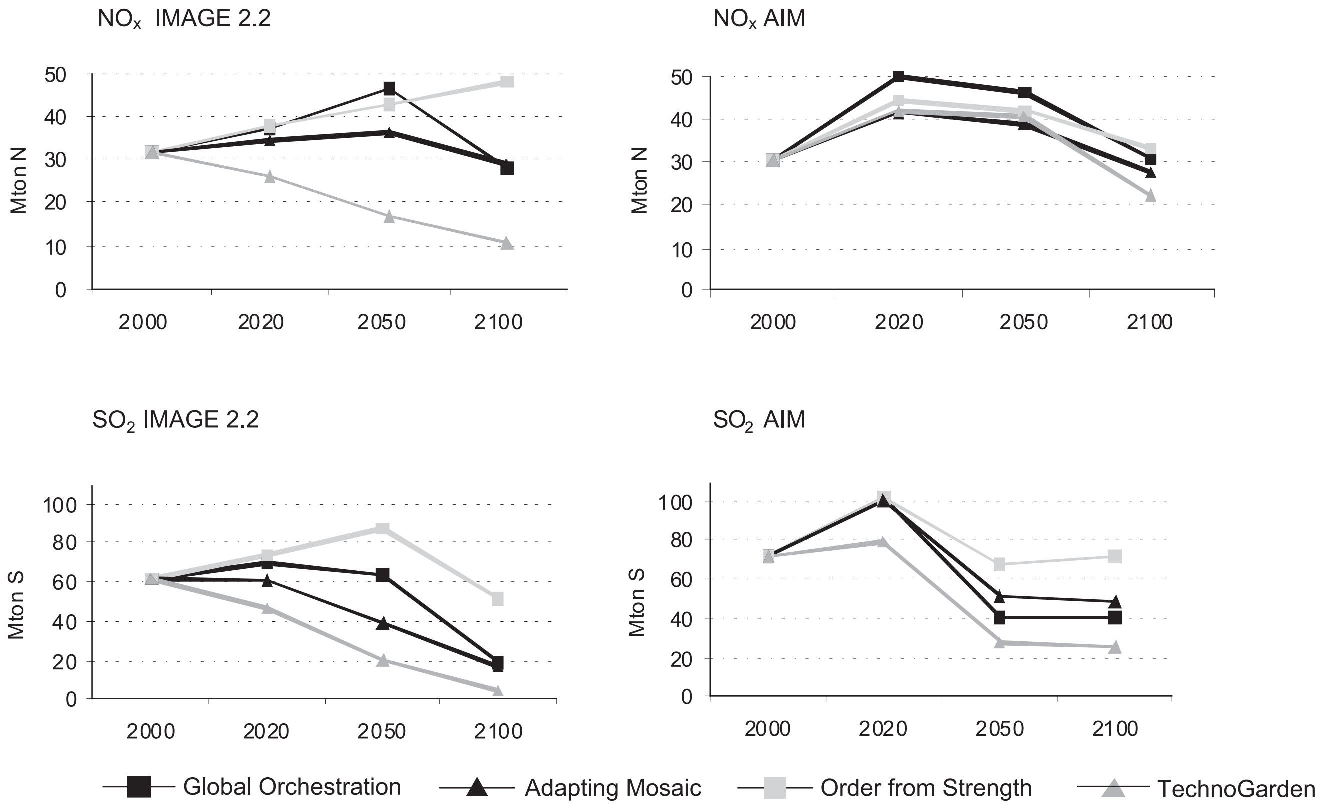

Figure 9.6. Trends in SO_2 and NO_x Emissions in MA Scenarios (IMAGE 2.2 and AIM)

9.3.2.3 Comparison of Nitrogen Oxides Emissions among Scenarios

Globally, the trend of nitrogen oxides emissions differs from that of sulfur dioxide. Global emissions of NO_x increase under every scenario except TechnoGarden.

Under Global Orchestration, worldwide emissions between now and 2050 increase by over 50%, following similar trends in IMAGE and AIM. At the same time, emissions decrease by nearly 60% in OECD countries. (See Figure 9.8.) Elsewhere, emissions are driven upwards by the expansion of energy use for transportation and power generation. The biggest increase is in Asia and the former Soviet region (by a factor 2 to 3), owing to their high economic growth rates. The increase in emissions is lower in sub-Saharan Africa and the MENA because of their lower economic growth, which leads to lower energy use.

In TechnoGarden, emissions tend to increase because of rapidly expanding transportation energy use and to decrease because of tighter controls and the co-benefits of climate policies. The final balance can result in increasing emissions in AIM and decreasing emissions in IMAGE (also depending on the type of climate action taken). In general, emissions decrease in currently high-income countries and increase in currently low-income countries. Increases in sub-Saharan Africa and the MENA are about the same as in Global Orchestration.

For Adapting Mosaic, the worldwide increase in emissions up to 2050 in both models is about 20–30%. NO_x emissions drop by two thirds in OECD countries and by over 40% in Latin America because of pollution controls. Increases in other regions are substantial because of expanded transportation energy use (a factor of 2.8 increase in Asia and the former Soviet Union).

In the Order from Strength scenario, emissions increase worldwide by 38% between now and 2050. Slow economic growth and other priorities for policy-making (poverty and security) lead in IMAGE to a continuous increase in global emissions (driven by low-income regions), while in AIM, emissions peak. The lower economic growth (compared with Global Orchestration) leads to a lower rate of emissions, but the lack of pollution controls in most regions leads to a higher rate. The growth of emissions is substantial in other regions: about 50% in MENA and Latin America, and about a factor of 2.6 in Asia and the former Soviet region.

9.3.2.4 Summing Up Air Pollution Emissions

The following more general observations regarding emission trends can also be made:

- Under Global Orchestration, emission trends are balanced between increasing sources of emissions and increasing commitments to emission controls as a result of increasing demand for clean air. Global SO_2 emissions are expected to stabilize while NO_x emissions increase between 2000 and 2050. Most of this increase occurs in Asia, the former Soviet Union, Africa, and MENA.
- Under TechnoGarden, we expect strong reductions in SO_2 and NO_x emissions as a result of strong investments in emission controls and the co-benefits of climate change policies.

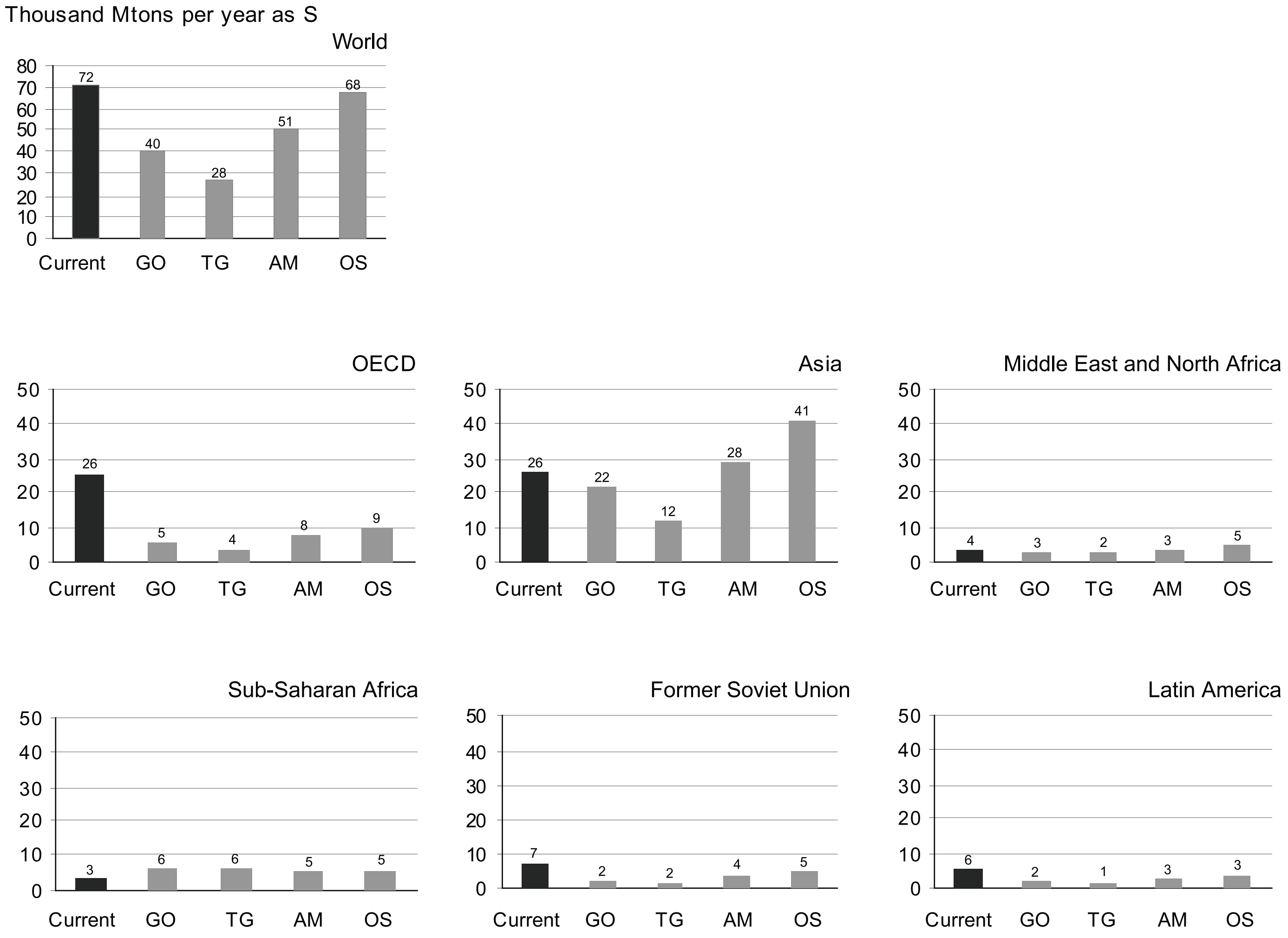

Figure 9.7. Emissions of Sulfur Dioxide in Different World Regions for MA Scenarios in 2050. Scenario names: GO: Global Orchestration; TG: TechnoGarden; AM: Adapting Mosaic; OS: Order from Strength. (AIM)

- Under Adapting Mosaic, environmental awareness is higher than under Global Orchestration, but lower economic growth in developing regions implies less energy use (and thus lower emissions) but also less investment in emission control technology. The result is that sulfur-related pollution declines in all regions except Asia, where it has a slight net increase. Trends for NO_x are similar to those in the Global Orchestration scenario.
- The level of sulfur-related air pollution declines only slightly worldwide under the Order from Strength scenario. Emissions decline in OECD, the former Soviet region, and Latin America. Asia and MENA have the largest emission increases of all scenarios. There is a significant decline in NO_x-related pollution in OECD countries, and a major increase elsewhere.

9.3.3 Risks of Acidification and Excess Nitrogen Loading from Air Pollution

9.3.3.1 Methodology and Assumptions

Atmospheric deposition of nitrogen and sulphur can lead to degradation of ecosystems as a result of the accumulation of excess nitrogen (also called terrestrial eutrophication) and acidification. These have been prominent environmental problems in North America and Europe for about 30 years. Recently, they also have been recognized as potential threats to ecosystems in other parts of the world. Excess quantities of nitrogen can alter ecosystems by causing shifts in species composition, increased productivity, decreased species diversity, and altered tolerance to stress conditions (Pitcairn 1994). Increases in sulfur and nitrogen input to ecosystems can also cause acidification of soils and thereby interfere with the growth processes of vegetation.

The risk to terrestrial ecosystems of the accumulation of nitrogen has been mapped at both the regional and global scale. For these estimates, the concept of "critical loads" has been used. A critical load is defined as "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt 1988). Two types of critical loads are evaluated here: the critical load for acidification, which is an estimate of the threshold of impacts for acid deposition (sulfur and nitrogen), and the critical load for terrestrial eutrophication, which is a measure of the threshold for the impacts of excess nitrogen deposition.

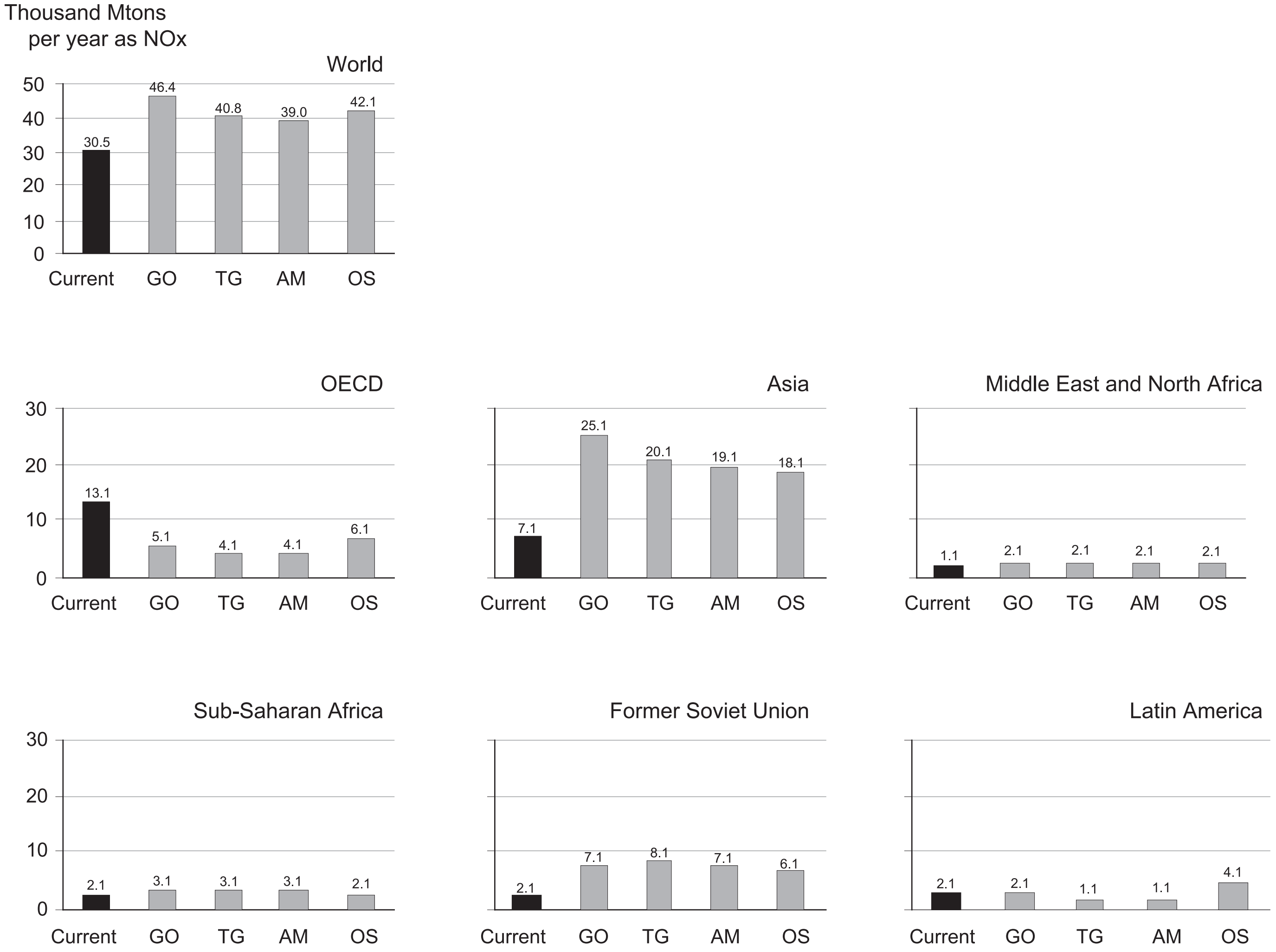

Figure 9.8. Emissions of Nitrogen Oxides in Different World Regions for MA Scenarios in 2050. Scenario names: GO: Global Orchestration; TG: TechnoGarden; AM: Adapting Mosaic; OS: Order from Strength (AIM)

In Europe, calculations with the RAINS model show considerable areas to be exposed to deposition levels above critical loads. The RAINS model has also been used in Asia and found high risks of acidification in Eastern China that were projected to increase in the future. Kuylenstierna et al. (1998), Rhode et al. (2002), and Bouwman et al. (2002) assessed acidification risks and nitrogen deposition risks at the global scale by overlaying deposition maps of S and N with critical loads maps. These studies indicate that current acidification risks are, relatively speaking, most severe in Europe and North America. Bouwman et al. (2002) evaluated scenarios of sulfur and nitrogen deposition and concluded that risks of acidification and nitrogen would increase in parts of China, Latin America, Africa, and Siberia.

It is possible to obtain a first crude estimate of air pollution–related risks under the MA by scaling the map of Bouwman et al. (2002) by the emission scenarios from the MA scenarios. This assumes as a first rough approximation that the deposition of SO_2 and NO_x in each region will linearly change along with the change in emissions in each region. The ratio between deposition and critical load is an indication of risks of acidification and nitrogen deposition, with values above one indicating that the ''local'' critical load for either acidification or excess nitrogen is exceeded and indicates a high risk to ecosystems.

9.3.3.2 Comparison of Risks of Acidification and Excess Nitrogen from Air Pollution among Scenarios

Figure 9.9 (see Appendix A) shows the results for acidification risks for the Order from Strength and TechnoGarden scenarios in 2050 (those with, respectively, the highest and lowest global emissions). Under Order from Strength, acidification risks decrease in OECD but increase in East Asia, Africa, and Latin America. Under TechnoGarden, the risks decrease markedly in North America, Europe, and East Asia and remain at current levels in Africa and Latin America. The low risk levels in this scenario are a consequence of both stringent emission control policies and the co-benefits of climate change policies (which reduce fossil fuel combustion).

The figure shows that similar trends occur for excess nitrogen deposition. In the Order from Strength scenario, risks of excess nitrogen deposition increase, especially in East and South Asia, while under TechnoGarden they decrease in OECD countries and stabilize in the rest of the world. Compared with acidification, the risks of excess nitrogen deposition occur farther away from industrial centers or densely populated regions. An important reason is that nitrogen emissions result from not only industrial activities and transport but also agricultural emissions. Moreover, several ecosystems are rather sensitive to excess nitrogen deposition. As discussed earlier, in contrast to sulfur emissions (which together with emissions of nitrogen oxides are the main cause of acidification), nitrogen emissions are expected to increase in most scenarios.

9.3.4 Climate Change

9.3.4.1 Methodology and Assumptions

The Intergovernmental Panel on Climate Change concluded in its latest assessment that there is new and stronger evidence that most of the climate change observed over the twentieth century is attributable to human activities (IPCC 2001). The report also indicates that future climate change is to be expected, as a function of continuing and increasing emissions of fossil fuel combustion products, changes in land use (deforestation, change in agricultural practices), and other factors (for example, variations in solar radiation).

Assessments of the potential influence of these factors indicate that increased greenhouse gas concentrations (caused by fossil fuel emissions and land use change) are the dominant factor in both historic and future changes of global mean temperature (IPCC 2001). The contribution of land use change to the increase in global mean temperature increase is assessed to be small compared with the fossil fuel emissions. At the local scale, however, changes in biophysical factors (surface roughness, albedo) related to land use change can be as important as changes in greenhouse gas concentrations. Moreover, under particular circumstances (for instance, in the case of a large-scale dieback of the Amazon), changes in land cover could also have a large contribution globally (Cox et al. 2000; Cramer et al. 2004).

The emissions of the MA scenarios cover the range of emission scenarios of the IPCC. The IPCC scenarios have been assessed in terms of their possible climate change, using both simple models (e.g., MAGICC; Wigley and Raper 2001) as well as state-of-the art climate models. IPCC (2001) concluded that the increase of greenhouse gas concentrations under the IPCC scenarios could cause a 1.4–5.8° Celsius increase in global mean temperature (in the absence of climate policies) between 1990 and 2100 (compared with preindustrial level, approximately 0.5° Celsius needs to be added).

Here, the influence of the MA scenarios is assessed using methods consistent with IPCC assessments and guidelines. The results are based on estimates of regional change in temperature and rainfall, made through an adapted version of the IPCC pattern-scaling approach (Carter et al. 2001; Schlessinger et al. 2000). This method combines global mean temperature trends estimated from the global energy balance model MAGICC (Wigley and Raper 2001) with a normalized pattern of climate change from the general circulation model HadCM3 (IPCC 1999).

Although trends in emissions vary considerably between the MA scenarios, the differences in calculated global temperatures in 2050 are not very large. By 2050, the results of the four scenarios ranges from a 1.6° Celsius (TechnoGarden) to 2.0° Celsius (Global Orchestration) increase (relative to pre-industrial levels) for a medium value for climate sensitivity (2.5° Celsius). This relatively small difference between scenarios is because of the lag time between the buildup of emissions in the atmosphere and the response of the climate system to this buildup. Moreover, low greenhouse gas emissions scenarios usually also have low sulfur dioxide emissions (as emissions stem from the same activity). While low greenhouse gas emissions lead to a slower increase of radiative forcing (and thus global mean temperature increase), lower sulfur emissions lead to a reduced cooling effect from sulfur aerosols.

Some recent studies have estimated climate policy scenarios that focus strongly on reduction of non-CO_2 greenhouse gases (e.g., Manne and Richels 2001; Hyman et al. 2003). Such studies generally find that costs savings can be obtained from also reducing non-CO_2 greenhouse gases. The implementation of the TechnoGarden scenario is consistent with the latest insights in emissions reduction of these gases, optimizing the reduction of the different gases on the basis of marginal costs (Delhotal et al. 2005; Schaefer et al. 2005). More extreme scenarios have been published (Hansen et al. 2000) in which even stronger reductions of non-CO_2 gases are achieved. Such scenarios can further reduce short- to medium-term climate change (to 2050), producing important ecological benefits but also at (probably) significant costs.

9.3.4.2 Comparison of Climate Change among the Scenarios

The calculated temperature increase in the 2000–50 period in all scenarios (1.0–1.5° Celsius) exceeds the increase in global mean temperature since 1850 (about 0.6° Celsius). Differences between the scenarios are much sharper by the end of the century. Under TechnoGarden, the increase in global average surface temperature in 2100 is slightly over 2° Celsius (above preindustrial). The increase is nearly 3.5° Celsius under the higher emissions growth of Global Orchestration. (See Figure 9.10.) Acknowledging the uncertainty in climate sensitivity in accordance with the range indicated by IPCC (1.5–4.5° Celsius) would lead to a wider range of temperature increase. Both the upper and lower end of this range would be shifted downward somewhat compared with the range for the IPCC SRES scenarios described earlier. This is because the TechnoGarden scenario includes climate policies (while the IPCC scenarios did not cover climate policies), and because the highest emissions scenarios (Global Orchestration and Order from Strength) show somewhat lower emissions than the highest of the IPCC scenarios, as explained earlier.

Among the scenarios, there are sharp differences in their decadal rate of temperature change. (See Figure 9.11.) This is of particular importance from the point of view of climate impacts because it is presumed that the faster the rate of climate change, the more difficult the adaptation of society and nature to the changes. Ecosystems differ greatly in their ability to adapt to this expected temperature change. The rate of temperature change during the 1990s was in the

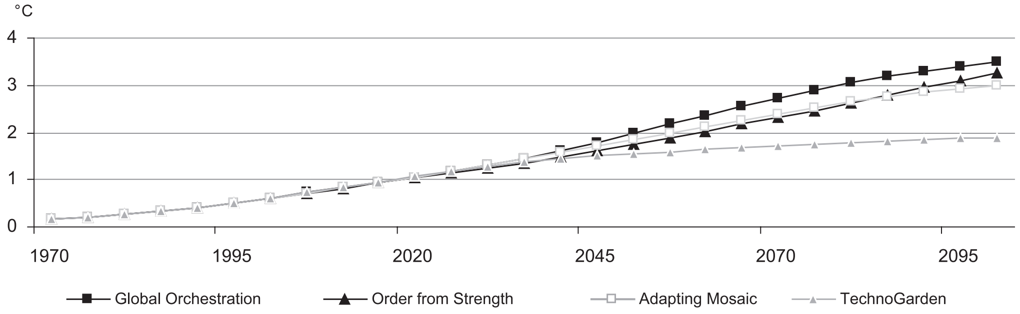

Figure 9.10. Change in Global Average Surface Temperature in MA Scenarios 1970–2100 (IMAGE 2.2)

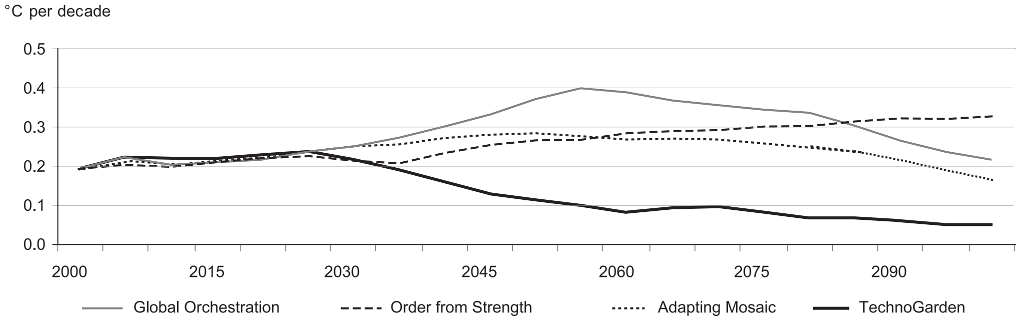

Figure 9.11. Decadal Rate of Change of Global Temperature in MA Scenarios (IMAGE 2.2)

order of 0.2° Celsius. Projections of future climate change are generally in the range of 0.1–0.4° Celsius per decade, assuming no major regime shifts in the global climate systems (such as breakdown of the North Atlantic Oscillation).

The rate of temperature change under the TechnoGarden scenario becomes slower and slower, reaching about 0.1° Celsius per decade in the middle of the scenario period. Meanwhile, the rate sharply increases under the Global Orchestration scenario until mid-century, when it reaches more than 0.4° Celsius per decade and then declines. The rate in the Adapting Mosaic scenario lies between these two scenarios, leveling off at mid-century at around 0.3° Celsius per decade and then declining. Meanwhile, at mid-century the rate in the Order from Strength scenario is lower (around 0.25° Celsius per decade) than that of Adapting Mosaic but is still increasing, so that it has the highest value of all scenarios (0.3° Celsius) at the end of the century.

Although these values may be uncertain, in each of the MA scenarios climate change is expected to be very likely. The benefits of assumed climate policies under TechnoGarden will help to slow down the rate of climate change during the 2000–50 period and will lead to much lower temperature increases compared with the other scenarios by the end of the century. The rate of climate change is likely to increase to at least mid-century in three of the four scenarios (all except for TechnoGarden), as a result of the reduced sulfur cooling effect and increases in greenhouse gas emissions. Likewise, it is likely that three out of four will have a declining rate of temperature increase after mid-century (all except Order from Strength).

While the computation of global mean temperature is uncertain, the patterns of local temperature change are even more uncertain. In its comparison of temperature calculations from different climate models, IPCC (2001) noted some areas of agreement (such as temperature increase likely being higher at higher latitudes than near the equator) but also many areas of disagreement. Disagreements, for example, typically occur in areas with complex weather patterns.

9.3.4.2.1 The influence of biophysical factors on climate change

As noted, land use changes can affect various biophysical factors that have a major impact on climate (and that form a direct linkage between ecosystems and climate change). With the MA scenarios, the impact of biophysical factors will be most pronounced for the scenarios with the largest land use changes. These include in particular Order from Strength and TechnoGarden. In Order from Strength, a continuously increasing population leads to a major expansion of agricultural lands, causing further deforestation in tropical areas. While impacts in tropical zones via albedo changes are relatively small, other influences of large-scale deforestation of tropical rain forests on (local) climate are highly uncertain but may be significant. In contrast, TechnoGarden is the scenario with the most reforestation in temperate zones. An even higher rate of reforestation might be expected under this scenario if reforestation is used as a climate policy for sequestrating CO_2. As indicated by Betts (2000), this actually could lead to increased warming as a result of reduced albedo. Again, these effects are still highly uncertain.

9.3.4.2.2 Precipitation changes

While future regional temperature is uncertain, still more uncertain are the computations of precipitation patterns within regions. Climate models can provide insight into overall global and regional trends but cannot provide accurate estimates of future precipitation patterns when the landscape plays an important role (as in the case of mountainous or hilly areas). Recognizing this uncertainty, we use a standard integrated assessment approach to estimate uncertain but plausible future changes in precipitation. Figure 9.12 shows a typical spatial pattern of changes in precipitation up to 2050 in Global Orchestration. According to this scenario, approximately three quarters of the land surface has increasing precipitation. This is a typical but not universal result from climate models. Some arid areas become even drier according to Figure 9.12 (see Appendix A), including the Middle East, parts of China, southern Europe, the northeast of Brazil, and west of the Andes in Latin America. This will increase water stress in these areas, as described later.

Although climate models do not agree on the spatial patterns of changes in precipitation, they do agree that global average precipitation will increase over the twenty-first century. This is consistent with the expectation that a warmer atmosphere will stimulate evaporation of surface water, increase the humidity of the atmosphere and lead to higher overall rates of precipitation. In general, climate models give a more consistent picture for temperature change than for precipitation.

9.3.4.2.3 Climate change impacts

Figure 9.13 (see Appendix A), from the IPCC assessment, summarizes the findings from a large number of climate impact studies. The main result is that risks of different types increase with increasing temperature, but at different tempos. Comparing the temperature increases from 2000 to 2100 with the risks indicated by the IPCC, the lowest temperature increase scenario, TechnoGarden, will still have high risks for unique and threatened systems and extreme climate events. For aggregate impacts, the 2° Celsius temperature increase experienced in this scenario falls in the middle category; while the risks of large-scale discontinuities (breakpoints in natural systems) are assessed to be low. The higher temperature increase scenarios (Global Orchestration, Adapting Mosaic, and Order from Strength) reach the range in which there are higher risks of large-scale breakdowns in natural systems.

9.3.5 Sea Level Rise

9.3.5.1 Methodology and Assumptions

One of the major impacts of climate change will be a rise in average global sea level as warmer temperatures melt currently permanent ice and snow and cause a thermal expansion of ocean water. Furthermore, climate change may cause stronger and more persistent winds in the landward direction along some parts of the coastline, and this will also contribute to rising sea level at these locations.

9.3.5.2 Comparison of Sea Level Rise among Scenarios

We have made a first-order estimate of the expected (global average) sea level based on the climate change scenarios corresponding to the four MA scenarios. The average rise up to 2100 ranges from 50 centimeters (in TechnoGarden) to 70 centimeters (in Global Orchestration). (See Figure 9.14.) The actual increase in different regions might be higher or lower, depending on changes in ocean currents, prevailing winds, and land subsidence rates.

Note in Figure 9.14 that sea level still has a rising tendency at the end of the century, even though Figure 9.10 indicated that air temperatures stabilize under three of the four scenarios. The increase in sea level lags decades behind the increase in temperature because there is a long delay in heating the enormous volume of the world's oceans. This means that the temperature could stabilize over the course of the scenario period while sea level continues to rise. For example, the trends shown imply that sea level could further rise by at least an additional 1m during the course of the twenty-second century.

9.3.6 Change in Land Use or Land Cover

9.3.6.1 Methodology and Assumptions

Land use change and its consequences for the land cover form an important component of global change (Turner et al. 1995). The type of land use and land cover has direct consequences for most ecosystem services, including provisioning services for food, fiber, and water; regulating services of carbon storage and erosion control; most cultural services; and biodiversity. Historically, large areas of natural ecosystems have been converted into agricultural areas; since 1700, for instance, more than 41 million square kilometers of ecosystems have come into production as either cropland or pasture (30% of the non-ice-covered land area) (Klein-Goldewijk 2004; Ramankutty and Foley 1999).

Land use changes, however, are not easy to capture in large-scale environmental models. They often evolve from diverse human activities that are heterogeneous in spatial and temporal dimensions. They also strongly depend on local environmental conditions and ecological processes. As a result, global models tend to focus on a selected number of major processes. The discussion here focuses on changes in forestland and agricultural land (pasture plus cropland for food, feed, and biofuel crops).[3]

It should be noted that comparisons with other land use change scenarios are difficult, since many published scenarios focus only on local and regional issues or on certain aspects of land use such as the environmental consequences of different agrosystems (e.g., Koruba et al. 1996), agricultural policies (e.g., Moxey et al. 1995), and food security (e.g., Penning de Vries et al. 1997).

Nevertheless, some typical trends can be observed in published scenarios. First of all, most of them show in the near-future a continuation of recent trends: that is, a steady increase of agricultural land (cropland and pastureland) in developing countries and constant or declining coverage of agricultural land in industrial countries (e.g., FAO 2003; IMAGE-team 2001). Crucial factors in existing scenarios involve population change, changes in agricultural output (mostly through intensification, but sometimes also extensification), changes in dietary practices, and agricultural trade.

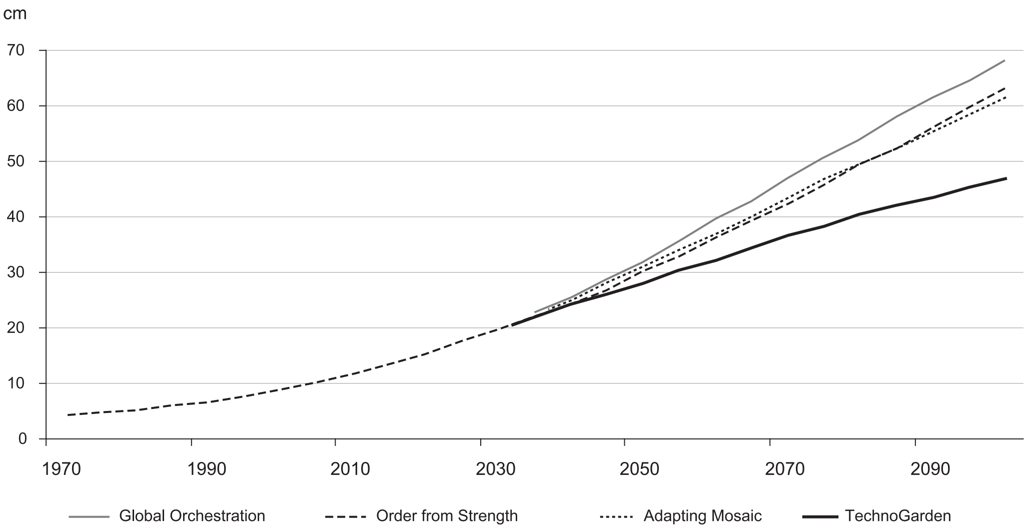

Figure 9.14. Sea Level Rise in MA Scenarios 1970–2100 (IMAGE 2.2)

In all published scenarios, increases in agricultural production in low-income countries are mostly achieved through increasing yields, but at the same time there is also a further expansion of agricultural land. This increase in desired production comes mainly from steep increases in food demand, especially the demand for animal products. For example, meat consumption in China increased yearly by 2.6 kilograms in the 1990s (FAO 2003). Such an increase is also expected in other developing countries in the next decades. Existing scenarios also show a further loss of forest cover in developing countries and a net gain in forest cover in high-income countries. Old-growth forest in industrial countries can be further reduced for timber production, however, and the net gain is achieved by an increase in new forest. In terms of ecological functions, there are important differences between primary and secondary forests.

9.3.6.2 Comparison of Land Use or Land Cover among Scenarios

In the twentieth century, major transformations in land use and land cover have created a large downward pressure on the potential of ecosystems to provide ecological services.[4] Over the last decades, however, this trend has become rather diverse, with increases in forest area in some regions (industrial regions) and further decline in forest area in others (developing regions). At the global level, this trend continues in the four MA scenarios.

In the first decades of the scenario period, all scenarios show an ongoing expansion of agricultural land replacing current forest and grassland. This expansion occurs mainly in poorer countries, while agricultural land in the OECD and former Soviet regions actually declines. (See Figure 9.15.) Despite the considerable differences in individual driving forces among the scenarios, differences in land use among them remain somewhat small. This is partly a result of counteracting trends in the driving forces (low population growth and high economic growth—so high caloric diets for fewer people—versus higher population growth but lower economic growth, which means more people eating less per capita). In addition, it is also a result of increases in different kinds of land use (for instance, a strong increase in land for fodder and grass under Global Orchestration to feed the animals versus a stronger increase in land used for biofuels to meet the climate targets in TechnoGarden).

Compared with the other three scenarios, Order from Strength exhibits by far the fastest rate of deforestation at the beginning of the scenario period. (See Figure 9.16.) The rate of loss of ''original'' forests actually increases from the historic rate (of about 0.4% annually between 1970 and 2000) to 0.6%. (See caption in Figure 9.16 for definition of ''original'' forest.) The estimation of annual historic loss of ''original'' forests is consistent with upper estimates in Chapter 5 in the MA *Current State and Trends* volume but is not strictly comparable because of different averaging periods and definitions of forests. This increase in the deforestation rate comes from the faster expansion of agricultural land, resulting mainly from rapidly growing population combined with slow improvements in crop yield in low-income regions. Since crop yield remains low compared with increasing demand for food products, more agricultural land is needed (although many increases in crop production are also achieved through intensification of existing agricultural land). In the other scenarios, the rate of loss of undisturbed forests is at the historic rate (Global Orchestration and Adapting Mosaic) or slightly below (TechnoGarden).

In 2020, the Order from Strength scenario shows an increase of arable land in poorer countries of almost 13% over the 2000 figure. This is almost twice the figure in the FAO prognosis for 2015 (a 6% increase) (FAO 2003). The increase of arable land in the other three scenarios is close to the FAO projection (5–6% increase). For pastureland, the TechnoGarden scenario shows a decrease, which can be explained by the assumed decrease in meat consumption and a shift toward high-efficient feed instead of grass for animals. This trend, however, is offset by a larger demand for cropland. The other scenarios all show increases in the amount

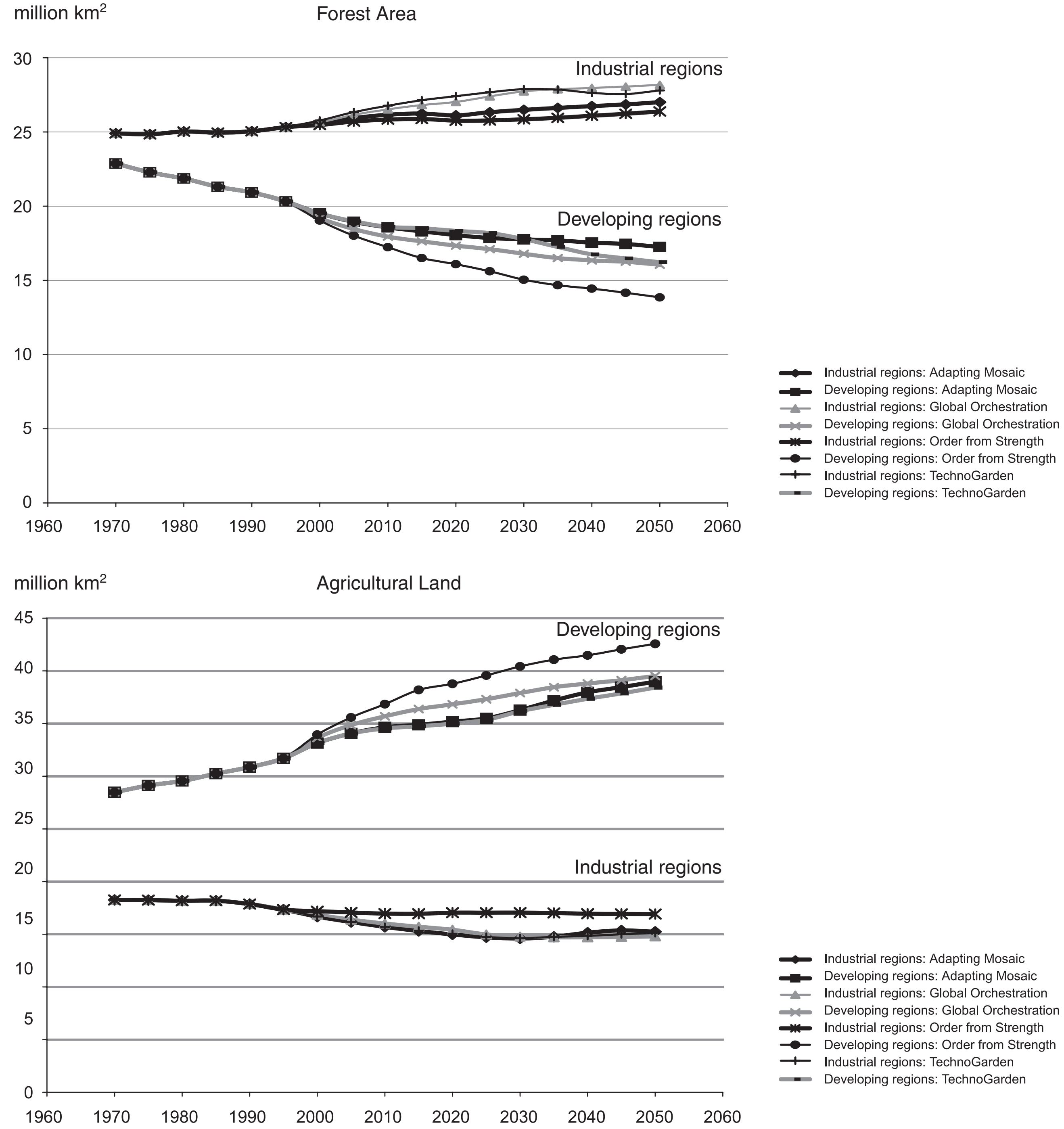

Figure 9.15. Changes in Global Forest Area and Agriculture Land for MA Scenarios. Agriculture land is defined as pasture and crop land. (IMAGE 2.2)

of pastureland. These trends are well in line with the constant prognosis of FAO (FAO 2003).

Figure 9.17 indicates the total land use in 2050 per region and scenario. While rapid depletion of forest area continues under the Order from Strength scenario, under TechnoGarden we expect an increase in net forest cover. Production of biofuels, particularly under the TechnoGarden scenario, is an important category of land use, especially in former Soviet countries, OECD countries, and Latin America. Although the coverage of energy crops remains relatively small, it actually has a large influence on the trends in land use.

Under the Order from Strength scenario (see Figure 9.18 in Appendix A), there is a continuous increase of agricultural area in poorer countries, particularly in sub-Saharan Africa and Latin America. Important factors include a relatively fast population growth and a limited potential to import food (particularly relevant for Africa). As a result, the depletion of forest area continues worldwide at a rate near the historic average, only to slow down after 2050 be-

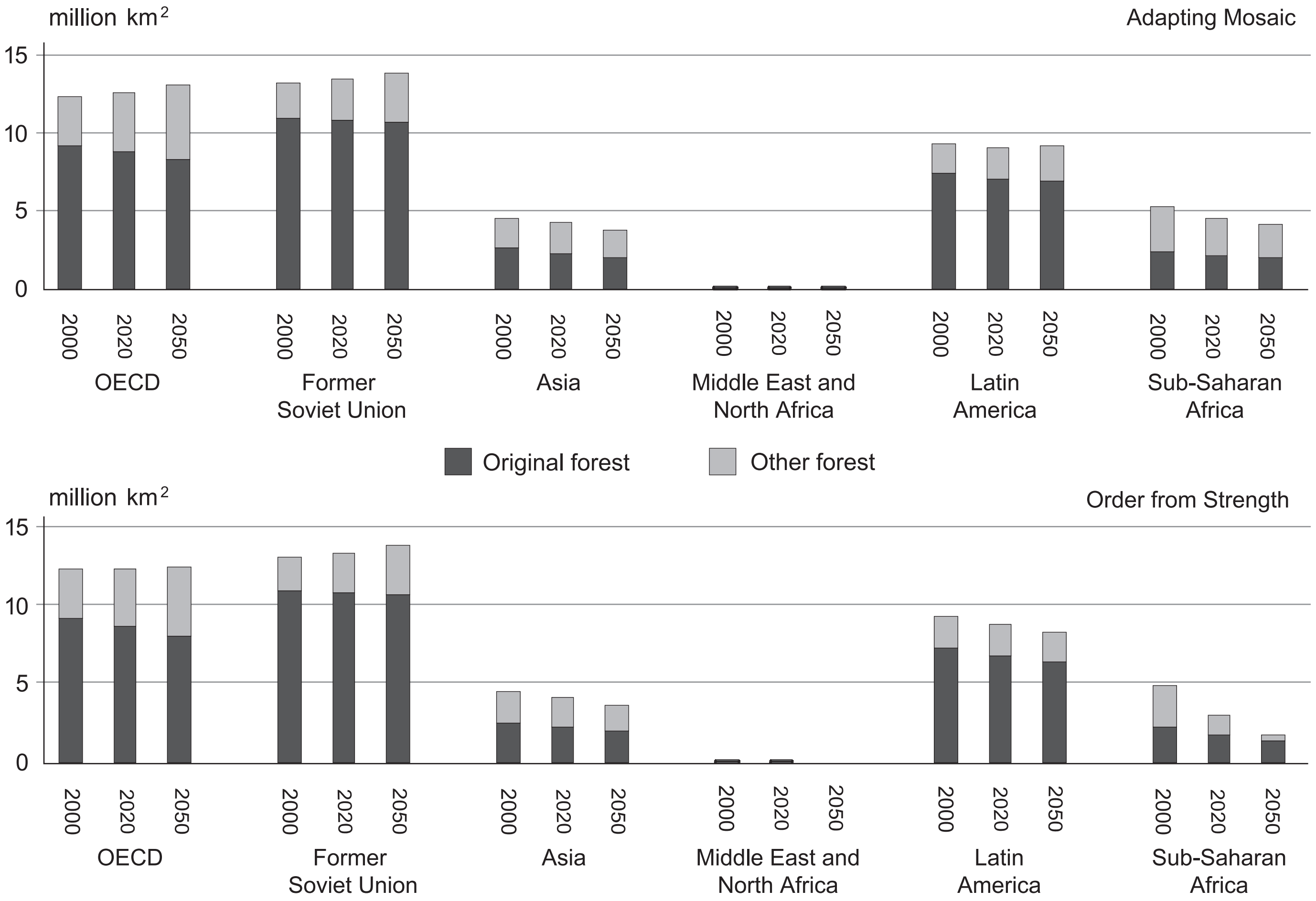

Figure 9.16. Trends in Forest Area by World Region in Two Scenarios. This figure distinguishes between "original" and "other" forests. "Original" forests are defined here as forests that were present in 1970 and have not changed their attributes through either expansion of agricultural land, timber production or climate change since then. "Other" forests are those forests which have been grown from abandoned agricultural or other land, or have been established from other types of land because of climate change. (IMAGE 2.2)

cause of slowing population growth. As a result, two thirds of the Central African forest present in 1995 will have disappeared by 2050. For Asia and Latin America, these numbers are 40% and 25%, respectively. In other regions the rate of forest loss slows down.

The land use conversion in this scenario clearly exceeds that of the FAO reference scenario in 2030 (FAO 2003). This difference mainly comes from a considerably lower improvement in agricultural yields that is expected under the Order from Strength scenario than under the FAO scenario. Fischer et al. (2002) also show a major increase of total agricultural land in a scenario that assumes a regionalized world (increase of nearly 20% in the second half of the twenty-first century for the IPCC A2 scenario compared with 15% in Order from Strength). Similarly, Strengers et al. (2004) report a similar result for the IPCC A2 scenario (increase of 22% in 2050).

Agricultural area under the Global Orchestration scenario also expands at a fast rate, but for other reasons than in Order from Strength. Here, rapid income growth and stronger preferences for meat result in growing demand for food and feed, leading to a rapid expansion of crop area in all regions. There is no net increase of pastureland, as low-input extensive grazing systems are replaced by more intensive, crop-intake forms of grazing, a result that is comparable to the FAO analysis for 2030 (FAO 2003). Undisturbed forests disappear at a slower rate than in Order from Strength, but still at near-current global rates. About 50% of the forests in sub-Saharan Africa disappear between 2000 and 2050.

The TechnoGarden scenario results in the lowest conversion of natural land to agricultural land. One important factor is the assumed decrease in meat consumption, which leads to lower land demands for feed crops and grazing. This is partly offset, however, by a strong increase in food demand in poorer countries. The improvement of yields (as a result of a widely available technology) ultimately leads to a slower expansion of agricultural land. In terms of total land, the results for TechnoGarden are comparable with those of FAO projections for 2030 (FAO 2003). Under TechnoGarden there is a small decrease in pastureland and a small increase in arable land or food production, mainly in poorer regions. However, there is a large increase in land for growing energy crops as part of climate policies for reducing greenhouse gas emissions. Although this scenario has the lowest rates of land conversion, the depletion of forestland is still significant in Africa and Southeast Asia. Global deforestation rates, however, are far lower than in the other scenarios.

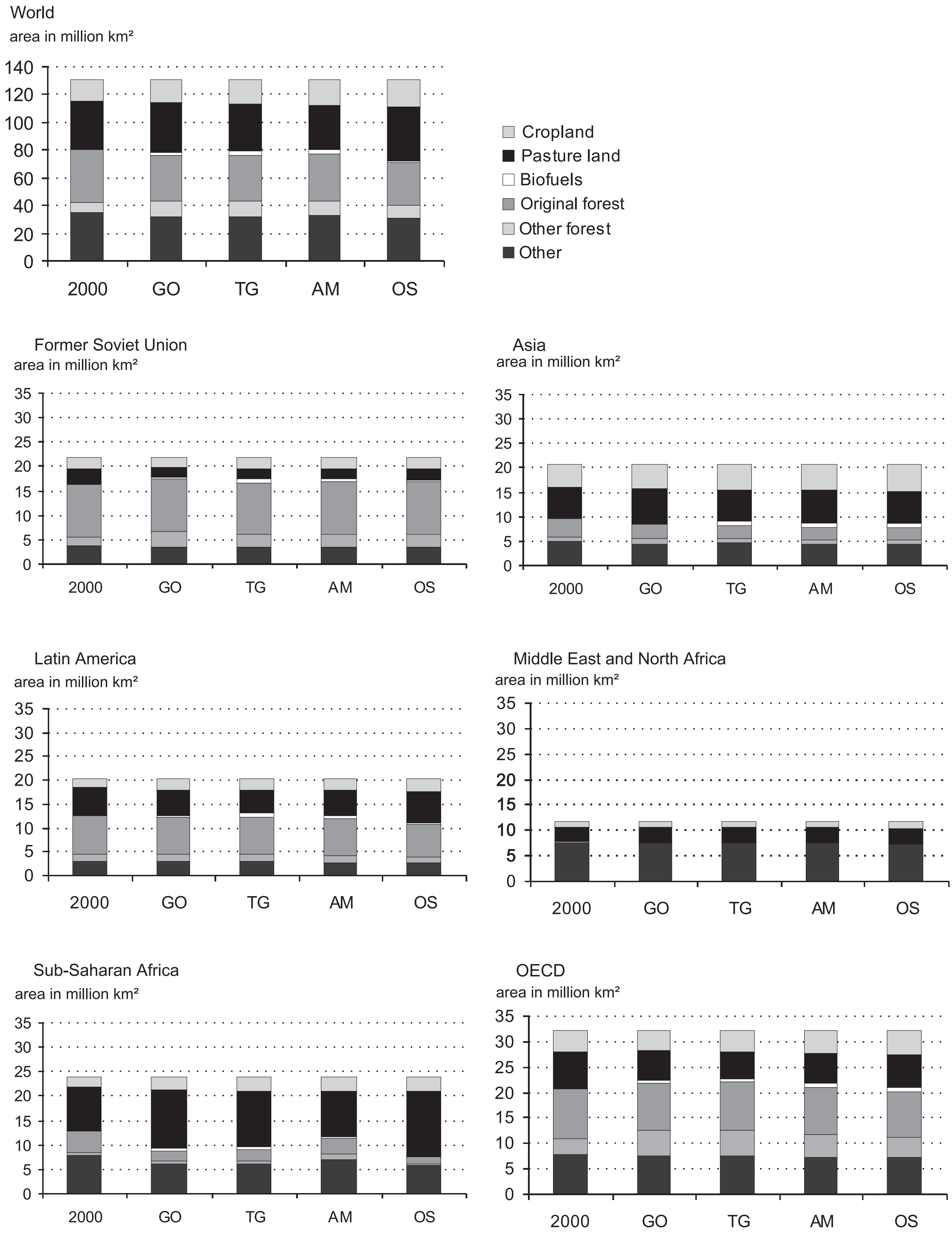

Figure 9.17. Land Use Patterns by Region in MA Scenarios in 2050. Scenario names: GO: Global Orchestration; TG: TechnoGarden; AM: Adapting Mosaic; OS: Order from Strength. (IMAGE 2.2)

The Adapting Mosaic scenario, like Order from Strength, also assumes relatively slow yield improvement in the first decades. However, a lower increase in population and locally successful experiments in innovative agricultural systems (translated into an increasing rate of improvement of crop yields) mitigate a further expansion of agricultural land in other regions after 2040. This is particularly important for trends in Africa; in fact, Adapting Mosaic shows the lowest deforestation rates for this region of all four scenarios. In contrast, however, the relatively low yield improvement causes a virtual depletion of forest areas in South Asia up to 2100. Globally, the long-term deforestation rates in this scenario are slightly above those of TechnoGarden.

The changes in land use just described will also have a tremendous impact on the vulnerability of different regions. Figure 9.19 shows the land use of each region in 2050 compared with the total potential area of productive arable land (that is, areas with potential productivity—based on soil and climatic condition—that is more than 20% of the maximum achievable yield of the best-growing crop). By 2050, under Order from Strength, Africa and Asia have put virtually all productive land under cultivation to fulfill the demand for crops and animal products. This clearly indicates a high vulnerability to abrupt changes in the natural system. A similar but less extreme situation occurs for Africa under the Global Orchestration scenario, and for Asia and Africa under both Global Orchestration and TechnoGarden. In these cases, however, large-scale global trade could help overcome problems of suddenly declining production levels as a result of abrupt ecological changes. The above-mentioned processes result in a less vulnerable situation for Africa in Adapting Mosaic.

Based on these results, we can conclude land use change will continue to form a major pressure on ecosystem services in the four MA scenarios. At the same time, all four scenarios find the loss of natural forests to slow down compared with historic rates. This mainly results from increases in natural areas in industrial regions (consistent with trends of the past few decades). In developing regions, the conversion rates slow down in three out of four scenarios. In Order from Strength, however, the rate of conversion continues at nearly the historic rate of the past three decades.

9.3.7 Use of Nitrogen Fertilizer and Nitrogen Loads to Rivers and Coastal Marine Systems

The presence of excess nutrients in water can lead to eutrophication. This nutrient enrichment of waters can lead to

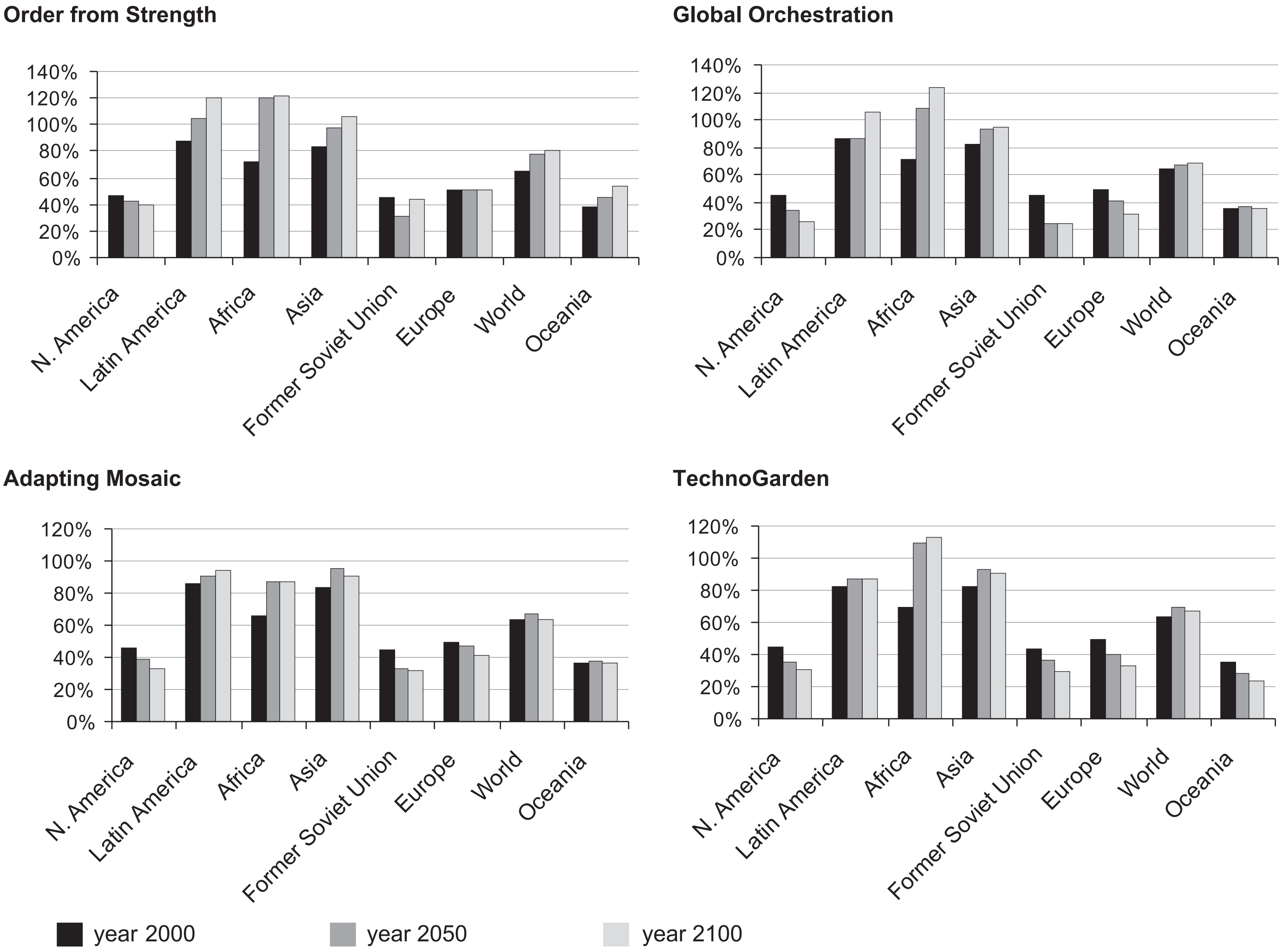

Figure 9.19. Ratio of Agricultural Land to Total Productive Arable Land in MA Scenarios (IMAGE 2.2)

algal blooms, changes in the organisms present, low oxygen levels in the water, and generally lower water quality. Nitrogen and phosphorus are commonly the nutrients contributing to eutrophication. In the context of the MA scenarios, we concentrate on changes in nitrogen loading given the presence of information that could be coupled to the scenarios. There is ongoing concern about nitrate leaching to waters because of eutrophication, about other environmental effects associated with high nitrate levels, and about the risk that high nitrate levels in drinking water may present to human health.

9.3.7.1 Methodology and Assumptions

9.3.7.1.1 Trends in the use of nitrogen fertilizer

Projections of global nitrogen fertilizer use cover a range of time horizons, scenarios, and underlying assumptions. Table 9.13 and Figure 9.20 (see Appendix A) summarize a set of recent fertilizer use scenarios. The Figure shows that all scenarios expect an increase of fertilizer use. The range among the different scenarios is considerable, with the highest scenarios indicating increases in N-fertilizer use of 80% or more until 2020, while the lowest show an increase of less than 10%.

Based on current insights in changes in nitrogen efficiency and agricultural scenarios, we expect the outcomes for the Global Orchestration scenario to be near the Constant Nitrogen Efficiency scenario of Wood et al. (2004) or the A1b scenario of IMAGE-team (2001)—that is, around 110 million tons in 2020 and 120–140 million tons in 2050. The TechnoGarden scenario is likely to correspond to the outcomes of the Improved Nutrient Use efficiency scenario of Wood et al. (2004), around 100 million tons in 2020 and 110–120 million tons in 2050. The Adapting Mosaic scenario is likely to fall between these two extremes, while fertilizer use under Order from Strength could be near the outcomes for Global Orchestration. Clearly, there are important uncertainties in projections, including the effective potential for improving efficiency, the paucity of data on crop-specific nutrient application rates, the area fertilized and corresponding yield responses, and the lack of explicit incorporation of market prices of fertilizers (Wood et al. 2004).

9.3.7.1.2 Nitrogen loads to rivers and coastal marine systems

Anthropogenic disturbance of the global nitrogen cycle is an important global environmental problem. On one hand, production on some agricultural land is not as high as it can be because of nitrogen deficiencies. On the other hand, the runoff of excess nitrogen from agricultural land and from other anthropogenic sources causes the eutrophication of rivers and other freshwater systems. Nitrogen loads in rivers eventually find their way to the coastal zone, where they also cause eutrophication. Here, we focus on the nitrogen loading to rivers and its routing to the coastal zone.

Several studies have estimated the past and current river nitrogen transport to oceans (Green et al. 2004; Meybeck 1982; Seitzinger and Kroeze 1998; Seitzinger et al. 2002; Turner et al. 2003; Van Drecht et al. 2003). Despite the fact that scenarios of nitrogen fluxes are still under development, there is a growing interest in the potential threat of further increases of nitrogen loading on aquatic systems. More qualitative work on nitrogen fluxes was published earlier as part of UNEP's Global Environment Outlook (UNEP 2002).

Table 9.13. Overview of Scenario Studies on Nitrogen Fertilizer Use

Reference	Method
Bumb and Baanante 1996	Projections of N fertilizer to 2000 and 2020 using three approaches—the Nutrient Removal Approach and the Cereal Production Method to assess N requirements to meet projected cereal needs in 2020 (Rosegrant et al. 1995) and the Effective Fertilizer Demand Method projecting N use on the basis of a range of economic, demographic, and other factors
Tilman et al. 2001	Projection based on linear regressions of N fertilizer usage and time, population, and GDP for the period 1960 to 1999, extrapolated mean values of N fertilizer use
Daberkow et al. 1999	Projection built on crop area and yield projections developed by FAO in support of the *Agriculture Towards 2015/30* study (Bruinsma 2003) to assess corresponding fertilizer needs. The authors used the Fertilizer Use By Crop database (FUBCD IFA, IFDC, FAO 1999) to derive crop-specific nutrient application and response rates for three scenarios: Baseline, Improved Nutrient Use Efficiency, and Nitrogen Use on Cereals
Galloway et al. 2004	Projection based on the Daberkow et al. (1999) "baseline" scenario for 2030, and extrapolated an N fertilizer use of 135 million tons in 2050, assuming a constant N fertilizer growth rate to 2050
Wood et al. 2004	Used the newest FUBCD data—Trend Analysis was based on an update of the Bumb and Baanante (1996) Effective Demand Approach and assumed that N fertilizer applications would be higher in areas of significant soil degradation between 2020 and 2050 as part of a broader strategy of soil fertility restoration; given the conservative assumptions about constant nitrogen use efficiency and the goal of soil rehabilitation embedded in this analysis, results likely present an upper bound on N fertilizer needs The Future Food Need Scenario used two scenarios, one assuming constant nitrogen use efficiency, based on the Nitrogen Use on Cereals approach of Daberkow et al. (1999), and the second based on the Improved Nutrient Use Efficiency approach of Daberkow et al. (1999), but with region-specific nitrogen use efficiencies
IMAGE-team 2001	Scenarios based on expansion of crop area and assumed changes in fertilizer used per hectare for the four IPCC scenarios

In order to assess changes in nitrogen fluxes from rivers to oceans in the context of the MA, we used a global model developed by Van Drecht et al. (2003). This model describes the fate of nitrogen in the hydrological system up to river mouths, at a spatial resolution of 0.5 by 0.5 degree and an annual temporal resolution. This model was used earlier to describe the development of river nitrogen fluxes based on the Agriculture Towards 2030 projection of the FAO (hereinafter referred to as AT 2030) (Bruinsma 2003), and a projection for sewage effluents (Bouwman et al. 2005b). We used these results as a reference to estimate the change in river nitrogen export on the basis of the four MA scenarios.

9.3.7.2 Comparison of Nitrogen Fertilizer and Nitrogen Loads to Rivers among Scenarios

On the basis of projections for food production and wastewater effluents, the global river nitrogen flux to coastal marine systems may increase by 10–20% in the coming three decades. While the river nitrogen flux will not change in most wealthy countries, a 20–30% increase is projected for poorer countries, which is a continuation of the trend observed in the past decades. This is a consequence of increasing nitrogen inputs to surface water associated with urbanization, sanitation, development of sewerage systems, and lagging wastewater treatment, as well as increasing food production and associated inputs of nitrogen fertilizer, animal manure, atmospheric nitrogen deposition, and biological nitrogen fixation in agricultural systems. Growing river nitrogen loads may lead to increased incidence of problems associated with eutrophication in coastal seas.

Regarding the oceans receiving nitrogen inputs from river systems, our results indicate that strong increases in the 1970–95 period occurred in the Pacific (42%), Indian (35%), and Atlantic Oceans (18%) and in the Mediterranean and Black Seas (35%), with a global increase of 29%. (See Table 9.14.) For the coming three decades, the increase will be even faster in the Indian Ocean (50%), while the increase for the Pacific (31%) and Atlantic Oceans (8%) is slower than in the 1970–95 period. For the Mediterranean and Black Seas (at −5%), a slow decrease of river nitrogen export is estimated.

It is possible to estimate the nitrogen fluxes of each MA scenario by assessing their relative differences for the various nitrogen-emission sources with respect to the AT 2030 projection.[5] This is possible because there are firm relationships between the total inputs of nitrogen in terrestrial systems (deposition, biological fixation, fertilizers, and animal manure) and the river transport of nitrogen.

Changes in the inputs from natural ecosystems to total river transport were assessed on the basis of estimates for nitrogen deposition for each scenario. The river transport from agricultural systems was assessed for each scenario on the basis of total nitrogen fertilizer use and animal manure production. Fertilizer use was assumed to be correlated with total crop production in dry matter, while animal manure production was assumed to be related to total livestock production in dry matter. The river nitrogen load from sewage effluents was assumed to be related to total population, whereby the human emissions and wastewater treatment were assumed to be related to GDP. Finally, the number of people connected to sewerage systems was held the same for each scenario, as we assumed development of sewerage systems has a high priority for human health reasons in all scenarios (although this could be seen as relatively optimistic in the case of Order from Strength).

The results of this comparison show considerable differences between the scenarios. (See Figure 9.21.) In Global Orchestration, fast economic development causes a shift toward more protein-rich food consumption and higher human-waste production. At the same time, the nitrogen removal in wastewater treatment will be higher than in the AT 2030 scenario. Agricultural production is not much different from the AT 2030 scenario, so that the river loads stemming from fertilizers and animal manure are similar. However, atmospheric nitrogen deposition rates in Global Orchestration are much higher than in any of the other scenarios, causing higher river nitrogen loads.

In TechnoGarden, a proactive attitude with regard to ecological management is assumed to lead to lower per capita meat consumption, while wastewater treatment has a

Table 9.14. River Nitrogen Export to Atlantic, Indian, and Pacific Oceans and to Mediterranean and Black Seas and Contributions from Natural Ecosystems, Agriculture, and Sewage for 1970, 1995, and 2030. Columns may not add up due to separate rounding. (IMAGE 2.2)

River Export by Source	Atlantic Ocean	Indian Ocean	Pacific Ocean	Arctic	Mediterranean and Black Seas	World
			(million tons per year)			
In 1970						
Natural	15	3	5	1	1	25
Agriculture	4	1	2	0	1	7
Sewage	1	0	1	0	0	2
Total	19	4	7	1	2	34
In 1995						
Natural	16	4	4	2	1	28
Agriculture	5	2	4	0	1	13
Sewage	1	0	1	0	1	3
Total	23	6	10	2	3	44
In 2030[a]						
Natural	16	5	5	1	1	28
Agriculture	6	3	6	0	1	17
Sewage	1	1	1	0	1	4
Total	24	9	13	2	3	50

[a] Results for 2030 are based on the AT 2030 projection (Bruinsma 2003) and presented by Bouwman et al. (2005b).

high policy priority for the prevention of eutrophication of surface water. Atmospheric deposition is much less than in the Global Orchestration scenario, causing a reduction of the nitrogen load in the coming three decades.

The river nitrogen loads in 2030 for the other scenarios will be lower than for Global Orchestration but higher than for TechnoGarden. Although the river nitrogen load stemming from agricultural sources and deposition levels are comparable between the scenarios, there is a difference in the inputs from sewage effluents. The population for 2030 is not different between Order from Strength and Adapting Mosaic, but in Order from Strength economic growth is slower, leading to a slower growth in removal during wastewater treatment than in Adapting Mosaic.

The results indicate that in three of the four scenarios, there is a further increase in nitrogen transport in rivers. The increase is in particular large under the Global Orchestration and Adapting Mosaic scenarios. Only TechnoGarden shows a decrease in nitrogen transport by rivers. The major drivers of increased nitrogen loading are agriculture and sewerage systems. Nitrogen deposition (from atmospheric emissions) increases less—or is even reduced.

Assuming similar regional patterns of increase among the different scenarios, it can be concluded on the basis of these global differences that the increase in nitrogen inputs to the Indian Ocean and Pacific Ocean will be faster in Global Orchestration than in the AT 2030 projection and slower in the TechnoGarden scenario. The development for the other two scenarios is comparable to that in the AT 2030 scenario. Although there are large uncertainties in such scenarios and there may be important regional differences between them, the global trends and expected changes for oceans and seas as a whole may be more robust.

9.3.8 Disruption of Landscape by Mining and Fossil Fuel Extraction

One factor affecting the degree of disruption of landscape will be the intensity and type of mineral exploitation. The MA scenarios only focused on energy production, but it can be assumed that extraction of other key resources will follow a similar trend. From the scenarios we can deduce that the biggest disruption by far will be caused by Order from Strength, where total fossil fuel use increases by more than a factor of 2.5 by 2100 compared with 2000. Not only is the magnitude of fossil fuel use large, but in this scenario society gives environmental protection low priority. This combination of factors suggests that mineral exploitation will have the largest impacts on the landscape under this scenario.

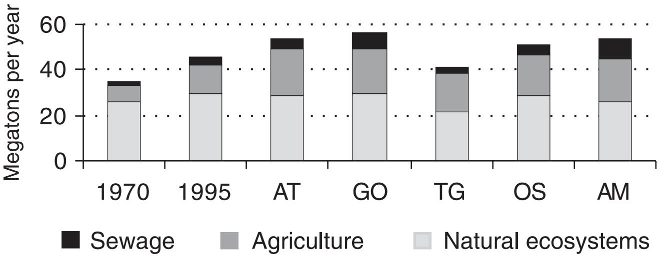

Figure 9.21. Global River Nitrogen Export Stemming from Natural Ecosystems, Agricultural Systems, and Sewage Effluence for 1970 and 1995 with Projections for 2030 and Model Results for MA Scenarios (FAO; IMAGE 2.2)

The Global Orchestration scenario will have the next largest impact, with fossil fuel use increases of about a factor of two over the same period and environmental management also largely neglected. The impact is likely to be the smallest under the TechnoGarden scenario, because fossil fuel use substantially declines up to 2100 and because environmental management is given high priority. An intermediate case is Adapting Mosaic, which also gives priority to environmental protection, but fossil fuel use nearly doubles up to 2100.

9.4 Provisioning Ecosystem Services

Provisioning ecosystem services include services that directly produce goods that are consumed by humans. The conceptual framework of the MA lists the following provisioning services:

- food (including a vast range of food products derived from plants, animals, and microbes);
- fiber (including materials such as wood, jute, hemp, silk, and several other products);
- fuel or biofuel (including wood, dung, and other biological material that serves as a source of energy);
- fresh water;
- genetic resources (including the different aspects of genetic information used for animal and plant breeding and biotechnology);
- biochemicals, natural medicines, and pharmaceuticals; and
- ornamental resources.

This section describes some of the possible changes in these services under the four MA scenarios. It focuses on the services where adequate differentiation between the scenarios can be achieved, based on model calculations, qualitative interpretation of the scenario storylines (see Chapter 8), assessment of recent literature, and interpretation of changes in possible drivers of these services. The services for which a sufficient assessment can be made include food, fiber, fuel, and fresh water. A short concluding section discusses possible changes for other provisioning services.

Overall, considerable differences in the pressure on ecosystems to produce provisioning ecosystem services can be found across the scenarios. An important factor here is that the (strongly) increasing demand for provisioning services is driven by population growth, economic growth, and consumption changes. Increases in demand are on a global scale particularly large in Global Orchestration (with increased welfare being an important driver), but also in Order from Strength (with lower welfare but higher population growth). Increases in demand for services are partly offset by increases in the efficiency at which these services are provided (for example, agricultural yields). However, they will also lead to increased pressures on the ecosystems that are providing these services or on service quality.

Another important factor in the relationship between provision of ecosystem services and pressure on ecosystems is the human attitude toward ecosystem management. Under Global Orchestration, ecosystem management is reactive, driven primarily by response to environmental crises. Consequently, vulnerability of provisioning ecosystem services grows as demands on ecosystems grow due to population growth, economic expansion, and other factors. In Order from Strength, vulnerabilities of provisioning ecosystem services also increase. In wealthy countries, ecosystem services are vulnerable because of the vulnerability of small patches to disturbance and climate change. In poorer countries, services are vulnerable due to these same factors, exacerbated by overexploitation, degradation of ecosystems, and expanding poverty.

In Adapting Mosaic, ecosystem management is often directed at reducing vulnerability; in many regions, decentralization and a focus on adaptive change allow ecosystem services to adjust smoothly to changes in climate and other environmental drivers. In TechnoGarden, the emphasis is on efficiency, which often increases the supply of provisioning ecosystem services at the cost of also increasing their vulnerability. The drive for efficiency leads to dependence on a narrow range of production systems that successfully produce high levels of ecosystem services but are vulnerable to unexpected change. Thus there is a generally high performance of provisioning ecosystem services, but with some surprising, dangerous disruptions that are difficult to repair.

9.4.1 Food

9.4.1.1 Methodology and Assumptions

The ecosystem services provided by agriculture are assessed in two ways: the services delivered by agriculture, using total food production as a measure of the services, and the services ''delivered'' to each person or the outcomes of these services, using per capita food availability and the number of malnourished children as a measure. Both are equally important: total food production is related to the amount of agricultural land, water, and other ecosystem resources required to deliver food services, while per capita food consumption and kilocalorie availability establishes a connection between ecosystem services and human well-being.

9.4.1.2 Comparison of Food Production among Scenarios

Various factors determine the global and regional food production in the MA scenarios. The most general drivers have been discussed in sections 9.2 and 9.3. Some more-specific drivers are discussed in Appendix 9.1. In addition, Appendix 9.2 indicates some of the assumptions of modeling dietary preferences and yield increases. All four MA scenarios result in increased global food production, both total and per capita, by 2050 compared with the base year. (See Figures 9.22 to 9.25.) Yet different means are used to achieve production increases, and—most important—outcomes vary for the food-insecure.

Under Global Orchestration, rapid income growth in all countries, increasing trade liberalization, and urbanization fuel growth in food demand. Global cereal and meat demand grow fastest among the four scenarios, with cereals being used increasingly as livestock feed. Grain production growth is driven by growth in yield as a result of large investments in the areas of agricultural research and supporting infrastructure, making large crop area expansion unnecessary; rapid growth in food demand is also met through increased trade. By 2050, international food prices are lower for livestock products and rice, whereas pressure on maize from demands for animal feed and wheat as a direct food item leads to increased prices for these commodities. Per capita calorie availability under this scenario in 2050 is highest among the four scenarios, and the number of malnourished children drops to just under 40% of current levels.

Under Order from Strength, economic growth in wealthy countries is somewhat lower and in poorer countries is much reduced, protectionist trade policies prevail, and total population in 2050 is highest among the four scenarios. Per capita food availability in 2050 is also higher, on average, but reaches only 83% of Global Orchestration levels. Moreover, production growth is achieved through significant expansion in crop-harvested area, as reduced investments in yield improvement are insufficient to keep up with demand levels. A second reason for crop area expansion lies in remaining trade protection levels , such as import tariffs and quotas, or trade-distorting subsidies, implemented by trading partners, which increase the cost of procuring food, particularly for poor people in low-income countries, at the same time that elites in wealthy as well as poorer countries continue to expand and diversify their diets.

As food production levels cannot keep pace with (albeit somewhat depressed) food demand, international food prices for major crops increase significantly. (Depressed livestock demand from slow income growth results in reduced livestock prices, on the other hand.) As high levels of crop prices surpass the cost of protection, food-deficit countries resort to food imports. As a result, trade levels are not much reduced under the Order from Strength scenario, compared with Global Orchestration, but the cost of procuring food is much higher. Calorie consumption levels improve only very slowly up to 2050, and the number of malnourished children by 2050 under Order from Strength is the highest among the four scenarios.

Under the TechnoGarden scenario, growing incomes in all countries are combined with medium-level population growth, increasing trade liberalization, and a drive for innovations in all sectors, including food production. TechnoGarden operates somewhat similarly to Global Orchestration, with substantial improvements in crop yields but here combined with a lower preference for meaty diets, both of which reduce pressure on crop area expansion. Increased food demand is also met through exchange of goods and technologies. Both calorie consumption levels and the reduction in the number of malnourished children are similar

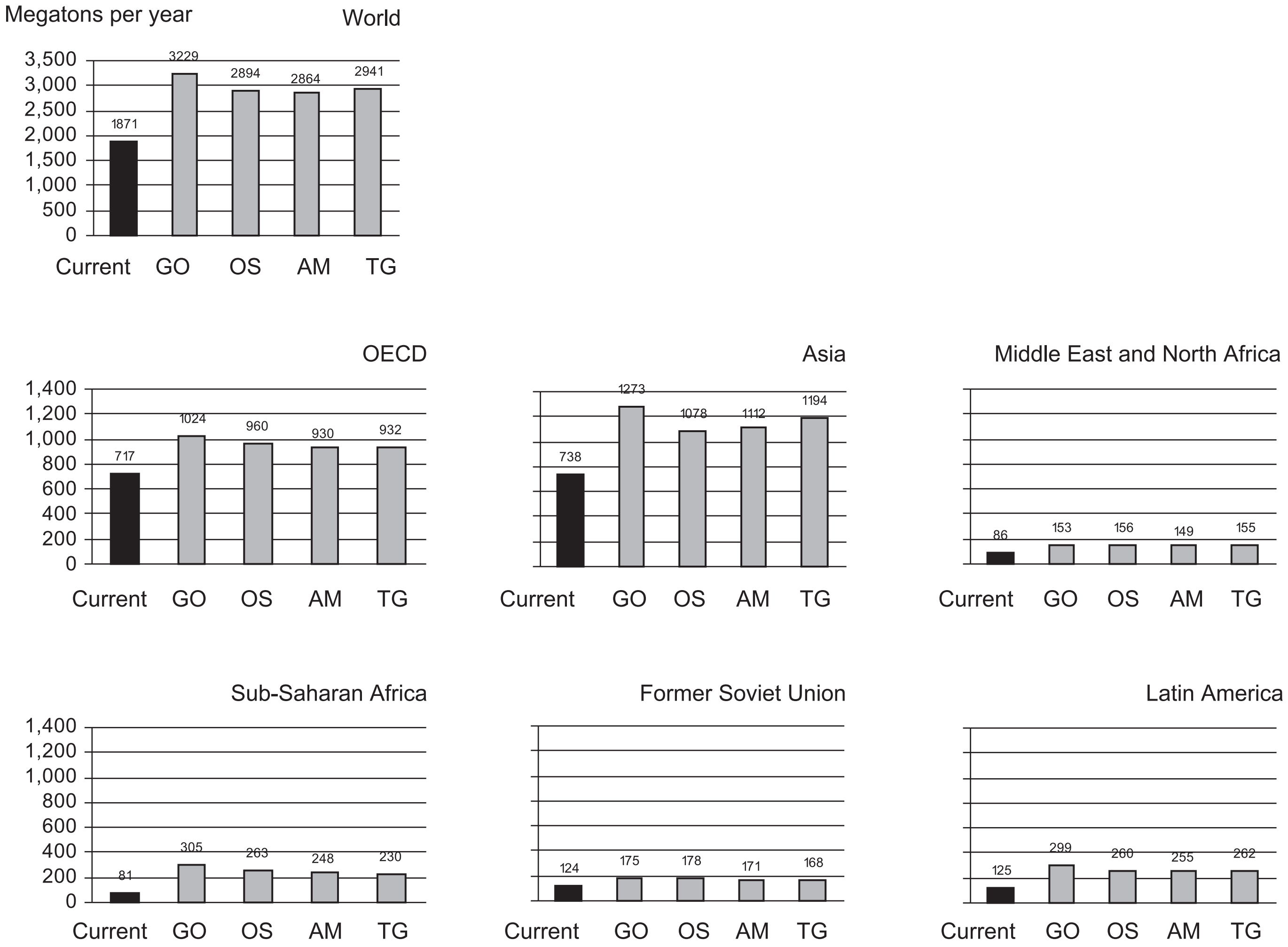

Figure 9.22. Cereal Production by World Region in MA Scenarios in 2050. Scenario Names: GO: Global Orchestration; OS: Order from Strength: AM: Adapting Mosaic; TG: TechnoGarden. (IMPACT)

to, albeit somewhat lower than, the Global Orchestration scenario.

Finally, under the Adapting Mosaic scenario, the focus is on the adaptation of local approaches to the improvement of ecosystem services. Incomes grow slowly, while populations continue to grow steadily up to 2050. Food production outcomes are achieved in ways similar to the Order from Strength scenario. Food is produced locally, on expanded crop areas, with little attention to yield growth; but expansion is insufficient to meet effective demand at current price levels in many areas of poorer countries; as a result, pressure on both food prices and demand for net imports increases. While calorie availability improves only very slowly, the number of malnourished children is reduced slightly more than under Order from Strength due to a focus on social investments under this scenario.

9.4.1.2.1 Food supply and demand to 2050

Under the Global Orchestration scenario, demand for food crops (including cereals, roots and tubers, soybean, sugar crops, vegetables, and fruit crops) is projected to increase by 3,321 megatons to 7,227 megatons in 2050; cereal production alone is expected to increase by 73% by 2050, the largest increase across the four scenarios, while global demand for livestock products is expected to grow by 357 megatons or 63%. Globally, average per capita demand for cereals as food is projected to increase slightly by 10 kilograms to reach 172 kilograms in 2050. While the relatively low OECD cereal consumption levels indicate highly diversified diets, Asia's and MENA's much higher cereal consumption levels are characteristic of far less diversified diets. In sub-Saharan Africa, low cereal consumption levels indicate gaps in food availability rather than diets diversified away from staple cereals, but also reflect the more root- and tuber-oriented diets of the region.

Per capita demand for livestock products is likely (*with high certainty*) to increase much more rapidly worldwide, driven by strong income growth and increasing preference for livestock products. Globally, annual per capita consumption is expected to increase from 36 kilograms in 1997 to 70 kilograms by 2050; with large increases in Asia, the former Soviet Union, and OECD. However, sub-Saharan Africa and MENA are unlikely to experience significant increases in per capita meat consumption, reaching levels of only 27 and 34 kilograms, respectively, by 2050.

Under the Order from Strength scenario, assumptions about how the world will respond to growing food produc-

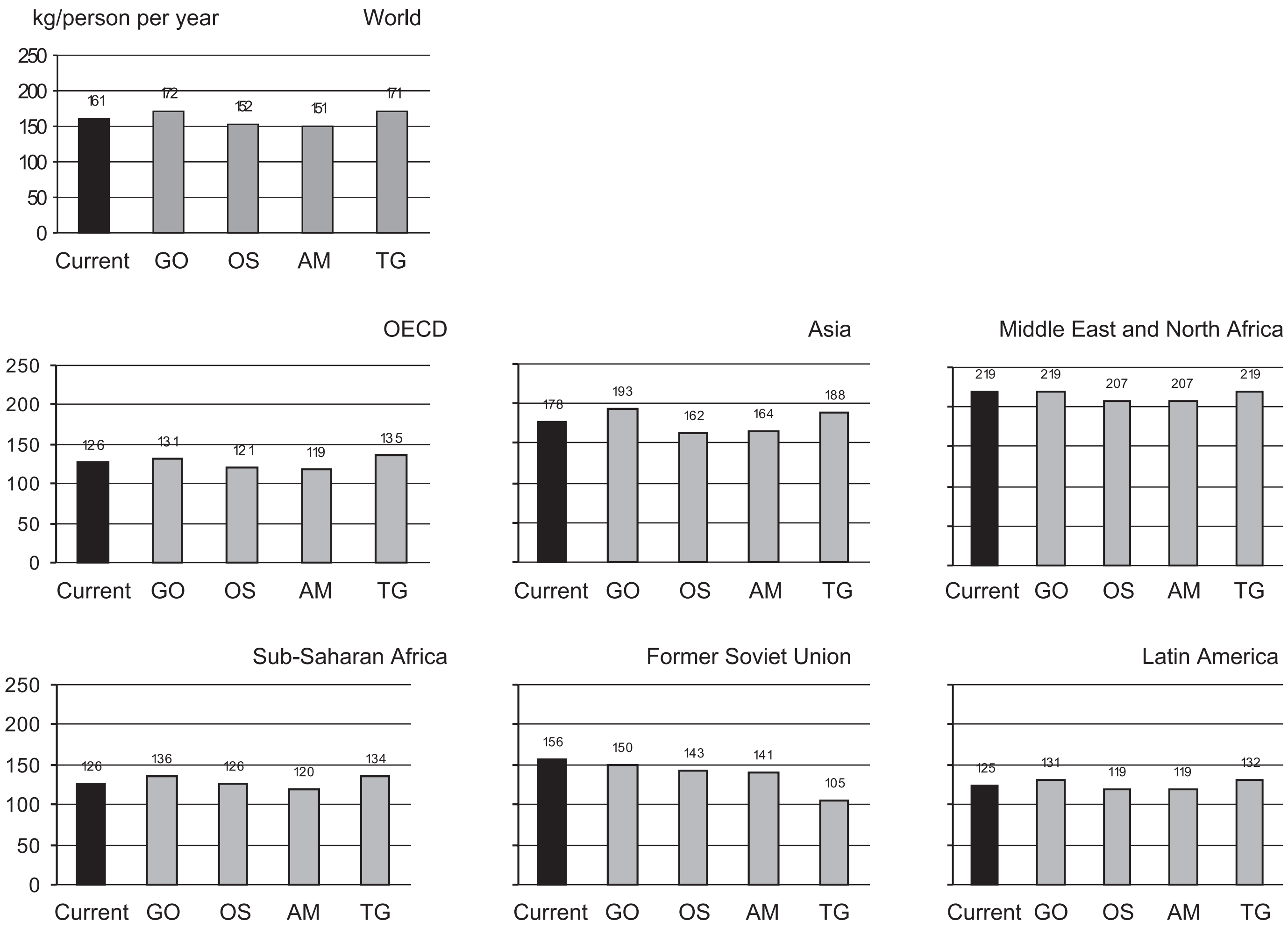

Figure 9.23. Cereal Consumption (as Food) by World Region in MA Scenarios in 2050. Scenario Names: GO: Global Orchestration; OS: Order from Strength; AM: Adapting Mosaic; TG: TechnoGarden. (IMPACT)

tion challenges play out in depressed demand for meat and grains in poorer countries. Food production in all categories increases substantially compared with today, but grain and particularly meat production levels are far below those achieved under Global Orchestration. By 2050, sub-Saharan Africa only achieves 20% of OECD's 1997 meat consumption level of 88 kilograms, and even Latin America, a region well known for meat consumption with 54 kilograms per capita in 1997, only increases consumption levels to 65 kilograms by 2050. Moreover, global average per capita cereal consumption as food declines by 10 kilograms by 2050.

Under the TechnoGarden scenario, total food crop demand increases by 3,017 megatons up to 2050; cereal demand goes up by 1,070 megatons; and meat demand, by 166 megatons. Per capita cereal as food demand is expected to increase by 9 kilograms overall, with the largest increases in South Asia (23 kilograms), the OECD, and the former Soviet regions (10 kilograms). Preference for meat products is lower under TechnoGarden than under Global Orchestration. As a result, per capita demand for livestock products grows by only 6 kilograms globally during 1997–2050. The increase is largest in Asia, at 12 kilograms, followed by Latin America, with 11 kilograms.

Under the Adapting Mosaic scenario, by 2050 demand for all food products is somewhat depressed as people cannot afford higher-value foods and focus on locally adapted production methods and consumption. Total food crop demand grows by 2,797 megatons to reach 6,704 megatons by 2050. Cereal demand increases by 994 megatons, and demand for meat products grows by 179 megatons. Average per capita cereal food demand decreases by 10 kilograms to 151 kilograms in 2050. The former Soviet region and Asia experience the sharpest declines, at 15 kilograms and 14 kilograms. Per capita meat consumption levels under Adapting Mosaic only increase significantly for the OECD region, by 24 kilograms.

9.4.1.2.2 Extensification versus intensification of agriculture

Under the Global Orchestration scenario, the rapid rate of technology development and investments in agricultural research will lead to substantial yield increases, rendering large expansion in new crop areas unnecessary. (See Figure 9.26.) Globally, harvested area for grains is projected to expand at 0.01% annually from 1997 to 2050 and then to contract at 0.28% annually up to 2100. Only in sub-Saharan Africa will a large expansion of cropland be necessary for increasing production.

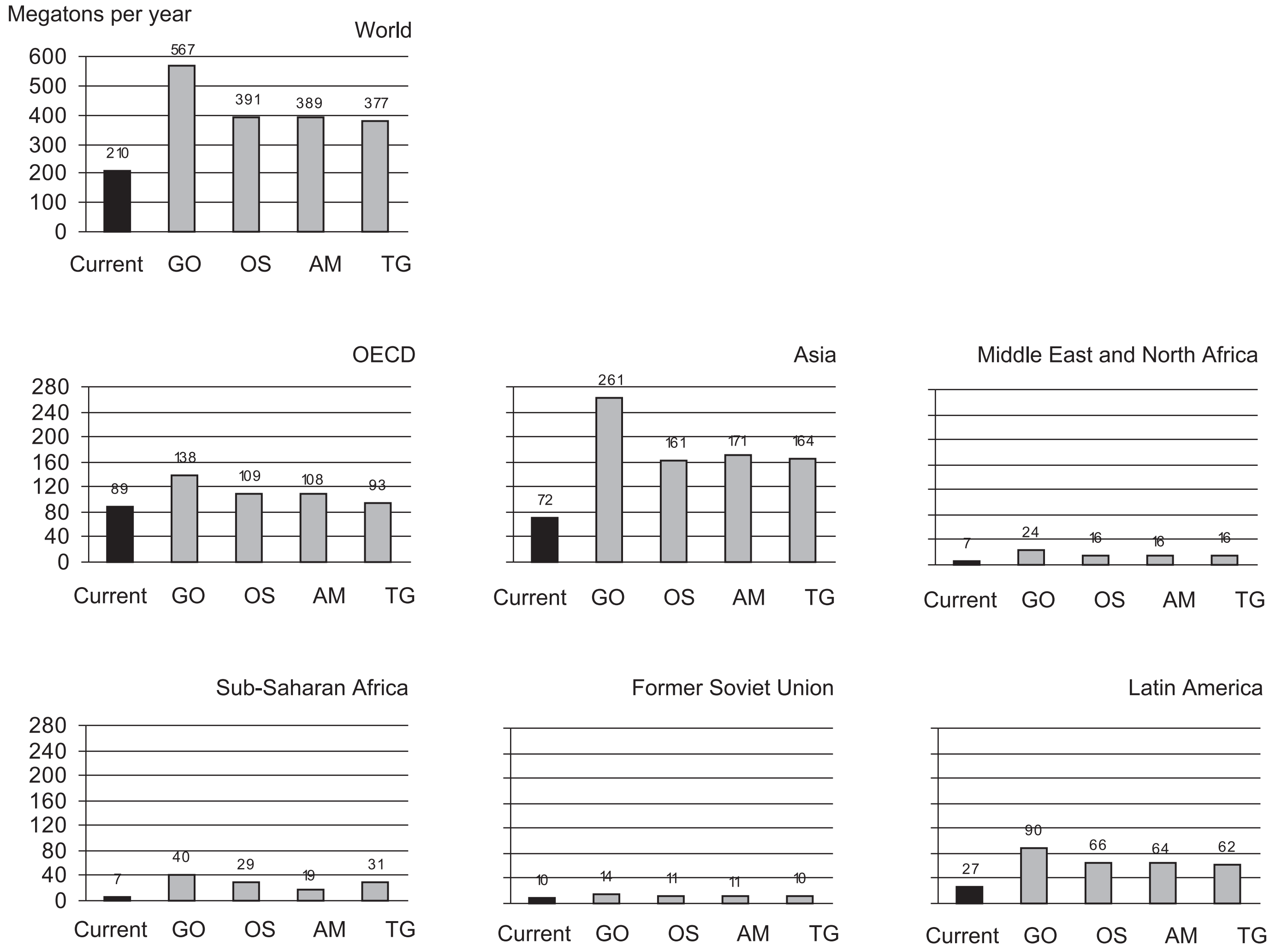

Figure 9.24. Meat Production by World Region in MA Scenarios in 2050. Scenario Names: GO: Global Orchestration; OS: Order from Strength; AM: Adapting Mosaic; TG: TechnoGarden. (IMPACT)

Although total cropland will not greatly expand, much more of it will be irrigated in 2050 then is today. Irrigated area will grow under Global Orchestration from 239 million to 262 million hectares (the largest increase among all four MA scenarios) spurred by large investments in irrigation systems. (See Figure 9.27.) The growth of irrigation is one of the main factors explaining productivity increases. The growth rate differs among the four MA scenarios based on the quantification of the storylines. (See Box 9.1.) Furthermore, total agricultural land will grow because of the demand for pastureland and biofuels, as described earlier.

Under Order from Strength, society invests relatively little in crop technology and supporting infrastructure. As a result, expansion in area will need to carry the brunt of food supply increases. Globally, crop area is projected to increase by 137 million hectares to reach 823 million hectares to supply future food needs, equivalent to an annual rate of 0.34%, before slowing to 0.25% per year from 2050 to 2100. Area expansion for cereals will be spread out among the poorer regions, with Latin America, sub-Saharan Africa, and MENA all experiencing harvested area expansion in the order of more than 40%. Expansion will be slightly lower in the former soviet and OECD regions and lowest in Asia. At the same time, irrigated area is expected to contract by 1 million hectares from 1997 to 2050 and a further 7 million hectares from 2050 to 2100, with area declines in Asia and the former Soviet Union more than offsetting net increases in the other regions.

The TechnoGarden scenario, characterized by innovations in agricultural technology and crop productivity but also less meat-based diets, requires even less area expansion than Global Orchestration. Up to 2050, irrigated area grows substantially, but less so than in Global Orchestration. In later periods, growth in irrigated area slows considerably due to slowing pressure on ecosystem services and food production. Globally, cereal harvested area contracts by 0.01% annually from 1997 to 2050 and a further 0.14% annually from 2050 to 2100, to 637 million hectares. However, total food crop area is expected to increase by 0.11% annually during 1997–2050 before contracting by a similar rate from 2050 to 2100. Although most regions will achieve production growth by intensification of existing cropland, expansion of cultivated land will still be important in sub-Saharan Africa, (accounting for 30% of total production growth up to 2050) and Latin America and MENA (accounting for about 11% of total production growth).

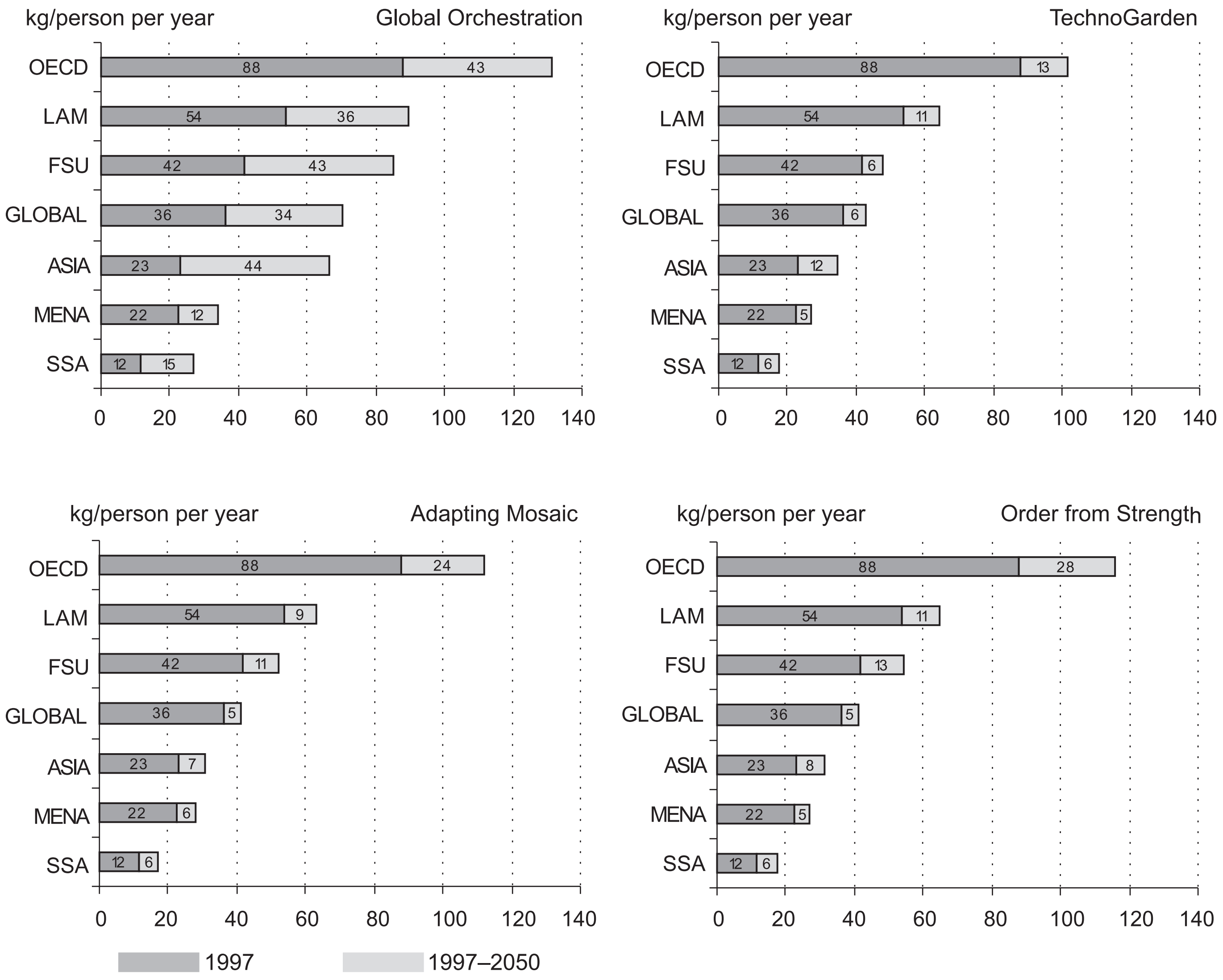

Figure 9.25. Meat Consumption by World Region in MA Scenarios in 2050. World regions: LAM: Latin America; FSU: Former Soviet Union; MENA: Middle East and Northern Africa; SSA: Sub-Saharan Africa. (IMPACT)

The Adapting Mosaic scenario postulates a combination of slow growth in food demand, low investments in food production technologies, and no breakthroughs in yield-enhancing technologies. Globally, irrigated area is expected to grow very slowly up to 2050, and then decline slightly. It will increase however in sub-Saharan Africa and Latin America. Depressed food demand under the Adapting Mosaic scenario will not be able to compensate for stagnant crop yields. As a result, crop harvested area is expected to increase at 0.16% per year for cereals and at 0.23% annually for all food crops, from 1997 to 2050, before contracting at −0.06% and −0.04% annually, respectively. Similar to the other MA scenarios, most cereal harvested area will be added in sub-Saharan Africa, at 39 million hectares, followed by Latin America (10 million hectares) and MENA (7 million hectares).

9.4.1.2.3 The potential impact of climate change on future agricultural yields

The impacts of climate change on crop yields have been assessed by IPCC (2001) in its Third Assessment Report. In fact, two combined effects have to be accounted for: the impacts of climate change and those of a rising atmospheric CO_2 concentration. The latter (also referred to as carbon fertilization) can increase yields and make plants more stress-resistant against warmer temperatures and drought. Climate change can lead to both increases and decreases in yields, depending on the location of changes of temperature and precipitation (climate patterns) and the crop type. IPCC concluded, with medium confidence, that a few degrees of projected warming will lead to general increases in temperate crop yields, with some regional variation. At high amounts of projected warming, however, most temperate crop yield responses could become negative. In the tropics, where some crops are already near their maximum temperature tolerance, yields could, depending on the region and the exact pattern of climate change, become adversely affected. Adaptation could mitigate these impacts.

Studies indicate that taking into account the carbon fertilization impact could be very important for final outcomes. For example, from studies in Montana in the United States it was concluded that climate change only decreases

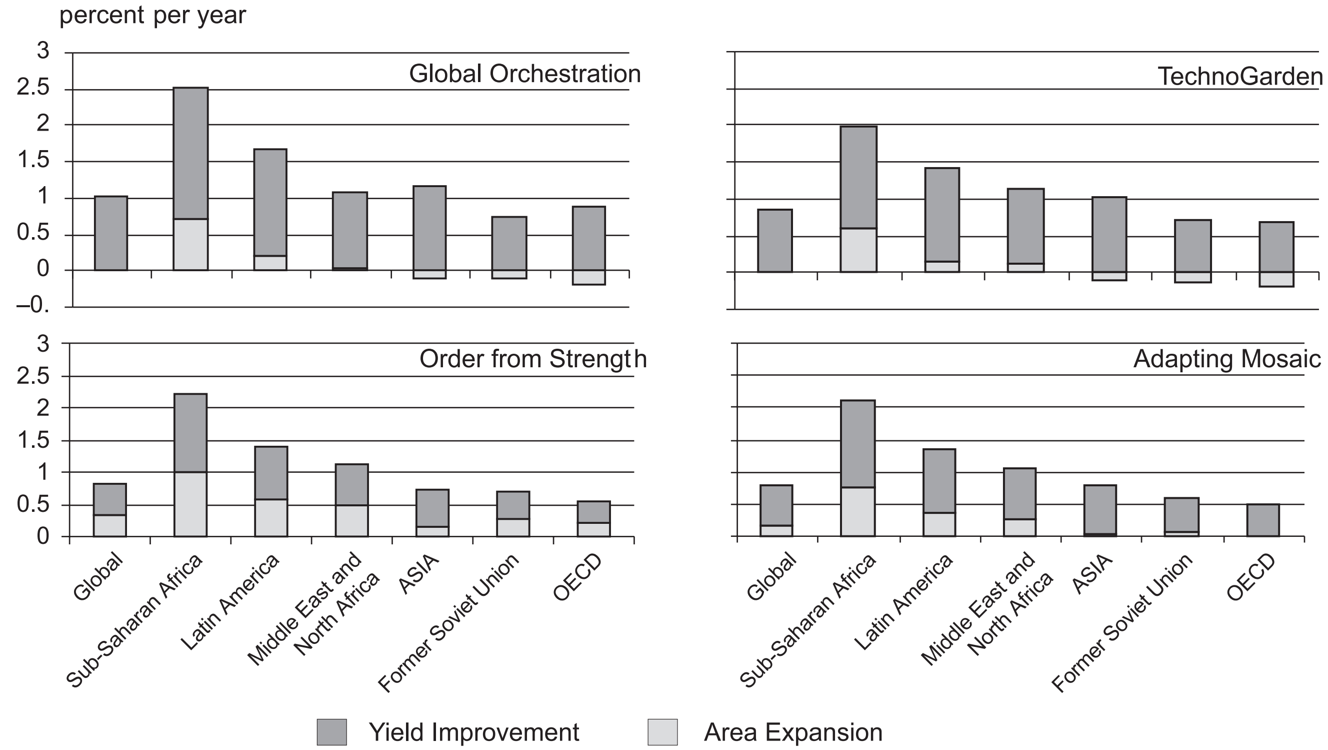

Figure 9.26. Factors Affecting Growth of Cereal Production in MA Scenarios, 1997–2050 (IMPACT)

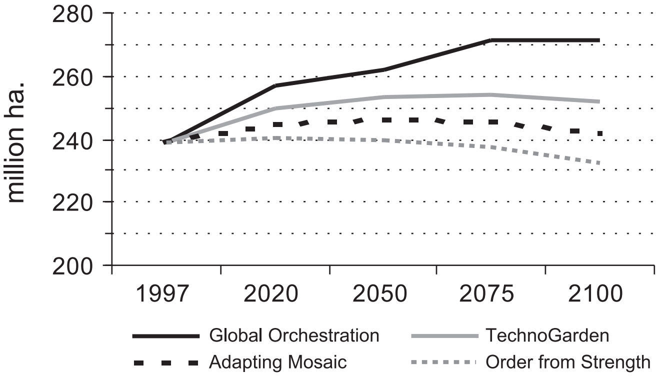

Figure 9.27. Global Irrigated Area in MA Scenarios, 1997–2100 (IMPACT)

the wheat yield from around −50 to −70%, while CO_2 fertilization leads to yield increases of +17 to +55%. The combination of both factors returns changes in wheat yield from −30% to +30% (Antle et al. 1999; Paustian et al. 1999). Parry et al. (1999) also conclude that the changes in crop yield range from negative impacts (–10% in North America, Latin America, Asia, and Africa) to positive impacts (+10% in Latin America) when both climate change and CO_2 fertilization are taken into account.

Because temperature increase enhances photo-respiration in C3 species,[6] such as wheat, rice, and soybean, the positive effects of CO_3 enrichment on photosynthetic productivity usually are greater when temperature rises (Bowes et al. 1996; Casella et al. 1996). However, the grain yield of CO_2-enriched rice shows about a 10% decline for each 1° Celsius rise above 26° Celsius. This decline is caused by a shortening of growth duration. Similar scenarios have been reported for soybean and wheat (Mitchell et al. 1993; Bowes et al. 1996). With rice, the effects of elevated CO_2 on yield may even become negative at extremely high temperatures (above 36.5° Celsius) during flowering (Horie et al. 2000).

BOX 9.1

Rate of Irrigated Area Growth among Scenarios

Among the four scenarios, effective growth in irrigated area is largest for Global Orchestration, at 0.18 percent per year during 1997–2050, followed by TechnoGarden, with growth of 0.11 percent annually.

Annual growth in irrigated area is much lower under Adapting Mosaic, at 0.06 percent per year, and under the Order from Strength scenario (0.01 percent annually). During 2050–2100, irrigated area declines under all but the Global Orchestration scenario.

Up to 2050, under Global Orchestration area expands most rapidly in Latin America, at 0.5 percent per year, followed by sub-Saharan Africa, at 0.3 percent annually. In the TechnoGarden scenario, growth in Latin America, sub-Saharan Africa, West Asia, and North Africa is similar to Global Orchestration, but growth slows in Asia, the former Soviet Union, and the OECD region.

Under the Adapting Mosaic scenario, area actually contracts in the former Soviet Union at 0.1 percent per year (by 0.8 million hectares) and in Asia at 0.03 percent per year (by 2.3 million hectares). Growth in sub-Saharan Africa and Latin America remains strong, however. Finally, under the Order from Strength scenario, irrigated area reductions in Asia and the former Soviet Union are even larger, at 3.3 million and 1.7 million hectares, respectively, whereas irrigated area growth remains strong in Latin America and sub-Saharan Africa.

For the MA scenarios, we have used the calculations of the IMAGE model to assess the impacts of yields. These impacts are fully included in the land use and food results shown in this chapter. It should be noted that the regional impacts are very uncertain, as the patterns of climate change are uncertain. Some signals, however, are visible across most models. In Figure 9.28 (see Appendix A), this is shown for selected regions in the Order from Strength scenario (the other scenarios show, in general, a smaller climate change impact). Regions that are positively affected in terms of yield changes include the United States and the former Soviet Union. In other regions, however, the impacts will clearly be negative—including, in particular, South Asia (that is, India), which in turn will have a strong negative impact on two very important crop types, rice and temperate cereals. On top of already existing difficulties feeding growing populations, this type of stress could have significant consequences. Other negatively affected regions under this climate change pattern include OECD Europe and Japan. These impacts are taken into account in the production levels discussed in this chapter.

9.4.1.2.4 The role of trade and international food prices

Under the Global Orchestration scenario, trade liberalization and economic opening helps fuel rapid increases in food trade. Total trade in grain and livestock products increases from 196 megatons to 670 megatons by 2050, the largest increase among the MA scenarios. (See Figure 9.29.) Net grain trade increases more than 200% from 1997 to 2050. The OECD region, in particular, responds to the increasing cereal demands in Asia and MENA with an increase in net cereal exports of 89 megatons. Moreover, the very rapid yield and area increases projected for the sub-Saharan Africa region turn the region from net cereal importer at present to net grain exporter by 2050. Net trade in meat products increases 674%, albeit from presently low levels. Net exports will increase particularly in Latin America, by 23 megatons, while the OECD region and Asia are projected to increase net imports by 15 megatons and 10 megatons, respectively.

Large investments in agricultural research and infrastructure, particularly in poorer countries, help bring down international food prices for livestock products and rice. Over the 1997–2050 period, livestock prices decline by 9–13% and rice prices drop by 31%, whereas maize and wheat prices increase by 14% and 39%, respectively, because of demand for animal feed. (See Figure 9.30.)

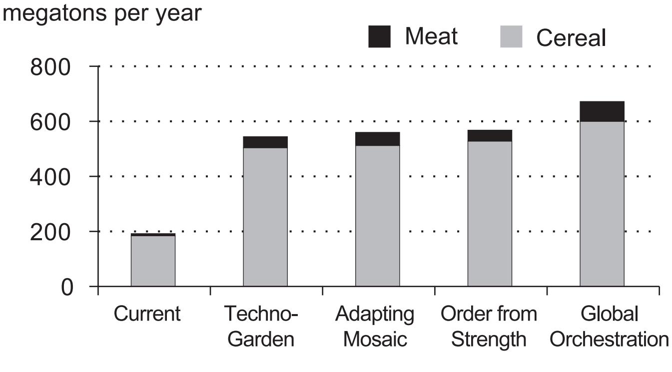

Figure 9.29. International Trade in Cereals and Meat Production in MA Scenarios in 2050 (IMPACT)

Under Order from Strength, countries maintain current protection levels. At the same time, food production stalls because of low investments in technology and infrastructure, and this puts pressure on countries to import food. Finally, low income growth dampens food demand somewhat in poorer countries. Hence, even though this is a scenario in which trade is not encouraged, total trade in food commodities more than doubles relative to 1997. The combination of population growth and lagging food production leads Asia to import from the OECD, despite existing barriers to trade. Meanwhile, sub-Saharan Africa is a net importer, albeit at reduced levels, due to higher costs of trading and depressed demand. Net trade in meat products is much lower than in the Global Orchestration scenario, reaching 41 megatons by 2050, but most trade is carried out intraregionally.

Depressed demand from lower income levels cannot compensate for even lower investments in food production and supporting infrastructure and for high population growth. As a result, prices for all cereals are projected to increase over the coming decades: with price increases ranging from 19% (maize) to 46% (rice). Meat prices, on the other hand, continue to decline by 3–12%.

Under the TechnoGarden scenario, trade liberalization continues apace. Pressure on trade is somewhat reduced due to the preference for a diet with less meat, relatively good production conditions in the various countries and regions, and somewhat lower income growth than in Global Orchestration. Total trade for grains and meat products grows to 543 megatons by 2050. Net cereal trade is dominated by Asian net imports of 124 megatons and OECD net exports of 159 megatons, followed by net imports in MENA of 70 megatons. Net meat trade is dominated by net imports in the OECD region (17 megatons in 2050), supplied through net exports from Latin America, sub-Saharan Africa, and Asia. Growth in production and trade will more than compensate for increased demand, resulting in declines for international food prices across the board. By 2050, prices for wheat, rice, and maize are projected to decline by 11–26% and prices for beef, pork, and poultry by 6–23%.

Under Adapting Mosaic, the focus is on local food production and conservation strategies, with limited exchange of goods and services. Low income growth depresses food demand, but the large increase in population puts upward pressure on food, which is being produced without technological breakthroughs or enhancements due to lack of investment in this area. Total grain and meat trade increases to 560 megatons by 2050. Cereal trade increases by 175% over 1997 levels, most of which is accounted for by increased net imports in Asia and MENA and increased net exports of the OECD region. Similarly to the other MA scenarios, the former Soviet Union can improve its net export position. Appropriate technologies and conservation strategies help sub-Saharan Africa become a small net cereal exporter by 2050. Total net meat trade increases by 31

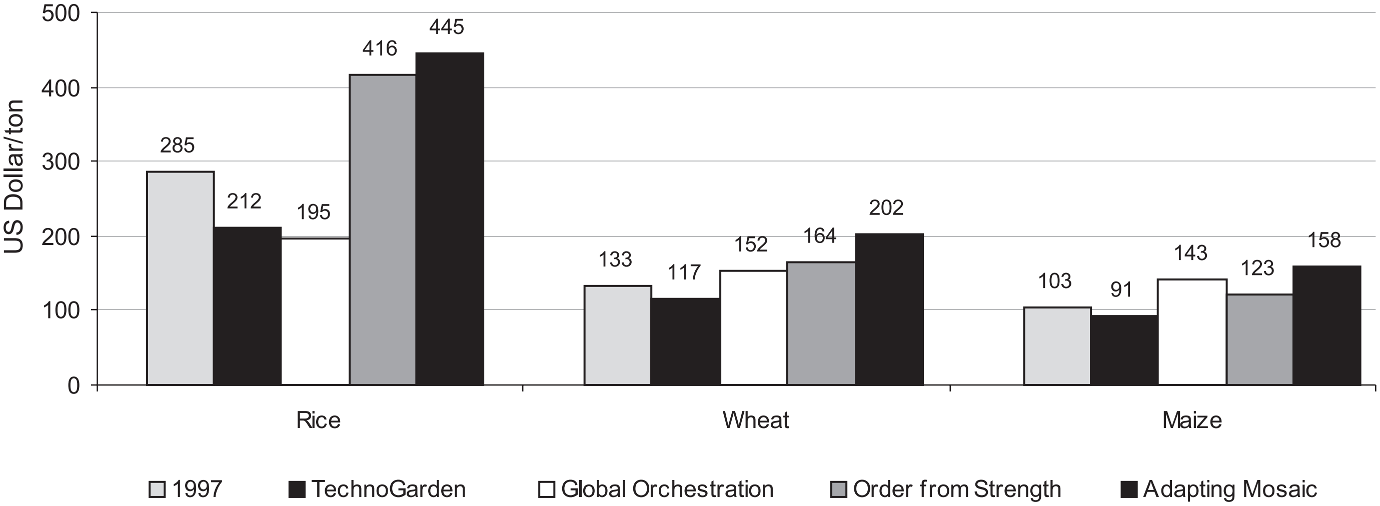

Figure 9.30. International Cereal Prices in MA Scenarios in 2050 (IMPACT)

megatons, the smallest increase among the MA scenarios. By 2050, Asia is projected to supply about 20 megatons of livestock products to all other regions except Latin America.

Insufficient food production causes international cereal prices to increase by 52–56% for wheat, maize, and rice, whereas livestock prices decline by 2% (beef and pork) and 15% (poultry).

9.4.1.2.5 Outcomes for calorie availability and child malnutrition

Although total food production levels by 2050 are similar across scenarios, outcomes for calorie availability and child malnutrition levels in poorer countries vary considerably. The increase in global average caloric availability is largest under Global Orchestration, at 818 kilocalories per capita per day between 1997 and 2050, followed by TechnoGarden at 507 kcal/cap/day, whereas increases are only 207 kcal/cap/day and 250 kcal/cap/day, respectively, under the Adapting Mosaic and Order from Strength scenarios. Under Global Orchestration, all regions experience large increases in calorie availability, led by Asia with an increase in 1,035 kcal/cap/day.

Under the Order from Strength scenario, on the other hand, the increase in per capita calories is largest in the OECD region, at 616 kcal/cap/day. Under TechnoGarden, caloric availability in all regions but sub-Saharan Africa surpasses 3,000 kilocalories. Under Adapting Mosaic, increases in calorie availability are very low. Similar to the Order from Strength scenario, by 2050 improvements in caloric availability in sub-Saharan Africa and Asia, particularly South Asia, are slow. The kilocalorie availability remains particularly low in sub-Saharan Africa, at less than 2,500 kcal/cap/day, and only reaches 3,000 kcal/cap/day in two regions, Latin America and MENA.

Food consumption together with the quality of maternal and child care and of health and sanitation are important determinants for child malnutrition outcomes. Three out of the four MA scenarios result in reduced child malnutrition by 2050. Under the Order from Strength scenario, there are 18 million more malnourished children in 2050 than in 1997. (See Figure 9.31.)

Today, South Asia accounts for slightly more than half of all malnourished children in developing countries, followed by sub-Saharan Africa, home to 20% of all malnourished children. Under the Global Orchestration scenario, the number of malnourished children is projected to decline by 50 million children in South Asia and by 15 million in sub-Saharan Africa. Under Order from Strength, on the other hand, the number of malnourished children is projected to increase by 18 million in sub-Saharan Africa and by 6 million children in South Asia as a result of depressed food supplies, higher food prices, and low investments in social services. Under the Adapting Mosaic scenario, the number of malnourished children would still increase by 6 million children in sub-Saharan Africa, but it would decline by 14 million in South Asia. Finally, under TechnoGarden, the number of malnourished children declines by 5 million in sub-Saharan Africa and by 32 million in South Asia.

9.4.2 Fish for Food Consumption

9.4.2.1 Methodology and Assumptions on Fish Consumption

Aquatic ecosystems of the world provide an important provisioning service in the form of fish and seafood. Fish are an important source of micronutrients, minerals, essential fatty acids, and proteins, making a significant contribution to the diets of many communities. Globally, 1 billion people rely on fish as their main source of animal proteins, and some small island nations depend on fish almost exclusively. Currently, 79% of fish products are harvested from marine sources (FAO 2000).

To assess future production of world fisheries, it is important to understand the different interpretations of trends in the last decades. Since 1970, total fisheries production has more than doubled, to more than 90 million tons, with most of the increase in the last 20 years from aquaculture. Global capture food fisheries, however, have been stagnant at around 60 million tons since the mid-1980s, as most of the world's capture fisheries stocks are fully or overex-

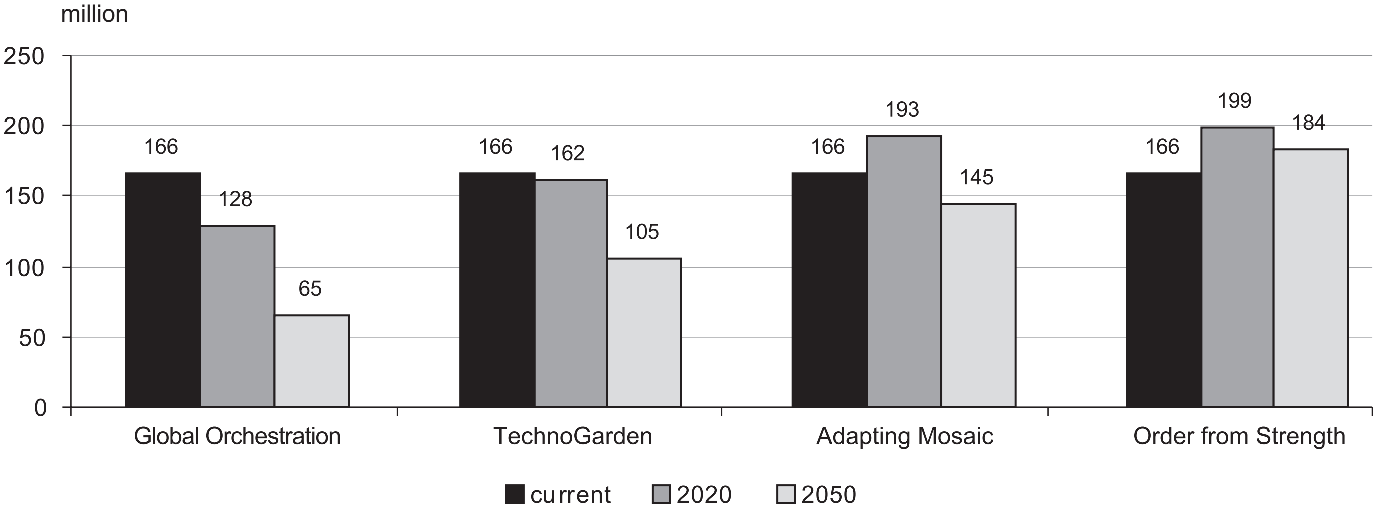

Figure 9.31. Number of Malnourished Children in Developing Countries in MA Scenarios in 2020 and 2050 (IMPACT)

ploited (Delgado et al. 2003; FAO 2000). In fact, some experts indicate that marine capture fisheries might actually have been declining for more than a decade if statistics are corrected for overreporting (Watson and Pauly 2001; Lu 1998). At the same time, developing countries have become major exporters of marine fish products. Developing-country aquaculture production rose from less than 2 million tons in 1973 to more than 25 million tons by 1997.

Yet aquaculture production relies partly on the supply of fish meal and fish oil. While some experts indicate that growth in aquaculture production could lead to greater pressure on stocks of fish used for feed (Naylor et al. 2000), others report instead that efficiencies in the use of fish feeds are improving and that substitute products based on plant matter are being developed (Delgado et al. 2003; Wada, N., personal communication, May 2004). This controversy plays a crucial role in the future of global fisheries. Other adverse impacts of rapid increases in aquaculture production could include the destruction of coastal ecosystems, like mangroves, and increased pollution levels in the form of effluent, chemicals, and escaped farm fish (Goldburg and Triplett 1997). Socioeconomic impacts include loss of property rights and declining incomes for local fishers who rely on capture fisheries (Alder and Watson submitted).

Based on the above, most experts agree that most unmanaged fisheries are near maximum sustainable exploitation levels and that their production will only grow slowly until 2020 (see, for example, FAO 2003 or Delgado et al. 2003) or will even decline (Watson and Pauly 2001). Moreover, there might be important trade-offs between production levels and other ecological services provided by marine ecosystems (such as biodiversity). Large fisheries collapses cannot be ruled out, as observed historically for specific coastal systems (Jackson et al. 2001). As a substitute for marine fishery production, aquaculture (including marine culture) has the greatest potential for satisfying future production increases (FAO 2003). Emerging land, water, and input constraints, however, will place additional pressure on technology to find alternative ways to increase productivity levels.

The forecast of fisheries outcomes needs to be based on stock assessment, on fish population dynamics, on biophysical modeling, on market interactions among producers, consumers, and traders, and on interactions with outcomes for other foods and feeds. Future trends in fish demand have been analyzed from an economic point of view by the International Food Policy Research Institute using the IMPACT model (Delgado et al. 2003, see Chapter 6 for discussion of methodology), as well as from an ecological point of view for various marine fisheries by Pauly et al. (2003) and others. Both perspectives are crucial for an understanding of the prospects of future world fisheries, but as of yet they have not been combined in a single consistent quantitative framework. Hence here we draw on results from both perspectives and combine them in a preliminary way. We first present computed trends of changing fish demand, and then draw on ecological modeling results to assess whether these future demands can be met from the ecological point of view. The assumptions used in the ecological modeling exercise are discussed in Appendix 9.2.

9.4.2.2 Comparison of Fish Consumption among Scenarios

For our estimations of future fish supply and demand we draw on a series of scenarios already available or especially prepared for the MA scenario analysis. (See Table 9.15.) Under the IMPACT baseline scenario, global fish production will increase slightly faster than global population through 2020, to 130 million tons (40% increase) with an increasingly tight supply situation indicated by jumps in real fish prices of 4–16% (livestock product prices, in contrast, are expected to decline). Aquaculture is projected to account for 41% of total production by 2020.

A scenario projecting even faster aquaculture expansion (which might fit well with Global Orchestration and TechnoGarden) suggests that despite short-term tendencies in the opposite direction, over the long run lower food fish prices resulting from more rapid aquaculture expansion could possibly reduce pressure on capture fishing efforts and generally benefit the health of fish stocks (see also Bene et

Table 9.15. Scenario Description for Alternative Outcomes in Future Fisheries

Scenario	Description
IMPACT Baseline	based on IFPRI/WorldFish most plausible set of assumptions
Faster aquaculture	production growth trends for 4 aquaculture output aggregate commodities are increased by 50 percent relative to the baseline scenario
Lower China production	Chinese capture fisheries production is reduced by 4.6 million tons for the base year; income demand elasticities, production growth trends, and feed conversion ratios are adjusted downward, consistent with the view that actual growth in production and consumption over the past two decades is slower than reported
Ecological collapse	a contraction by 1 percent annually in production for all capture fisheries commodities
MA scenarios	based on MA macroeconomic drivers, but without specific changes to fish parameters

Table 9.16. Projected Per Capita Food Fish Production in 2020, Alternative Scenarios. The first four scenarios are based on Delgado et al. 2003. Outcomes for fish supply, demand, and trade are reported for 2020 only. For the MA scenarios, no specific changes to fish parameters have been introduced. However, drivers, such as economic growth, population growth, and changes in the various substitutes and complements of fish products do, indirectly, affect outcomes for fish supply and demand.

Scenario	Food Fish Production, 2020
	(kilograms per person per year)
Actual in 1997 (MA)	15.7
IMPACT Baseline	17.1
Faster aquaculture	19.0
Lower China production	16.1
Ecological collapse	14.2
Global Orchestration	17.3
Order from Strength	14.8
Adapting Mosaic	15.1
TechnoGarden	16.0

al. 2000; Clayton and Gordon 1999; Anderson 1985; Ye and Beddington 1996; Pascoe et al. 1999; and similar supply elasticity assumptions made by Chan et al. 2002). Total food fish production under this scenario is projected to increase to 145 million tons.

Experts do have different visions on whether such production levels are attainable, as it requires considerable technology advances in aquaculture. If the Watson and Pauly (2001) values of overestimated fish catch (mainly in China) are incorporated into IMPACT, then fish production in 2020 would be 7 million tons lower than the IMPACT baseline, and annual per capita consumption would decline by 1–16 kilograms. An additional scenario exploring the outcomes of potential large fisheries collapses results in production declines of 17%, with shortfalls mitigated by production responses to major output price increases of 26–70% in both capture food fisheries and aquaculture. Under this scenario, per capita food fish consumption would drop to 14 kilograms by 2020.

For the MA scenarios, rapid increases in urbanization and income growth result in the highest per capita demand levels for the Global Orchestration scenario (17.3 kilograms), and production of 128 million tons by 2020. Under Order from Strength, on the other hand, rapid population growth combined with slower economic progress result in the lowest production increases, at 117 millions tons in 2020, corresponding with depressed per capita demand levels of 14.8 kilograms. (See Table 9.16.). The values of the other MA scenarios fall between these two extremes.

9.4.2.3 Methodology and Assumptions on Fish Landings

The future of wild capture fisheries depends on several factors, such as changes in average climate and climate variability causing shifts in species distributions and abundance (increase of species at some locations, decline at others), fishing subsidies that will affect the catch at the fisheries level, the danger of overfishing due to the absence or failure of fisheries management, and factors such as population growth and food preferences affecting the demand for marine products. In this section and in Figure 9.32, we describe changes in the fisheries of three marine ecosystems—the Gulf of Thailand, Central North Pacific, and North Benguela—for the four MA scenarios.[7] These case studies were selected because they represent a variety of fishery conditions. The qualitative assumptions for the three case studies under the MA scenarios are summarized in Table 9.17.

9.4.2.4 Comparison of Fish Landings Among Scenarios

All four scenarios maintain the weight and value of current landings in the Gulf of Thailand. However, the consequence of this is a severe decline in the diversity of landings (see Chapter 10), which could increase the vulnerability of the fishery to disease, climate change, and other stresses. In Global Orchestration, the weight of landings (primarily high-valued invertebrates) remains stable until 2010, while profits are increased. The policy focus changes in 2010 to a balance between increasing profits, jobs, and ecosystem structure (where ''increasing ecosystem structure'' means rebuilding the trophic structure of the fishery). This policy results in a temporary and slight decline in the weight of landings until the system responds and stabilizes to a level similar to the year 2000. In 2030, the policy focus changes to a balance between increasing profits and ecosystem structure resulting in a slight increase in the weight of landings and a substantial increase in their value.

Order from Strength has high weight and value of landings until 2010, when policies are reoriented to optimizing profits and jobs. Under this policy there is a slow and steady increase in the weight of landings and their value. After 2030, the policy is to rebuild demersal species as well as optimizing jobs rather than profits, with the system responding and then stabilizing at a slightly higher level of weight and substantially higher value.

In the TechnoGarden scenario, landings in the Gulf of Thailand are initially stable. In 2010 the weight and value

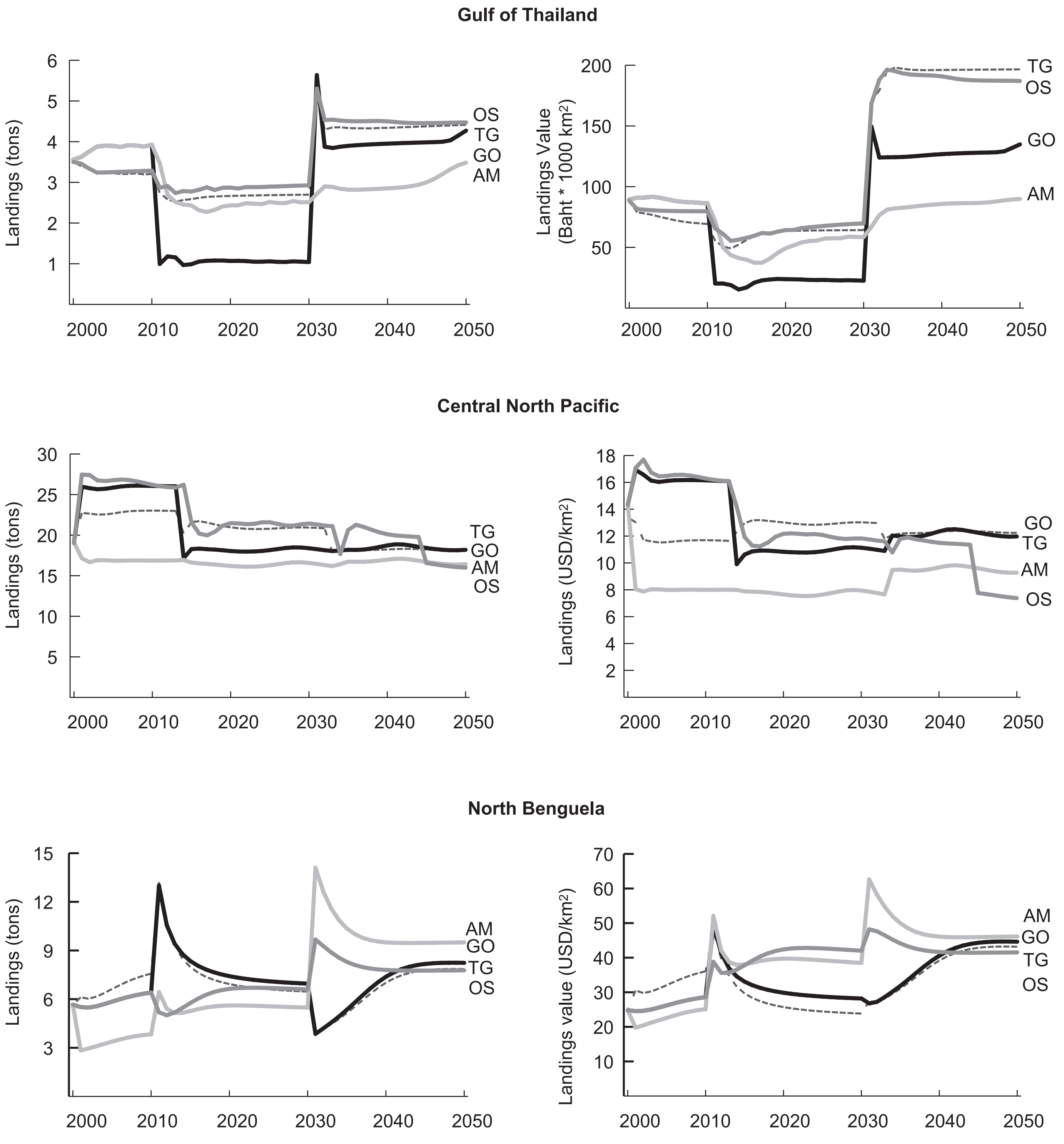

Figure 9.32. Comparison of Fish Landings in Three Specific Regions for MA Scenarios. Scenario names: AM: Adapting Mosaic; GO: Global Orchestration; OS: Order from Strength; TG: TechnoGarden. (Ecopath/Ecosim)

of landings decline until the fish industry is reoriented from optimizing the catch for small pelagic species to support of the growing aquaculture industry. The system responds quickly, and the weight of landings soon stabilizes until the next policy change, which aims to further optimize small pelagics directly or as bycatch from the invertebrate fisheries. The value of the landings has a similar trend.

There is an overall decline in the weight of landings to 25% of the 2000 level in the Adapting Mosaic scenario, but this trend is reversed in 2030 when levels begin to increase. In this scenario, profits are maximized first and jobs have a minor focus. However, by 2010 the policy focus changes to a rebuilding of the ecosystem, including demersal species, and therefore there is a detectable decline in landings and substantial decline in profits. The ecosystem continues to rebuild and demersal stocks and their value increase. However, landings do not recover, and by 2050 they are the lowest level of any scenario.

Table 9.17. Qualitative Assumptions for Case Studies of Regional Marine Fisheries in MA Scenarios (EcoSim/EcoPath)

Assumption	Global Orchestration	Order from Strength	Adapting Mosaic	TechnoGarden
Objective for fisheries production	optimize profits (mostly) and jobs—later in the scenario, also attention to preserving ecosystems	optimize profits; also some attention to ecosystem preservation	mixed focus among profits, jobs, and ecosystems	optimize profits and jobs (more mixed)
Climate change	GoT: medium—high	GoT: med	GoT: high	GoT: high
	NB: Medium—Low	NB: low-med	NB: low to high	NB: med
	CNP: Low	CNP: low	CNP: low	CNP: low
Specific additional assumptions	jobs less important in the CNP because much of the fishing is done by distant water fleets	concentration on fishing for fishmeal for aquaculture	assumes that CNP continues to have a significant distant water fleet while GoT and NB fleets are primarily domestic	increased fishing efforts from more distant (high-income countries) that aim for food security

Key: GoT = Gulf of Thailand, NB = North Benguela, and CNP = Central North Pacific.

None of the four scenarios are able to increase or even maintain current landing levels in the Central North Pacific. In Global Orchestration, the weight of landings declines well below the 2000 level and remains low. The value of landings follows a similar trend because fishery policy focuses primarily on profits, followed by jobs, until 2030. After 2030 the focus changes to a balance between maximizing profits and ecosystem structure, which is reflected in the decline in landings in 2030.

Under Order from Strength, the weight and value of landings significantly decline over the scenario period with brief intervals of recovery. The weight of landings declines under TechnoGarden and Adapting Mosaic, but the value of landings increases slightly. The value of landings is maintained under the TechnoGarden scenario because of the development of a highly profitable aquaculture industry that uses fish feed from sources not based on small pelagic fisheries.

The North Benguela ecosystem landings and profits can be maintained under the four scenarios. In the Global Orchestration scenario the North Benguela system initially increases slightly from the 2000 level. When policies shift after 2010 from a balance between profits and jobs to a focus on jobs followed by profits, some fisheries begin to harvest small pelagic fish as feed for a growing aquaculture industry. In response, the weight of landings declines until 2030, when landings again increase to a level slightly higher than in 2000. The value of landings follows a similar trend, with the weight of landings peaking in 2010, declining until 2030, and then increasing again to a higher level in 2050.

Order from Strength results in an overall increase in the weight and value of landings as profits and jobs are maximized. Rebuilding of ecosystem structure starts in 2025 but jobs remain the priority until 2030, when profits are first maximized, followed by jobs.

Under TechnoGarden, landings initially increase as profits and jobs are optimized. When the focus of policy changes to maximizing profits followed by jobs, landings decline to levels slightly higher than in 2000. The trend continues until 2030, when policies are again changed, this time to the simultaneous optimization of profits, jobs, and ecosystem structure. As part of this policy shift, fisheries focus on harvesting small pelagic fish to supply the aquaculture industry. The net effect of this policy shift is a substantial decline in the weight and value of landings. There is an overall increase in landings and value in Adapting Mosaic from 2000, peaking in 2030 but declining to a stable level within about eight years. Initially, the policy focus is on jobs, followed by profits, until 2010.

Very dynamic changes are found for the weight and value of landings for the different scenarios under all case studies. Not only total fish landings change but also the type of species. (See Chapter 10.) Overall, no single scenario was superior in its performance across the three modeled ecosystems for landings or landed value. The pattern that does emerge is that to maintain or improve the provisioning services or the economic value of these three ecosystems, there is a trade-off between the magnitude of production and the diversity of the landings, especially in the Gulf of Thailand. (See Chapter 10.) In some ecosystems, there is a trade-off between increasing the number of landings (food provisioning) and the economic value of the landings (profits), as seen in the Central North Pacific model, where landings declined in the TechnoGarden scenario while profits improved.

The conclusions of these three case studies can be summarized as follows: Policies that focus on maximizing profits do not necessarily maintain diversity or support employment. Similarly, policies that focus on employment do not necessarily maximize profits or maintain ecosystem structures. The diversity of the stocks exploited can be enhanced if policy favors maximizing the ecosystem or rebuilding stocks. Diversity, however, is lost if the sole objective of management is to maintain or increase profits.

9.4.2.5 Comparing Two Approaches to Model Fish Consumption and Production

Two different approaches have been used to explore the possible development of the provisioning service of fish for food consumption under the four MA scenarios—an economic modeling approach and an ecological modeling approach. The two highlight different results. The IMPACT modeling framework shows that total demand for food fish will continue to increase under the MA scenarios. The important question, however, is whether it is feasible to increase production to meet this demand. As shown in our assessment, aquaculture may play an important role here, but it is constrained by its current dependence on marine fish as a major feed source. This dependence must be reduced by advances in, for example, feed efficiency and alternative, plant-based sources of feed.

The ecological modeling of three regional fisheries show that maintaining or increasing current levels of landings will lead to the depletion of predators at the top of the food web, and ecosystems could become dominated by short-lived species at lower trophic levels. This development can compromise the diversity of the ecosystem and make it more vulnerable to external perturbations (such as those stemming from the variability of climate, nutrient availability, or demand). Diversity is also lost if the sole objective of management is to maintain or increase profits. The diversity of the exploited stocks can only be enhanced if policy favors maximizing the ecosystem structure or rebuilding stocks.

9.4.3 Uncertainty of Agricultural Estimates and Ecological Feedbacks to Agriculture

As a whole, the quantified scenarios show a confident picture of the future—both food supply and demand increase into the future along with economic development, while global food trade smoothes out the differences in food-growing ability among nations, assuming that importing countries find the financial resources to do so. But the Order from Strength scenario shows that unfavorable developments in the food sector could threaten this relatively positive global picture. Moreover, the global picture masks significant regional problems. Although average food availability continues to increase, access to sufficient food will continue to remain out of reach for many people in poorer countries, particularly in sub-Saharan Africa and South Asia, leading to a continuing substantial level of child malnutrition in these regions. Moreover, it is uncertain whether the global growth projected in these scenarios is feasible from the standpoint of ecological sustainability.

On the one hand, this confident view of the future is not unlike our experience over the last 100 years, in which food production and consumption have steadily increased as countries have gotten richer, despite temporary setbacks due to political crises, poor planning, or the occasional drought. On the other hand, we should not assume that the global agricultural system will remain as robust as it apparently is now. Several in particular could pose increasing risks to the agricultural production computed in these scenarios.

First, scarcity of water is a concern. Many of the areas where crop and fish production will intensify or expand are also areas currently in the ''severe water stress category,'' as described later, and are expected to have an increasing level of water stress across all scenarios (such as the Middle East, sub-Saharan Africa, parts of China, and India). This is particularly important because irrigation will continue to play an important role in the agriculture of these regions. It is also shown that wastewater discharges are likely to double over much of this area, also endangering the source of freshwater fish not coming from aquaculture. Unfortunately, the model results for agricultural production do not take water scarcity into account in their calculations. While solutions for water scarcity may be found, this should not be taken as a given. Therefore, the role of water as a limiting resource should be kept in mind when interpreting the food production scenarios.

Intensification of agricultural inputs is a second factor to consider. Nearly all scenarios assume improvements in efficiency of agricultural input use, including increased efficiency of land use through yield increases and multiple cropping, increased efficiency of irrigation water use, and increased uses of agricultural machinery, fertilizers, and pest control. However, whereas some of these drivers were explicitly varied across scenarios, like yield growth or efficiency of irrigation, others, like fertilizer applications or changes in nitrogen-use efficiency, were not quantified or changed. We also have not evaluated the long-term risks of intensive agricultural inputs on pest outbreaks, groundwater contamination, soil degradation, and other ecological impacts. We expect these risks to be of greatest concern in Global Orchestration, which has the highest level of agricultural inputs and a low level of environmental protection. Next in line could be either Order from Strength, because of its low environmental consciousness, or TechnoGarden, because of the possibility of technological failure. Perhaps the Adapting Mosaic scenario would have the lowest level of risk because of its lower level of agricultural inputs and higher level of actions to protect the environment.

Sustainability of marine fisheries must be considered as well. The scenarios show a medium to large increase in fish production and consumption in all regions of the world. But we have not yet analyzed in detail the ability of the world's marine fisheries to sustain the computed fish production.

The fourth factor of concern is food insecurity and the affordability of food. In the model calculations, rising food demand will be met through increased production and food trade. If production levels are below food demand, then prices adjust upwards until a lower or depressed effective demand can be met. Moreover, higher food prices induce additional small supply expansion. As of yet we have not analyzed in detail the affordability of increased food prices for income groups. We have noted, however, that lack of technological development under the Order from Strength and Adapting Mosaic scenarios will force lower-income countries to import cereals at prices substantially above those of today. Cereals at these prices may not be within easy reach of lower-income groups, as indicated by the large number of malnourished children under these two scenarios.

The outcomes for food production do not vary significantly across scenarios at the global level, with cereal production in 2050 projected to be 50% larger under all four scenarios and with basic staple production projected to stagnate or decline in MENA and increase very little in sub-Saharan Africa by 2050. However, scenario outcomes do vary by region and within regions, particularly for the poor. Moreover, the means by which food production levels are increased vary significantly by scenario, with some focusing on area expansion and local production, whereas others rely on yield improvements and enhanced trade.

Differing means of increasing production could have an impact on pressure on ecosystems due to agricultural production. In the Order from Strength and Adapting Mosaic scenarios, protectionist policies, together with lack of investments in agricultural research and agriculture-related infrastructure, result in increased food prices, depressed food demands, and slow improvements in food consumption on a caloric basis. Moreover, under Order from Strength, the number of malnourished children will be higher by 2050 than today. The outcome is different for the Global Orchestration and TechnoGarden scenarios, where more food is produced by boosting crop yield and increasing the international exchange of goods, services, and knowledge. In these scenarios, crop area can be conserved, food prices increase much less, per capita food consumption increases faster, and the number of malnourished children declines.

9.4.4 Fuel

9.4.4.1 Methodology and Assumptions

The biosphere provides humanity with both traditional fuelwood and so-called modern biofuels, a category that includes alcohol derived from fermenting maize and sugar cane, fuel oil coming from rape seed, fast-growing tree species that provide fuel for power-generating turbines, and agricultural wastes, also burned to generate power. While fuelwood has been steadily replaced by other energy carriers, it still accounts for a large percentage of total energy use in some places. At the same time, the current use of modern biofuels is quite modest, although it could greatly expand, according to some energy scenarios (as described earlier). An important advantage of these is that in terms of greenhouse gas emissions they are neutral (the CO_2 emitted by burning biofuels has been absorbed first by plant growth). For this reason they play a significant role in the TechnoGarden energy scenario, where climate policy is given high priority. In the MA scenarios, biofuels play a role both for electricity production and as transport fuel. While many existing scenarios agree on an increase in modern biofuel use, major uncertainties exist regarding where the biofuels are produced and consumed and when the major penetration of biofuels into the energy mix will occur.

9.4.4.2 Comparison of Fuels among Scenarios

Under Global Orchestration, the global production of biofuels increases from its current level by a factor of six—mainly driven by cost increases for fossil fuels. (See Figure 9.33.) The regions making the biggest contribution to this increase are Asia (factor of eight), followed by the MENA countries (nearly a factor of six), and sub-Saharan Africa (about a factor of 4.5). There are two main factors leading to this large expansion in biofuel use. First, good land is available for biofuel production because competition from food production is low—food crops are grown very efficiently on existing crop areas in most regions (because of the high crop yield achieved from investments in agricultural research and fertilizer and other inputs). Second, the demand for electricity is high because of strong economic growth. Hence there is a large demand in general for energy and for biofuel electricity in particular because biofuels can be grown on relatively cheap and productive land. However, one unwelcome consequence of this intense use of biofuels is a high rate of deforestation in the regions committed to biofuel production.

Global production of biofuels under TechnoGarden increases by about a factor of four, mainly driven by climate policy. Production lags behind that scenario, however, because income (and therefore energy demand) is lower in the TechnoGarden scenario.

The level of investment in agricultural technology is low in the Order from Strength scenario, and as a result crop productivity is also relatively low. At the same time, population growth is larger than the other scenarios, and food demand is proportionately large. Since productivity is low on existing cropland, the increased demand for food has to come at least partly from new croplands. Energy crops must compete with food crops for land, and this makes land and biofuels more expensive. In addition, slower economic growth leads to lower growth in energy demands. These factors result in the slowest growth of biofuel production among all the MA scenarios. Nevertheless, global biofuel production still grows by more than a factor of two to fulfill the needs of the growing population.

The Adapting Mosaic scenario is an intermediate case compared to the others. Economic growth and crop productivity are higher than in Order from Strength but lower than in the others. As a result, energy demand is somewhat higher and competition with food production somewhat lower than in Order from Strength, and biofuel production is also somewhat higher. Globally, biofuel production increases by a factor of 2.8 over today, led by the MENA countries (factor of six), sub-Saharan Africa (factor of four), and Asia (factor of three).

9.4.4.3 Major Uncertainties of Fuel Estimates

Although calculation of the land requirement of energy crops takes into account current productivity of soils, it does not factor in the degradation that will result from these crops. Biofuel crops tend to degrade soils faster than many other crop varieties because they have high productivities and require large amounts of fertilizer and other inputs. Therefore, it is important to keep in mind that because of soil degradation, energy cropping is ecologically damaging over the long term and may thus be less economical.

9.4.5 Freshwater Resources

9.4.5.1 Methodology and Assumptions

The ecosystem services provided by freshwater systems have many dimensions. This section looks especially at water supply for households, industry, and agriculture and

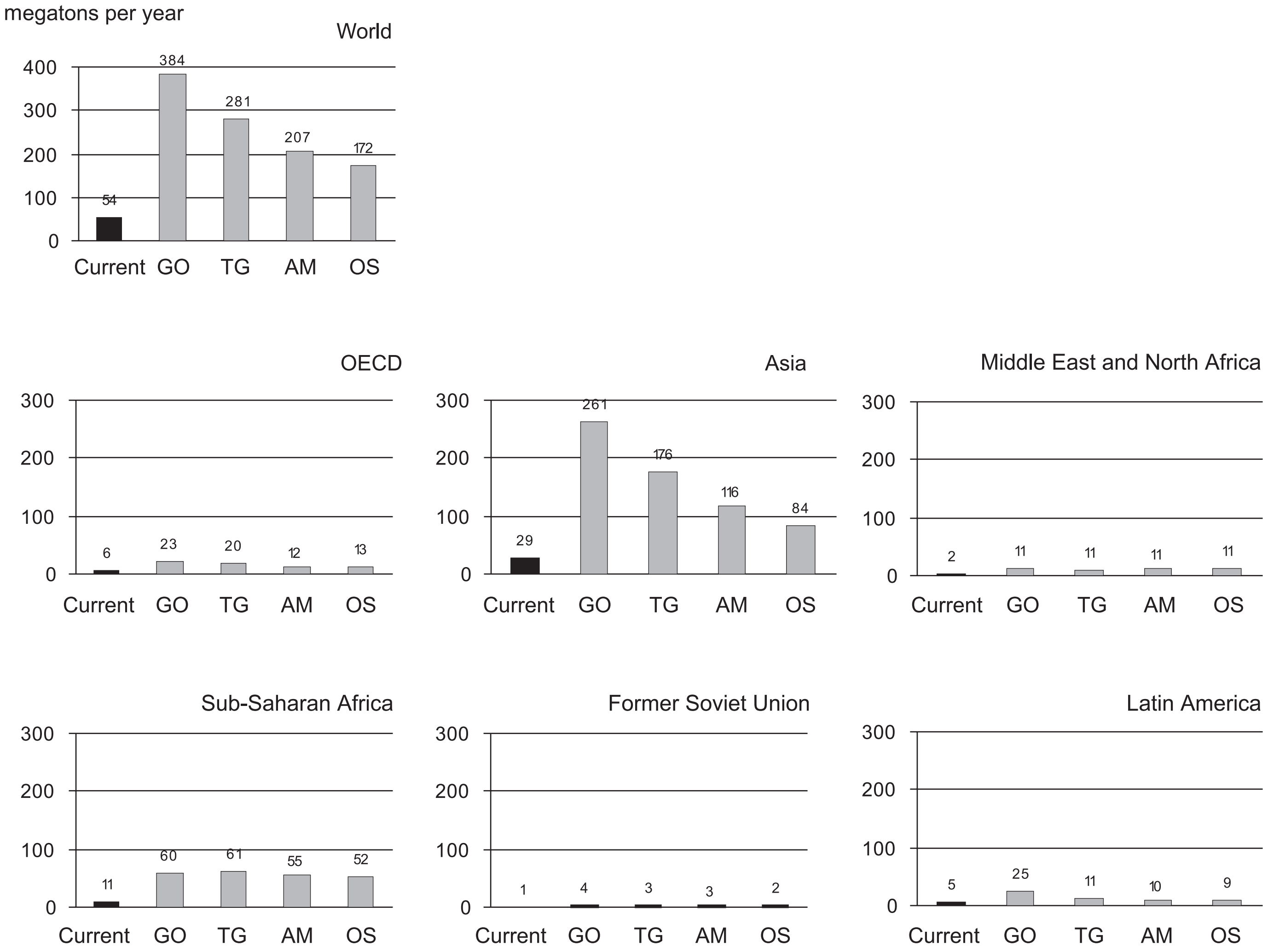

Figure 9.33. Total Biofuel Production by World Region in MA Scenarios in 2050. Scenario names: GO: Global Orchestration; TG: TechnoGarden; AM: Adapting Mosaic; OS: Order from Strength. (AIM)

at habitat for freshwater ecosystems, including fisheries. As indicators of these services, we describe the changing state of water availability, water withdrawals, water stress, and return flows. Each of these topics is useful for describing a different aspect of the ecosystem services delivered by freshwater. The end of the section summarize their consequences for the different MA scenarios.

9.4.5.2 Comparison of Water Availability among Scenarios

"Water availability" is used here to mean the sum of average annual surface runoff and groundwater recharge. This is the total volume of water that is annually renewed by precipitation and theoretically available to support society's water uses and the needs of freshwater ecosystems. As used here, the term does not refer to availability in a technical or economic sense. In reality, society can exploit only a small fraction of this volume because water-rich areas are not necessarily near high population areas, because water is "unusable" as it rushes past cities in the form of floods, or because society cannot afford adequate water storage facilities. One estimate is that only about 30–60% of typical river basin water resources are "modifiable" (Falkenmark and Lindh 1993). On the other hand, water availability may be underestimated in the sense that we do not take into account the possible availability of water from desalination or waste recycling in the future. Despite its drawbacks, we believe that the concept of water availability used here gives a useful estimate of the total quantity of water available to meet the freshwater needs of society and ecosystems.

Since estimates of current water availability vary greatly, two independent estimates (from the WaterGAP and AIM models described in Chapter 6) are presented in Figure 9.34. Current global availability is estimated to be from 42,600–55,300 cubic kilometers per year.

The differences between scenarios are not as large as the differences between regions. By 2050, global water availability increases by 5–7% (depending on the scenario), with Latin America having the smallest increase (around 2%, depending on the scenario), and countries from the former Soviet Union the largest (16–22%). The changes in availability are small up to 2050 because of two compensating effects: increasing precipitation tends to increase runoff while warmer temperatures intensify evaporation and transpiration, which tends to decrease runoff. Hence, the direction of change of runoff does not correspond exactly to the

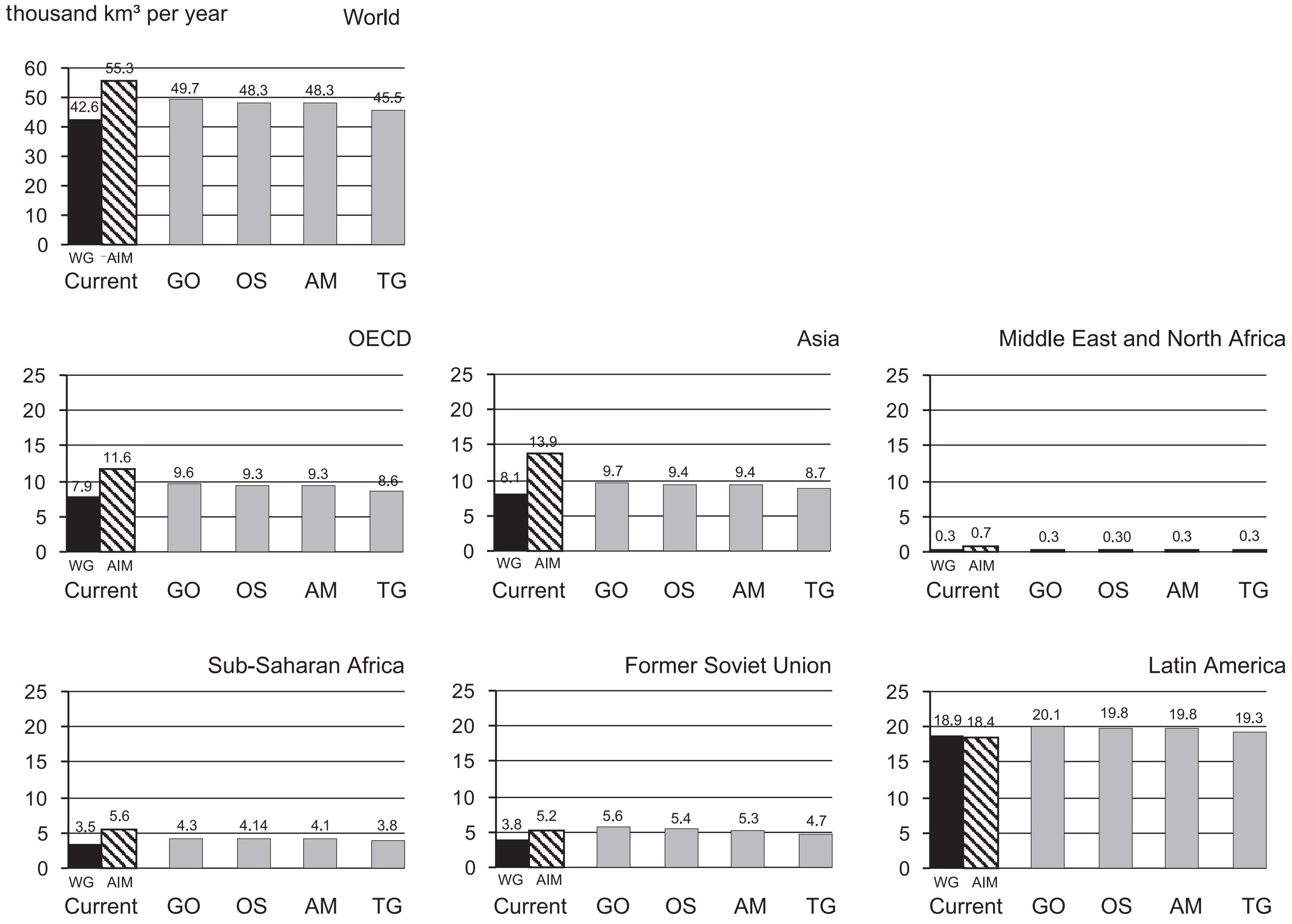

Figure 9.34. Water Availability in MA Scenarios in 2100. Scenario names: GO: Global Orchestration; OS: Order from Strength; AM: Adapting Mosaic; TG: TechnoGarden. (WaterGAP; AIM)

direction of change of precipitation shown earlier in Figure 9.12.

By 2100, the effect of increasing precipitation becomes more important, and runoff increases over most land areas. Still, the differences between scenarios are not as large as the differences between regions. Large areas on each continent have 25% or more runoff by 2100 (relative to the current climate period). Although availability increases in most areas, there are important arid regions where availability drops 50% or more under all scenarios, including Southern Europe, parts of the Middle East, and Southern Africa.

The largest increase in water availability occurs under the Global Orchestration scenario (17%) because it has the fastest rate of climate change through most of the scenario period. The smallest change occurs under TechnoGarden (7%) because it has the lowest rate of climate change. For these scenarios, the water availability in the already-arid MENA countries sinks by 1.5% under Global Orchestration and 3.5% under TechnoGarden scenario. Results for the Order from Strength and Adapting Mosaic scenarios fall between these figures (except for the MENA countries, in which the decrease is 4% in both cases).

While the increase in availability makes more water available for water supply, an increase in runoff can also correspond to more frequent flooding. We estimate that regions with the largest increases in water availability will also have more frequent high runoff events. We did not analyze this effect because no validated model is currently available in the literature for making worldwide calculations of flooding.

9.4.5.3 Comparison of Water Withdrawals and Use among Scenarios

While water availability indicates the amount of water theoretically exploitable, water withdrawals give an estimate of the water abstracted by society to meet its domestic, industrial, and agricultural needs. Hence it is a useful indicator of ecosystem services. (The water requirements for supporting a freshwater fishery are discussed later.) Compared with availability, water withdrawals show large changes over time and between scenarios up to 2050. Worldwide withdrawals in 1995 are estimated to have been about 3,600–3,700 cubic kilometers per year, or approximately 7–8% of estimated water availability, depending on the model used for calculations. While this does not seem like much, the intensity of withdrawals is high relative to water availability in several regions of the world.

Under Global Orchestration, strong economic growth coupled with an increase of population leads to a worldwide increase in withdrawals of around 40%. (See Figure 9.35.) But the changes are only slight in OECD, MENA, and former Soviet countries because of compensating effects—continuing improvements in water efficiency and stabilization or decrease of irrigated land tend to lower water use, while economic and population growth tend to increase water use. Although the efficiency of water use also improves over time in other regions, the effect of increasing population and economic growth leads to fulfillment of pent-up demands in the domestic and industrial sectors and to very large increases between 1995 and 2050 in sub-Saharan Africa, Latin America, and Asia. According to this scenario, many more people gain access to a water supply, as domestic water use substantially increases in nearly all regions. (See Figure 9.36.) The only exception is OECD, where domestic water use declines because nearly the entire population already has access to an adequate water supply and because the efficiency of water use continues to improve.

In TechnoGarden, strong structural changes in the domestic and industrial sectors and improvements in the efficiency of water use in all sectors lead to decreases in water withdrawals in OECD (10%) and the former Soviet Union countries (23%). The same factors lead to a slowdown in the growth of withdrawals in the rest of the world. Nevertheless, water withdrawals grow by a factor of 2.4 in sub-Saharan Africa because of pent-up demand for household water use and growing industrial water requirements.

Although Adapting Mosaic and Order from Strength do not have the largest economic growth, they have the largest water withdrawals because of slower improvement of the efficiency of water use and faster population growth. Withdrawals increase substantially worldwide (52–82%) and moderately in the OECD (7–34%) (under Adapting Mosaic and Order from Strength, respectively). In the former Soviet countries, withdrawals decrease under Adapting Mosaic (9%) and level off under the Order from Strength scenario. Increases in withdrawals are very substantial in sub-Saharan Africa (a factor of 3 under both scenarios), in Latin America (factor of 2.5–3), and Asia (60–100%), while they are more moderate in the arid climate of the MENA countries (28–46%).

9.4.5.4 Comparison of Water Scarcity and Water Stress among Scenarios

The changes in water availability and withdrawals just described have consequences on water stress in freshwater sys-

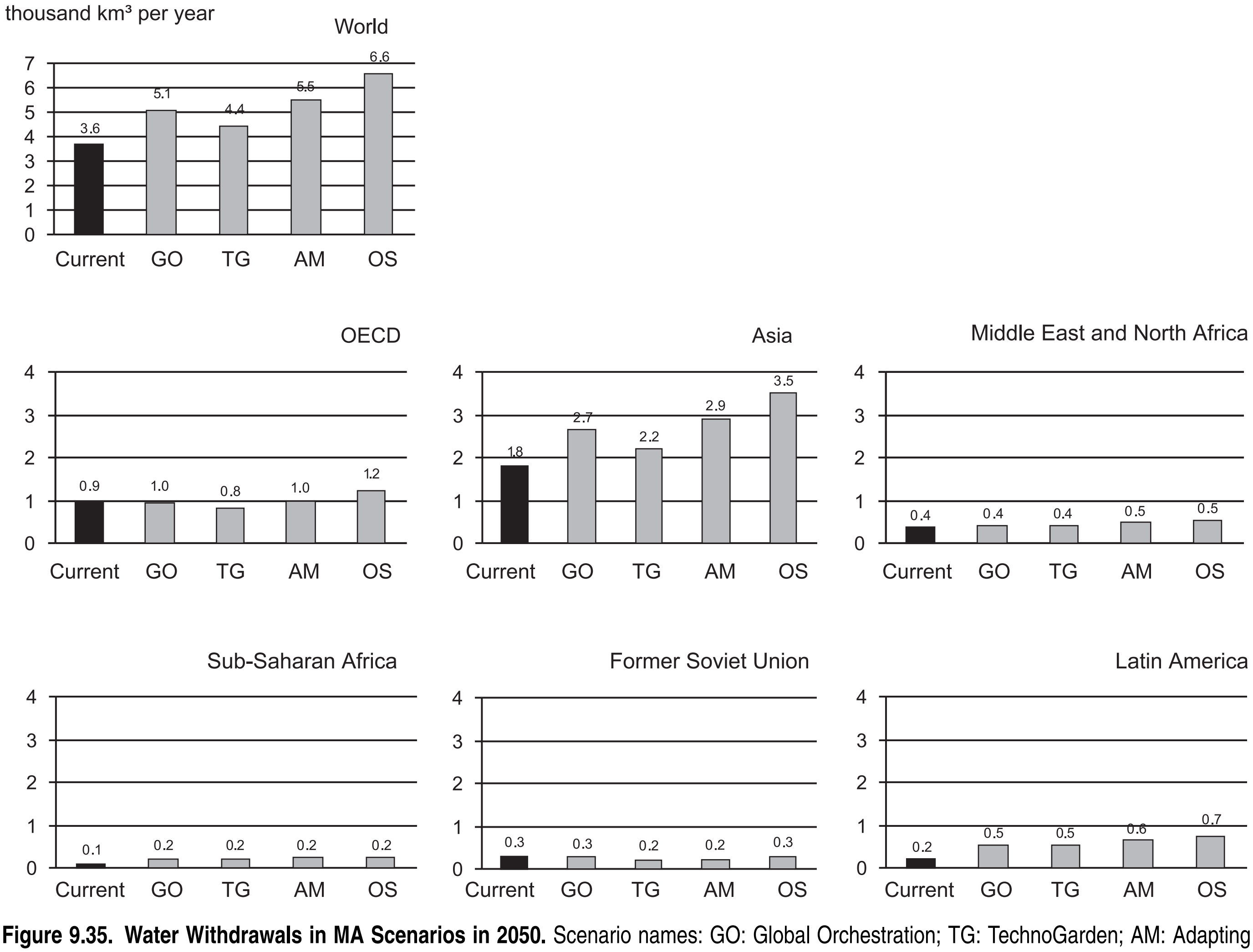

Figure 9.35. Water Withdrawals in MA Scenarios in 2050. Scenario names: GO: Global Orchestration; TG: TechnoGarden; AM: Adapting Mosaic; OS: Order from Strength. (WaterGAP)

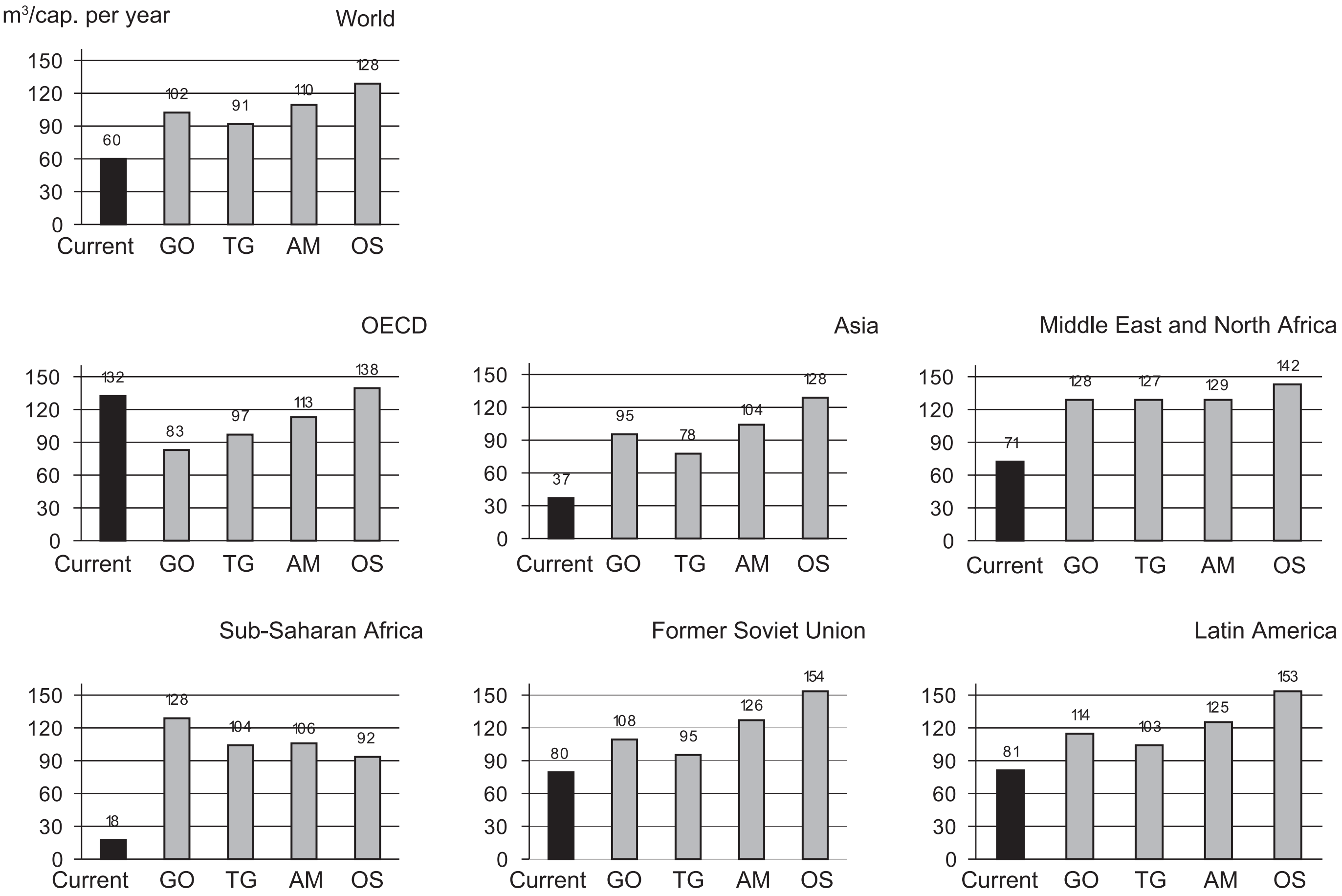

Figure 9.36. Domestic Water Use in MA Scenarios in 2050. Scenario names: GO: Global Orchestration; TG: TechnoGarden; AM: Adapting Mosaic; OS: Order from Strength. (WaterGAP)

tems. The concept of ''water stress'' is used in many water assessments to obtain a first estimate of the extent of society's pressure on water resources (Alcamo et al. 2000 and 2003; Cosgrove and Rijsberman 2000; Vörösmarty et al. 2000). It is assumed that the higher the level of water stress, the greater the limitations to freshwater ecosystems, and the more likely that chronic or acute shortages of water supply will occur. A common indicator of water stress is the withdrawals-to-availability ratio, or wta. This indicator implies that future water stress will tend to decrease in general because of growing water availability, but increase because of increased withdrawals. An often used approximate threshold of ''severe water stress'' is a wta of 0.4 (Alcamo et al. 2000 and 2003; Cosgrove and Rijsberman 2000; Vörösmarty et al. 2000). River basins exceeding this threshold, especially in developing countries, are presumed to have a higher risk of chronic water shortages and thus greater threats to freshwater ecosystems.

Figure 9.37 depicts the area of the world in the ''severe water stress'' category in 1995. Much of northern and southern Africa, as well as central and southern Asia, is included. In total, about 18% of the world's river basin area falls into this category. About 2.3 billion people live in these areas.

The area in the severe water stress category under the Global Orchestration scenario in 2050 is shown in the bottom half of Figure 9.37. Some areas, especially in OECD, fall out of the severe stress category because of stabilizing withdrawals and increasing water availability due to higher precipitation under climate change. The areas of severe water stress expand slightly in the rest of the world. A total of about 4.9 billion people live in these areas. Over most of these areas, increasing withdrawals tend to increase the level of water stress over today's level.

Under TechnoGarden, water withdrawals up to 2050 drop in OECD and the former Soviet Union and grow more slowly in other regions. Water stress follows these trends and declines in many parts of these two regions, while increasing more slowly than the other scenarios in other parts of the world.

Under the Adapting Mosaic and Order from Strength scenarios, water withdrawals increase sharply as just described, and the area under severe water stress in 2050 covers about 17–18% of the total watershed area. Water stress increases over all these areas. About 5.3–5.5 billion people live in river basins with severe water stress—some 60% of the world's population.

9.4.5.5 Comparison of Water Quality and Return Flow among Scenarios

The concept of ''return flows'' is used here to assess changes in water quality. Return flows are the difference between withdrawals and consumption and therefore provide a

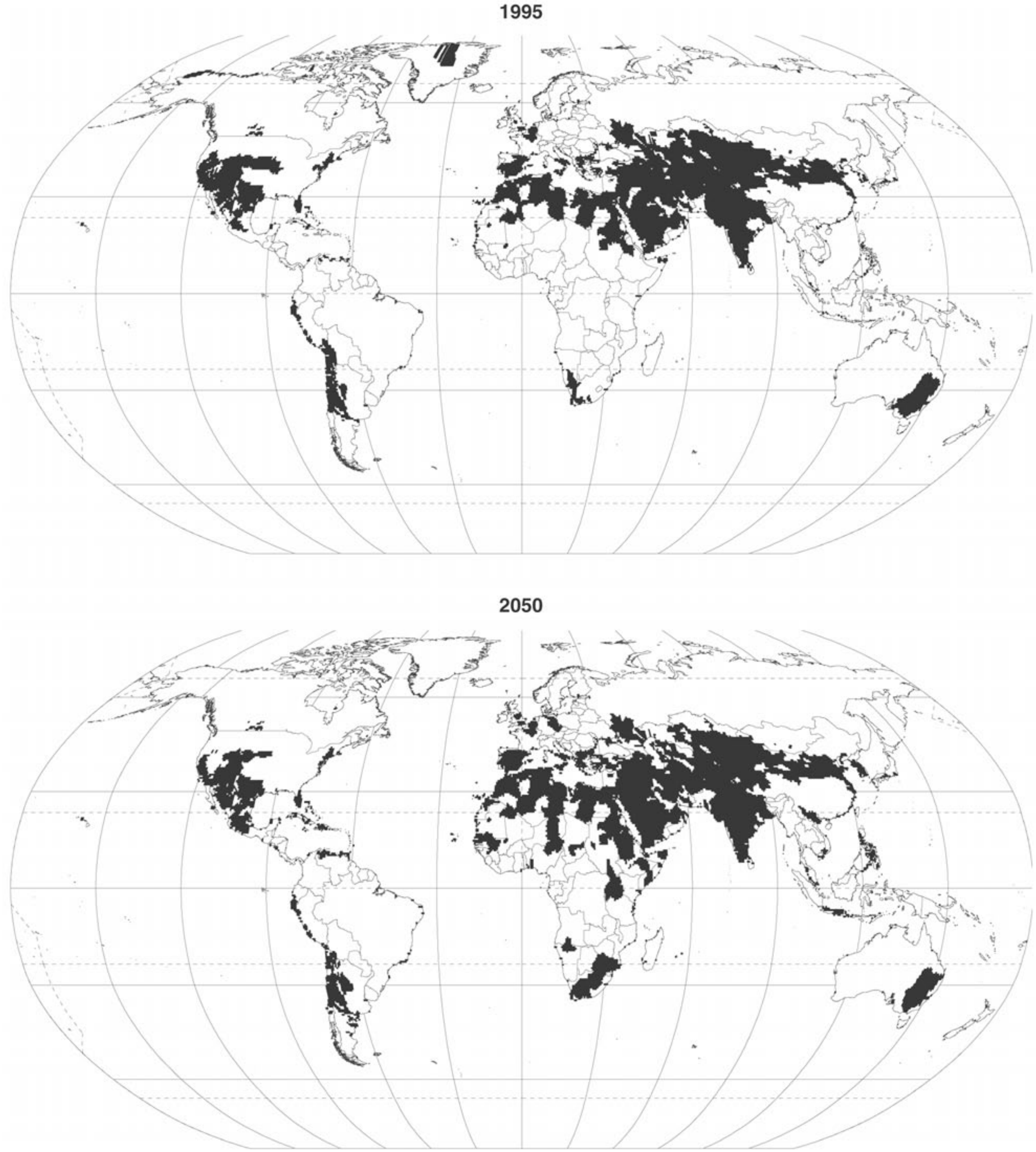

Figure 9.37. Areas under Severe Water Stress in the Global Orchestration Scenario in 1995 and 2050 (WaterGAP)

rough estimate of the magnitude of wastewater discharged into the receiving water in a watershed. Depending on the type of return flows, high rates of these flows could correspond (*with medium certainty*) to low water quality and high levels of water contamination and pressure on freshwater ecosystems. We use return flows as a surrogate variable for water quality because it is not possible at this time to compute worldwide changes in water quality for the different scenarios.

Since irrigation usually consumes more water than domestic or industrial uses, the return flows for irrigation are also usually a smaller fraction of its withdrawals. Another important point is that the type and concentration of water pollutants is quite different from different sources. The wastewater discharged by a power plant after it is used for turbine cooling is hot but relatively clean compared with wastewater discharged by a typical municipality. Untreated municipal wastewater contains pathogens, organic wastes, and toxic materials that typically contaminate a receiving water; only the simplest of aquatic ecosystems can survive and the contaminated water cannot be used for human contact or water supply.

Irrigation return flows are normally not returned to rivers in a single large discharge pipe as a typical municipal or industrial source, but they enter the river in a diffuse way along many kilometers. These return flows are an important source of herbicides and pesticides that are bio-concentrated in aquatic ecosystems and can interfere with or poison various organisms in the ecosystem, as well as of nutrients that promote eutrophication of natural waters. Hence, the impact of irrigation return flows will not be the same as the impact of return flows from a city or industry.

Perhaps the most important factor to take into account in assessing the impact of return flows is whether they will be treated or not. In OECD, the partial treatment of wastewater (removal of organic wastes and pathogens) is very common, and the trend is toward at least partially treating nearly all municipal and industrial wastewater discharges. It is much more uncertain whether agricultural return flows will be collected and treated (because of the high costs of collecting and treating high volumes of diffuse wastewater sources). Wastewater treatment elsewhere, however, is now quite uncommon except in some cities, and it is difficult to anticipate the future coverage of wastewater treatment (except perhaps that there is a trend toward disinfecting wastewater before discharge.)

Under Global Orchestration, by 2050 worldwide return flows increase by 42%. The magnitude of these flows follows that of withdrawals, meaning the larger the volume of withdrawn water, the larger the size of wastewater discharges. Return flows decrease on the average in OECD and the former Soviet countries because of leveling off population and improving efficiency of water use. These factors tend to decrease withdrawals and hence return flows. Furthermore, even though low priority is given to environmental protection, the richer societies in this scenario maintain their current efforts at environmental management. Hence it is reasonable to assume that the level of wastewater treatment in OECD countries will remain at least at its current level.

Because of the rapidly increasing water withdrawals under Global Orchestration, return flows also substantially increase between 2000 and 2050 in sub-Saharan Africa (factor of 3.7), Latin America (factor of 2), and Asia (49%), and more moderately in the MENA countries (24%). Figure 9.38 illustrates the large area where return flows are estimated to at least double under this scenario between now and 2050. Over 78% of the watershed area of sub-Saharan Africa is in this category, as is substantial parts of MENA (37%), Asia (26%), and Latin America (38%). (See Table 9.18.) Consistent with the storylines of this scenario, low priority will be given to environmental management in the world's poorer regions. Therefore, it is likely that wastewater will remain untreated in many areas and that the level of water contamination and degradation of freshwater ecosystems may increase. Since much of this return flow will come from agricultural areas, under this scenario we expect a large increase in nitrogen loading to rivers and subsequently to coastal areas, as described earlier.

We estimate that 4.4 billion people or nearly 55% of the world will live in these areas in 2050. (See Table 9.19.) We emphasize, however, that return flows will cause major problems only if they remain untreated.

Under TechnoGarden, the trends up to 2050 are in the same direction as Global Orchestration, but the stronger emphasis on improving water efficiency and somewhat lower economic growth rates lead to a stronger decrease in return flows between now and 2050 in OECD (18%) and the former Soviet countries (43%). The same factors lead to slower growth of return flows in sub-Saharan Africa (factor of 3.5), MENA (17%), and Asia (nearly 20%). The change in Latin America is the same as in Global Orchestration (increase by a factor of two). Similarly, large areas will have increases of 100% or more return flows, and a total of 3.9 billion people will live in these areas. Since the emphasis in this scenario is on environmental management, and since return flows do not increase too much in MENA or Asia, it may be that most of the wastewater flows in these regions will be treated. It is less likely that the enormously increasing return flows of sub-Saharan Africa and Latin America will be fully treated.

In Adapting Mosaic, return flows decrease in the former Soviet Union between now and 2050 because withdrawals decrease. In all other regions, return flows increase much more than in Global Orchestration or TechnoGarden because of the lower level of water use efficiency and the larger population, which leads to higher withdrawals and more return flows. Return flows increase very substantially in sub-Saharan Africa (factor of 5.5), Latin America (factor of 2.6), Asia (76%), and the MENA countries (56%) and increase slightly in OECD (4%). The area of watersheds with at least a 100% increase in return flows between now and 2050 is considerably larger than in Global Orchestration or TechnoGarden, and 6.4 billion people—67% of the world's population in 2050—live in these areas. Since Adapting Mosaic puts a strong emphasis on local environmental protection, and since wastewater treatment technology is simple and can be applied easily on the local level, we expect (*with medium certainty*) a high level of wastewater treatment.

As noted, Order from Strength has the largest withdrawals because of its slower improvement of the efficiency of water use and faster population growth. Accordingly, it also has the largest return flows, with a doubling of worldwide total flows between now and 2050. The smallest increase is in former Soviet countries (9%), followed by OECD, with a nearly 40% increase. All other regions experience much larger increases—Asia and MENA countries (approximately a doubling), Latin America (more than a factor of 3), and sub-Saharan Africa (a factor of 4.7). The area with a doubling of return flows is somewhat larger than in Adapting Mosaic, and 6.7 billion people live in these areas (70% of global population). The level of environmental concern here is much lower than in Adapting Mosaic, and therefore the expected level of wastewater treatment is also much lower. The combination of exploding wastewater discharges and negligence of the environment could lead to large risks to freshwater ecosystems and water contamination. An additional dimension of this scenario is that return flows continue to increase rapidly after 2050. For example,

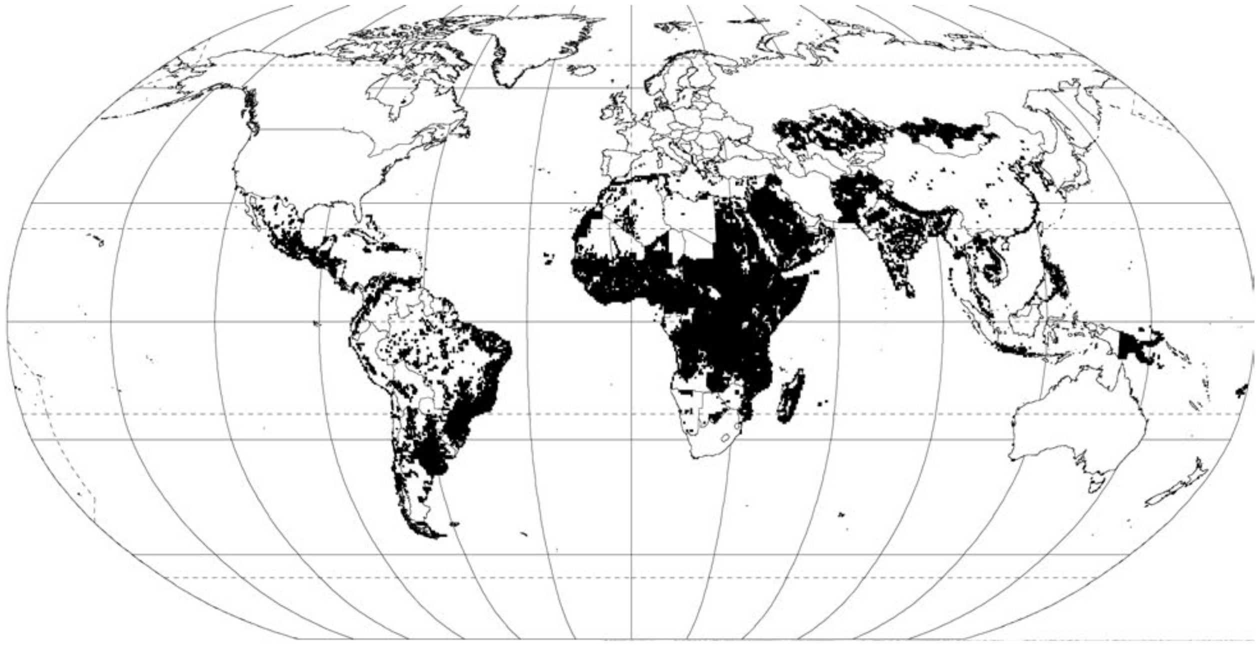

Figure 9.38. **Areas Where Return Flows Increase at Least 100% in the Global Orchestration Scenario, Present–2050** (WaterGAP)

Table 9.18. Total Area of River Basins, by Region, Where Return Flows Increase at Least 100% between Now and 2050 in MA Scenarios (WaterGAP)

Region	Global Orchestration	Order from Strength	Adapting Mosaic	TechnoGarden
	(thousand square kimometers)			
Former Soviet Union	4,810	6,103	7,009	5,092
Latin America	7,798	18,441	17,286	10,814
Middle East and North Africa	4,306	9,148	8,798	4,856
OECD	7,271	8,837	13,699	7,230
Asia	5,375	10,220	7,244	4,587
Sub-Saharan Africa	18,724	22,299	22,215	17,661
World	**48,284**	**75,047**	**76,251**	**50,239**

Table 9.19. Total Number of People, by Region, Living in Areas Where Return Flows Increase at Least 100% between Now and 2050 in MA Scenarios (WaterGAP)

Region	Global Orchestration	Order from Strength	Adapting Mosaic	TechnoGarden
	(million)			
Former Soviet Union	1.5	32.8	70.4	5.8
Latin America	719.1	926.1	908.2	701.9
Middle East and North Africa	327.8	633.9	684.2	333.2
OECD	13.9	31.5	66.3	12.4
Asia	2,156.2	3,582.0	3,238.3	1,689.5
Sub-Saharan Africa	1,222.5	1,518.8	1,445.7	1,196.6
World	**4,440.9**	**6,725.0**	**6,413.1**	**3,939.4**

return flows increase in sub-Saharan Africa by a factor of 4.6 between 1995 and 2050, and double again between 2050 and 2100.

9.4.5.6 Uncertainty of Freshwater Estimates

The concept of "water availability" used in this section does not refer to the freshwater resource available to water users in an economic or technical sense, but only to the total theoretical volume of water annually available in each watershed due to precipitation. It is currently not possible to estimate water availability more precisely on a global basis.

Return flows are used as an indicator of water quality, but it would be more desirable to have a direct indicator of future water quality so there is a more certain connection with the state of freshwater ecosystems and risk of water contamination. This is not yet possible globally.

An important source of uncertainty in estimating return flows is the uncertainty of the ratio of consumption to withdrawals in different water use sectors. In addition, the tools used to estimate the indicators of ecosystem services of fresh water are too aggregated to include the role of local water policies and management.

9.4.5.7 Summary: Freshwater Services

In the Global Orchestration scenario, water availability increases in most countries because of climate change, but it decreases in some important arid regions, especially in poorer countries. Water withdrawals and domestic water use level off in wealthy countries but increase substantially in poorer ones that are providing access to adequate water supply for many needy people. Water stress and the volume of return flows go down in the rich countries because of climate change and stabilization of water withdrawals. Water-related problems (eutrophication, for instance, and competition between human and environmental water requirements) continue in these nations but do not intensify greatly.

Water stress goes up in poorer countries under Global Orchestration because of a massive increase in withdrawals and return flows. Wastewater discharges are left mostly untreated because the priority is given to expanding economic and industrial capacity without incurring extra costs for environmental protection. This leads to an intensification and expansion of water resource problems in poorer countries, including more frequent water shortages during low flow periods, as well as deterioration of aquatic ecosystems. The increased wealth in poorer countries allows society to deal with some of these problems on a case-by-case basis, and luckily there are no major ecological collapses, such as water-related disease outbreaks, or hunger shortages because of the disappearance of freshwater fisheries.

Under the TechnoGarden scenario, the water availability situation is similar to Global Orchestration except the changes are not as great because the rate of climate change is not as great. Water withdrawals and domestic water use decrease in wealthy countries and slowly grow in poorer ones except in Africa, where they increase very rapidly. Although per capita domestic water use does not increase as rapidly as in Global Orchestration, a greater emphasis is put in TechnoGarden on providing minimum adequate water supply to those needing it.

Water stress goes down in wealthy countries in TechnoGarden because precipitation increases and withdrawals decrease. Return flows decrease there too and therefore society can afford advanced treatment of municipal and industrial wastes, as well as the collection and control of agricultural runoff. These actions greatly reduce the load of nutrients and toxic substances to freshwater systems. Furthermore, wealthy countries intervene to physically restore natural habitat in freshwater systems. As a result, there is a significant restoration of aquatic ecosystems. At the same time, the overconfidence of society that it can engineer solutions to water resource problems leads it to overlook continuing problems. For example, heavy storm runoff overloads wastewater treatment plants, and contaminated sediments of riverbeds continue to leach toxic materials accumulated during the twentieth century.

The increase in withdrawals and return flows is slower than in Global Orchestration but still very fast, especially in Africa and Latin America. Society puts a heavy emphasis on bringing wastewater treatment up to current OECD standards (secondary treatment of municipal wastes, control of toxic discharges from industry). But agricultural sources are not controlled, and a resulting rapid increase in nutrient and pesticide discharges causes eutrophication, toxicity, and other water quality problems. Furthermore, Africa and Latin America cannot keep up with the increase in return flows and are not able to achieve OECD standards.

In Adapting Mosaic, changes in climate change and hence water availability are similar to Global Orchestration and TechnoGarden scenarios, but intermediate in intensity. Water withdrawals and domestic water use stabilize in wealthy countries and are moderate to large in poorer nations. While per capita domestic water use is lower than in Global Orchestration and TechnoGarden, more local effort is invested in providing people with a minimum amount of household water supply. Water stress goes down in rich nations because of increased precipitation and stabilization of withdrawals, and the amount of return flows stabilizes. Local authorities and communities in these countries do not have to deal with increasing wastewater loadings and therefore have time to find local solutions to the competition for water resources between water use sectors and human and ecosystem requirements.

The level of water stress and volume of return flows explodes in poorer countries under Adapting Mosaic, but in many cases local solutions are found for allocating water supply to different sectors (integrated watershed management) and for preserving the viability of many aquatic ecosystems. But it is difficult to find local solutions fast enough in Latin America and Africa, where return flows increase by a factor of 3.6 and 5.5, respectively. Hence water problems in these regions increase over the first half of the twenty-first century. One advantage of the local or watershed approach to water management everywhere is that it is usually well tailored to local ecosystems, and thus failures in water management can be easily corrected. Hence, under this scenario there is slow but steady progress in protecting or restoring aquatic ecosystems and providing freshwater ecosystem services.

The water availability situation under Order from Strength is similar to that of Adapting Mosaic. Water withdrawals and domestic water use moderately increase or level off in wealthy countries and are moderate to large in poorer ones. There is much lower access to adequate water supply than in the other scenarios, and it is likely that the Millennium Development Goal for access to adequate water supply would not be met under Order from Strength. The level of water stress stabilizes in wealthy countries but increases substantially in poorer ones. The volume of return flows also has a massive increase in the first half of the twenty-first century (in Latin America a factor of 4, and in

Africa a factor of 5.6). Three quarters of the world lives where return flows double in the first half of century. Environmental management is not given a priority, and the technology and capacity for ecological management are not built up. Ignorance of the implications of the large increase in water stress and return flows in poorer countries leads to severe regional water quality crises, with widespread destruction of aquatic ecosystems, the contamination of water supply, and widespread water shortages. Poorer countries fall behind in development.

9.4.6 Other Provisioning Ecosystem Services

9.4.6.1 Methodology and Assumptions

Although the future states of genetic resources, biochemicals, and ornamental resources were not directly evaluated by model calculations, we examine here the trends of some related indicators. These include the extent of natural versus agricultural land, since these resources usually require undisturbed habitat; the rate of change of this habitat as indicated by the rate of deforestation and the rate of climate change, since the faster the change, the more doubtful that plants and animals can adapt to these changes; and the level of water stress in freshwater resources, which indicates the pressure on aquatic and riparian species. Moreover, the storylines in Chapter 8 also indicate certain trends in human behavior and policies that will affect these services. By examining the trends of these variables we make some preliminary judgments about the future trends of genetic resources, biochemicals, and ornamental resources. (Note that these are only a few of the many important factors that will influence the state of genetic resources, biochemicals, and ornamental resources in the future; for example, these do not include an indicator for the marine environment.)

9.4.6.2 Comparison of Genetic Resources among Scenarios

UUnder the Global Orchestration scenario, pressures grow on remaining undisturbed terrestrial and aquatic ecosystems. Throughout the twenty-first century, existing forests disappear at rates comparable to the last few decades. The decadal rate of temperature change is much higher than at present, and ranks as the highest among the four MA scenarios throughout most of the period. As a result of changing temperature (and precipitation), the type and viability of current vegetation also changes over extensive areas, especially in wealthy countries. To meet growing food demand due to higher incomes and population, the level of agricultural production on existing cultivated land is intensified in poorer countries by increasing the application of fertilizer and other inputs, and these chemicals also contaminate nearby protected natural areas. In freshwater ecosystems, the level of water stress increases over wide areas, especially in poorer countries, because of rapidly increasing withdrawals. In addition to these pressures, society is also not particularly mindful of the connection between its activities and the state of ecosystem services. In sum, it is possible that genetic resources may severely decline under this scenario.

Under the TechnoGarden scenario, global climate protection policies lead to lower rates of temperature change (compared with the first decades of the twenty-first century), but vegetation areas still change extensively, especially in richer countries. Stabilizing water demands and efficiency improvements lead to decreases in water withdrawals and reduced stress on freshwater ecosystems. In wealthy countries, the drive for efficiency narrows the range of genetic resources used by people. This offsets the effects of reduced water stress, conservation, and genetic technology, leading to little net change in genetic resources.

Under TechnoGarden, the rate of deforestation in poorer countries is high, but it eventually drops below current rates. Efficient water use leads to lower growth in water withdrawals and slower increases in stress on freshwater ecosystems. However, high levels of fertilizer and pesticides are used on agricultural land to boost crop yields, which leads to contamination of natural areas. Counter to these trends, genetic diversity is enhanced in poorer countries by intensified efforts to preserve landraces. Under this scenario, we also expect that ecological engineering of plants and animals will have an influence on overall genetic resources. But at this time we cannot estimate what this influence will be. Finally, we also expect (*with low certainty*) only a small change in genetic diversity in poorer countries.

Under the Order from Strength scenario, the rate of forest disappearance in poorer countries is even greater than under Global Orchestration (because of more inefficient agricultural production). Also, growing population and inefficient water use in these countries leads to rapid growth in water withdrawals and stress on freshwater ecosystems. A side effect of the lower level of wealth in this scenario is that farmers in poorer countries cannot afford to apply as many pesticides and fertilizer to cropland, meaning that the loading of these chemicals onto nearby natural areas is somewhat lower than under Global Orchestration. On the other hand, climate change is not as great overall; therefore, while climate-related changes in vegetation still occur in wealthy countries, they are not as extensive as in Global Orchestration. Society in this scenario also gives low priority to environmental protection. Summing up the different factors, we expect (*with low certainty*) that genetic resources could decline at around the same rate as in the Global Orchestration scenario.

In Adapting Mosaic, the rate of climate change is not as high as in Global Orchestration, nor as low as in TechnoGarden. Therefore, the extent of area with changed vegetation in wealthy countries due to climate change is also between these two scenarios. The rate of forest disappearance in poorer countries under Adapting Mosaic drops below current rates but is still high. Water withdrawals significantly increase in these countries, but not as much as under Order from Strength because water is used more efficiently. Under this scenario, society is mindful of the connection between its activities and ecosystem services. Therefore, the use of fertilizer and other inputs on agricultural land is somewhat lower than in Order from Strength. Moreover, genetic diversity used by people is increased by the greater spatial heterogeneity of ecosystem management in all countries. Considering the different factors, we expect (*with low certainty*) that genetic diversity could either remain about the same or slightly increase under this scenario.

9.4.6.3 Comparison of Biochemical Discoveries and Ornamental Resources among Scenarios

The trends just described for Global Orchestration—high deforestation rates, steadily increasing temperature and climate-related changes in vegetation, intensification of agricultural land, increasing water withdrawals and water stress—tend to threaten ecosystems in poorer countries and eventually to decrease biodiversity. This is somewhat compensated for by increasing investments in biochemical exploration, so that the net rate of biochemical discoveries is roughly constant in poorer countries up to 2050. At the same time, the sum of ornamental resources declines (*with low certainty*) along with biodiversity.

While these trends pertain especially to poorer countries, pressures on biodiversity also increase elsewhere because of intensification of agriculture and a failure to devise policies to deal with current threats to biodiversity. We expect (*with low certainty*) that the decline in biodiversity will be accompanied by a decline in biochemical discoveries and ornamental resources.

As noted, the pressures on ecosystems under TechnoGarden—climate change, rate of increase of water withdrawals, deforestation—will be somewhat lower than under the other scenarios. Moreover, biochemical innovation is also a high priority for society. Hence, we expect (*with low certainty*) that biochemical discoveries will increase in all countries up to 2050. At the same time, the TechnoGarden scenario emphasizes the utilitarian uses of ecosystems. Therefore, we estimate (*with low certainty*) that ornamental resources receive no special attention and remain about the same as today.

Pressures on ecosystems, as noted above, are relatively high in Order from Strength in all countries, with a resulting decrease in biodiversity. In addition, conflict and a poor security situation will hamper biochemical exploration in some parts of the world. In sum, we expect (*with low certainty*) that biochemical discoveries and the availability of ornamental resources will decline up to 2050 under the Order from Strength scenario.

In Adapting Mosaic, there are lower pressures on ecosystems as compared with Global Orchestration and TechnoGarden, and biodiversity is conserved. Because of the scenario's focus on local and regional development, however, there is relatively low impetus for the international development and trade in biochemicals. Hence we estimate (*with low certainty*) that both the level of biodiversity and the rate of biochemical discovery are maintained at roughly today's levels. Since this scenario emphasizes the local individuality of ecosystem management, we estimate (*with low certainty*) that the availability of ornamental resources will increase.

9.5 Regulating Ecosystem Services

Regulating ecosystem services are defined as the benefits obtained from regulation of environmental conditions through ecosystem processes. The conceptual framework of the MA lists the following clusters of regulating services:

- air quality maintenance (through contribution to or extraction of chemicals from the atmosphere, as a result of ecosystem function);
- climate regulation (through the influence of ecosystems on the energy, water, and carbon balance of the atmosphere);
- water regulation, erosion control, and water purification (through the effect of ecosystems on runoff, flooding, aquifer recharge, and water quality);
- human disease control (through the effect of ecosystems on human pathogens, such as disease vectors);
- biological pest and disease control (through the influence of ecosystems on the abundance of animal and plant pathogens);
- pollination (through influences of ecosystems on the abundance and distribution of pollinators); and
- coastal protection (through the protecting effect of ecosystems such as coral reefs and mangroves on coastal structures).

On the basis of the analyses in the MA *Current State and Trends* volume, this section describes the impact of MA scenarios on some of these services. The presentation focuses on services where differentiation between scenarios can be achieved, based on either calculations with numerical models or on an assessment of recent scientific literature or both. The impacts of ecosystems on human disease control are treated in Chapter 11. Additional information on changes in regulating services can be found in Chapter 8.

Overall, the vulnerability of most regulating services contrasts clearly across the scenarios. In Global Orchestration, a predominantly reactive approach to ecosystem management rarely addresses regulating ecosystem services. The net result is greater vulnerability of regulating ecosystem services, especially in poorer countries. The exceptions are a few cases in which the connection between ecosystem services and human welfare is direct and clearly understood. In Order from Strength, the vulnerability of regulating ecosystem services generally increases as the availability of regulating ecosystem services declines. The wealth of richer countries sometimes allows adaptations that conserve regulating ecosystem services, but in poorer countries the regulating ecosystem services become much more vulnerable due to the effects of population growth, conflict, slow economic growth, and expanding poverty.

In Adapting Mosaic, society emphasizes local or regional ecosystem management. Maintenance or expansion of regulating ecosystem services will often be the goal of this ecosystem management, leading to declines in the vulnerability of these services. However, the primary focus is local or regional ecosystem issues. Global regulating services, such as those related to climate or marine fisheries, could become more vulnerable during Adapting Mosaic. In TechnoGarden, society emphasizes engineering of ecosystems to provide regulating ecosystem services. While this approach is successful for some ecosystem services in some places, in other cases oversimplification of ecosystems increases the system's vulnerability to change and disturbance. Impacts of unforeseen disturbance create the need for new technological innovations. In some cases, this leads to a spiral of increasing vulnerability.

9.5.1 Climate Regulation/Carbon Storage

9.5.1.1 Methodology and Assumptions

The biosphere, and the ecosystems it consists of, plays a key role in the climate system, for example, by respiring and taking up CO_2, by emitting other trace gases such as CH_4, and by reflecting and absorbing solar energy. On the global scale, the biosphere currently helps "regulate" climate by capturing carbon due to increased growth, thereby reducing the concentration of CO_2 in the atmosphere and slowing down climate change (Schimel et al. 2001).

For the theoretical case of a biosphere/atmosphere equilibrium, the biosphere takes up as much CO_2 for plant growth as it emits by plant and soil respiration. But under most circumstances, one or the other of these fluxes dominates, with frequent oscillations due to temporal and spatial environmental variability. Overall, the land biosphere currently takes up 2.3 gigatons per year (± 1.3 gigatons) more carbon than it emits (Bolin et al. 2000). Contributing factors to this important global service are increasing forest area in some regions and the stimulation of plant productivity through increasing temperature or atmospheric CO_2. The result is that warming, and other climate change, occurs at a slower rate than would be expected in the absence of the carbon sink.

9.5.1.2 Comparison of Climate Regulation among Scenarios

As described earlier, climate policy is not assumed to be a priority under Global Orchestration. Nevertheless, being a relatively low-cost measure, climate regulation by ecosystems could be a focus of global policy during Global Orchestration, being implemented through the protection of old-growth forests for their soil carbon stocks and through other measures that avoid unnecessary release of carbon from the biosphere. Consequently, the role of ecosystems in climate regulation becomes more important in all countries. It is, however, not clear how much the carbon sequestration capacity of ecosystems could increase in wealthy nations during Global Orchestration, nor how long this effect might last.

During Order from Strength, the capacity to regulate climate is expected to decline in both rich and poorer countries due to lack of international coordination. Global issues are not a primary focus of ecosystem management in Adapting Mosaic. However, climate regulation would be a secondary consequence of improving ecosystem management in many regions. On balance, we expect little change in climate regulation by ecosystems during Adapting Mosaic. During TechnoGarden, great strides are made in all countries in engineering ecosystems to regulate climate. It is unclear, however, whether biospheric carbon storage can be much enhanced beyond what is already achieved by protective measures in Global Orchestration.

It is outside the scope of this analysis to assess the effect of vegetation on local climate, but we use model simulations to estimate here the effectiveness of the land biosphere in taking up CO_2 from the atmosphere. Net primary productivity of the land biosphere has been used as an indicator for a change in this service—however, since NPP is mostly balanced by soil respiration processes and the results of natural disturbance (fire, windstorms, and so on), it does not in itself allow for the direct estimation of climate regulation. At the local scale, for example, high NPP occurring after a clear-cut during regrowth of quickly growing trees and their understory can be more than balanced by the respiration flux from decaying organic material in the soil, thereby turning the ecosystem into a carbon source for some time (WBGU 1998). At the broader scale, however, NPP changes, such as those estimated by the IMAGE model, may give at least a hint at the changing regulating capacity of the land biosphere, because there is, at any point in time, only a small percentage of the land in early successional stages.

NPP was estimated in 2000 by IMAGE to be about 61.4 gigatons of carbon per year (within the typical range of other estimates; cf. Cramer et al. 1999). Based on IMAGE calculations, NPP increases across all scenarios and regions because of increasing temperature and atmospheric CO_2. Global estimates for 2050 range from 70.4–74.6 gigatons. Global Orchestration has the largest increase because it has the fastest pace of increasing temperature and atmospheric CO_2. Conversely, the TechnoGarden scenario has the smallest carbon uptake because it has the lowest temperature and CO_2 levels. The largest uptakes of CO_2 occur in regions with extensive forests, such as Russia and Canada.

On one hand, these estimates give a realistic representation of the future climate regulation function of the biosphere because they take into account the effect of deforestation in reducing the area of the biosphere, as well as shifts in vegetation zones caused by climate change. On the other hand, they may be overly optimistic because they do not factor in possible changes in soil processes that may lead to a net release rather than uptake of CO_2 by the biosphere (cf. the conflicting findings of Cox et al. 2000 and Friedlingstein et al. 2001). Moreover, the processes by which higher CO_2 stimulates greater carbon uptake by plants are not yet sufficiently understood and may be incorrectly represented in current models. Finally, the estimates of CO_2 uptake presented here do not take into account the future establishment of large-scale forest plantations for storing CO_2 from the atmosphere.

In conclusion, therefore, no scenario can count on a great effectiveness of the land biosphere as a climate-regulating factor independent of management. If an additional mitigation effect is achieved, then this will be due to favorable circumstances and probably not last much longer than for the twenty-first century (Cramer et al. 2001).

9.5.2 Risk of Soil Degradation

9.5.2.1 Methodology and Assumptions

The world's land resources play an important role in the production of food. The capacity of soils to perform this function can be seriously impaired by soil degradation (such as wind or water erosion), chemical degradation (such as salinization), and physical deterioration (such as soil compaction). Water erosion, as one of the degradation processes occurring most extensively at global level, has been singled out for this study. It is influenced by natural conditions, but also in the way that soil is used. Important factors that influence the rate of soil erosion (in the future) include agricultural practices, land use change (in particular loss of vegetative cover), and changes in precipitation as a result of climate change.

9.5.2.2 Comparison of Erosion Risk among Scenarios

Historical trends in cropland degradation rates have been reported in UNEP's Global Assessment of Soil Degradation study (Oldeman et al. 1991; GRID/UNEP 1991) and in other studies (e.g., Kendall and Pimentel 1994). At present, the global hot spots of soil erosion by water are China, the Himalayan Tibetan ecosystem, the Andean region, the Caribbean (Haiti), the highlands of East Africa and Central America, southeastern Nigeria, and the Maghreb region. Similarly, the global hot spots of wind erosion are West and Central Asia, North Africa, China, sub-Saharan Africa, Australia, and the southwestern United States. Asia and Africa are the worse off regions in terms of land areas affected by at least moderate erosion. Anthropogenic causes responsible for erosion in these regions are deforestation, overexploitation of natural vegetation, overgrazing, and extension of agricultural activities to marginal land (such as steep land).

Changes in the risk of water-induced erosion from land use and climate change can be assessed with a methodology used for UNEP's Global Environmental Outlook (Hootsman et al. 2001; Potting and Bakkes 2004).[8] Here, water erosion risks are calculated by combining three indices: terrain erodibility, rainfall erosivity, and land cover:

- The terrain erodibility index is based on soil (bulk density, texture, soil depth) and terrain properties (slope angle), both of which are assumed to be constant in time.
- The rainfall erosivity index is determined by changes in monthly precipitation.
- The land cover pressure expresses the type of land cover. It is large for most agricultural crops, and small for natural land cover types such as forests.

The resulting index is a measure of the potential risk of water erosion, but it does not capture management practices. Such practices can make an enormous difference in actual erosion. Susceptibility to erosion is exacerbated by soil tillage and other mechanical disturbance. However, mechanical conservation measures (such as contour plowing, deviation ditches, and terracing and agronomic soil conservation practices) will prevent much water erosion in the real world.

Current climate models expect global precipitation to increase as a result of climate change (as described in the section on climate change). As a result, rainfall erosivity will also increase. Precipitation increase is likely to be strongest under the Global Orchestration scenario (see Table 9.20), but as noted before, in the comparatively short period until 2050 differences among the scenarios are still relatively small. The risk of water erosion is largest in agricultural areas, independent of the soil and climatic conditions. In the section on land use change, it was found that the largest increase in agricultural land will occur for the Order from Strength scenario. In the other scenarios, however, agricultural land also increases, particularly in poorer countries.

Table 9.20. Overview of Trends for Water-induced Erosion in MA Scenarios (IMAGE 2.2)

Variable	Global Orchestration	Order from Strength	Adapting Mosaic	Techno-Garden
Precipitation increase	+ +	+	+	+
Land use change	+	+ +	+	+
Agricultural practices	O	O/+	−	−

Key: + = Increased pressure on erosion control; O = neutral impact; − = decreasing pressure on erosion control.

Combining trends in climate and land use change and the erosibility index allows a calculation of the water erosion risk index. Compared with the present situation, the soil area with a high water erosion risk more than doubles by 2050 in all scenarios. (See Figure 9.39.) Differences among the scenarios up to 2050 are relatively small, with risks under TechnoGarden and Global Orchestration being somewhat less than under the other scenarios. Increases in risk areas occur in nearly all regions, with the exception of parts of the OECD region (Central Europe, Australia, and New Zealand)). Here, the area with a high erosion risk decreases, mainly as a result of gradually decreasing grazing areas. Areas with the most apparent increases in risk include North America (OECD region), Latin America, sub-Saharan Africa, and parts of Asia. (See Figure 9.40.) Increases are largest under Order from Strength, mainly due to higher larger food demand (due to larger population growth) combined with slower technological improvements. These two trends lead to the most rapid expansion of agricultural land.

In terms of potential agricultural practices that could mitigate the changes in the risk factors just calculated, we expect under Global Orchestration mainly a continuation of today's practices. Reforming socioeconomic policies in poorer countries could, however, lead to a much higher awareness of soil degradation. In Order from Strength, degradation rates in non-OECD regions for land owned by the poor could be more rapid, as they work low-quality land with insufficient resources, while the most productive agricultural land is managed by the elite. Here, changes in agricultural practices are not likely to reduce erosion risks. In Adapting Mosaic, local objectives on prevention of soil erosion could somewhat reduce erosion rates, slowing degradation on active agricultural land and significantly restoring currently degraded land. Under TechnoGarden, finally, the relatively low population levels and more ecologically proactive agricultural practices could in fact lead to a decline in net cropland degradation rates over the course of the scenario.

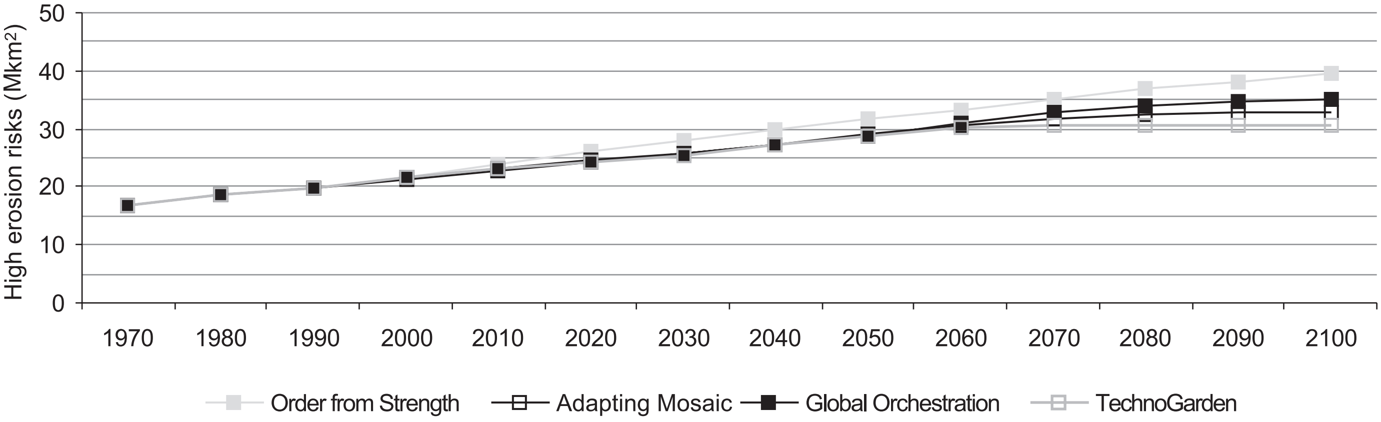

Figure 9.39. Global Area of Soils with High Water Erosion Risk in MA Scenarios (IMAGE 2.2)

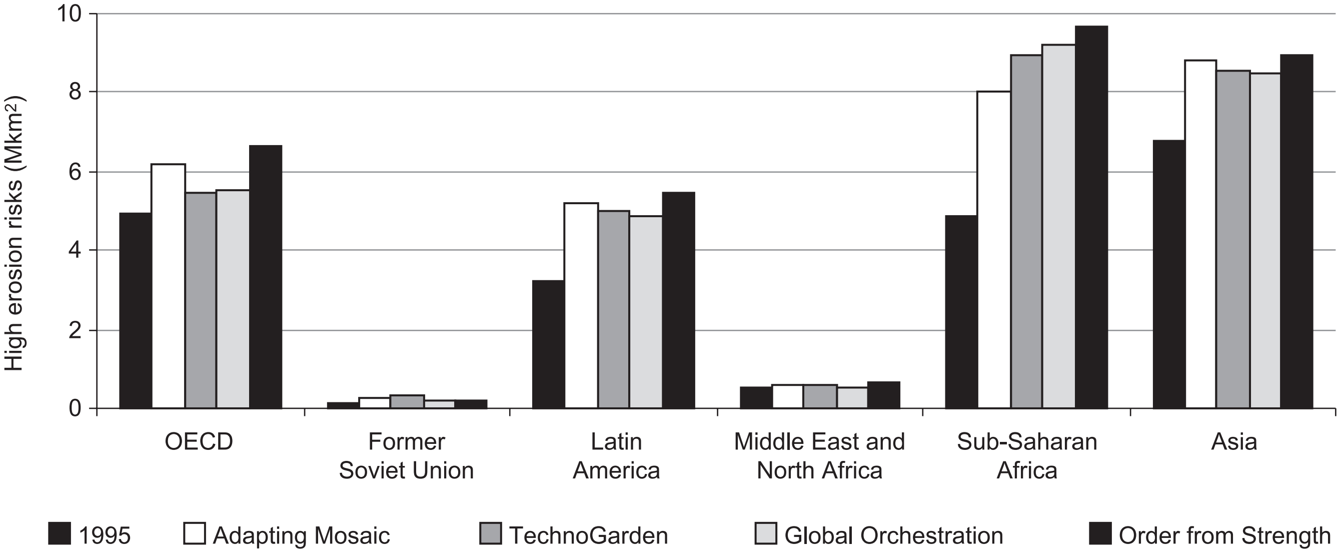

Figure 9.40. Global Area of Soils with High Water Erosion Risk in MA Scenarios in 2050 (IMAGE 2.2)

9.5.2.2.1 Regional trends

As indicated, soil erosion risks will be exacerbated in densely populated countries of the tropics and sub-tropics, where natural resources are already under great stress. The projected increase in soil erodibility is attributed to the decrease in soil organic matter content, reduction in the magnitude and stability of aggregates, and increase in the proportion of rainfall lost as surface runoff. The problem of soil erosion by water will be exacerbated in China, South Asia, Central Asia, the midwestern United States, East African highlands, the Andean region, the Caribbean, northern Africa, and the Maghreb. It should be noted that, in contrast to water erosion, the wind erosion hazard may not increase with the projected climate change. It may either stay the same or decrease slightly, because the projected increase in rainfall may improve the vegetative cover and decrease wind erosion.

9.5.2.2.2 Soil erosion and climate change

Soil erosion is not only influenced by climate change, it also contributes to greenhouse gas emissions. Soil organic matter (that is, carbon) is preferentially removed by both water and wind erosion. The fate of this matter is determined by a series of complex processes. Of the 4.0–6.0 gigatons of carbon per year translocated by water erosion, 2.8–4.2 gigatons are redistributed over the landscape, 0.4–0.6 gigatons are transported into the ocean and may be buried with sediments, and 0.8–1.2 gigatons are emitted into the atmosphere (Lal 2003). As this is a relatively large flux (cf. the 6 gigatons of carbon per year emitted from fossil fuel burning), changes in erosion can be relevant. Increases in soil erosion risks under each of the scenarios could lead to an increasing contribution of soil erosion to climate change.

9.5.2.2.3 Soil erosion and world food security

Productivity loss by soil erosion is attributed to the decline in effective rooting depth, reduction in available water-holding capacity, decline in nutrient reserves, and other short-term and long-term adverse effects on soil quality. Although no estimates of future yield losses are available, we can get some indication of potential losses by looking at review studies on current impacts on agricultural yields. Estimates on global productivity losses, in different periods, range from about 0.5% to 12.7% (Crosson 1994; Oldeman 1998; Den Biggelaar et al. 2001, 2004a, 2004b).

There are several regions where the productivity impacts are much higher, up to 20% per year or more (Dregne 1990, 1992, 1995; Lal 1995, 1998). For instance, Oldeman (1998) indicates impacts of 25% for Africa, 36.8% for Central America, 12.8% for Asia, and 13.9% for South America. Lal (1995) estimated that the reduction in crop yield due to past erosion was 8.2% for the African continent. In terms of future change, Lal (1995) estimated that if the accelerated erosion continues unabated, yield reductions in Africa by 2020 may double (to 16.5%). In our scenarios, this situation could especially occur under Order from Strength and Global Orchestration. In the other two scenarios, the impacts might increase for some time, although improvements might be possible later on.

9.5.2.2.4 Summary

All four scenarios are likely to experience an increased risk of water-induced erosion due to increased precipitation and further conversion of forest areas into cropland or pastureland. Changing agricultural practices, and other types of measures, will determine whether this will also result in increased erosion levels. Such measures could include adapting to climate change, taking soil conservation practices, and preventing further expansion of agricultural land, for instance by intensifying livestock production where possible.

9.5.3 Water Purification and Waste Treatment

9.5.3.1 Methodology and Assumptions

"Water purification" and "water regulation" refer to services provided by freshwater ecosystems, including wetlands, that help break down and remove substances harmful to humans and ecosystems. "Waste processing" is a more general term applied to all wastes and ecosystems. Here we focus on the ecosystem service of "water purification" although we believe (*with medium certainty*) that outcomes for "waste processing" are similar.

Although changes in water purification and waste processing depend on many factors, we can only quantify (and in an approximate manner) a few of these factors:

- *Dilution capacity of receiving waters.* Wastewater discharged into receiving waters is diluted and dispersed, although not necessarily below harmful concentrations in the vicinity of the wastewater discharge. Nor does dilution necessarily protect society or ecosystems from downstream impacts of these substances or the bio-concentration of harmful substances. As a surrogate of this dilution capacity we use runoff (see earlier description). In principle, an increase in runoff (outside of flooding periods) also increases dilution capacity.
- *State and areal extent of wetlands.* Wetland processes remove undesirable substances and treat and detoxify a variety of waste products (see MA *Current State and Trends,* Chapter 15). Denitrification processes convert nitrogen from the form that promotes eutrophication (nitrate) to nitrogen gas. Concentrations of easily degraded chemicals are reduced by the long residence time of water in wetlands. More persistent metals and organic chemicals in water are adsorbed to wetland sediments and therefore removed from the water column, but this can create hot spots of contamination in sediments. While we do not compute the state or extent of wetlands, we use two surrogate variables for this information: runoff and land encroachment. First, a large enough reduction in runoff can reduce the area and effectiveness of wetlands for processing wastes; the larger the reduction, the higher the risk to the waste processing ability of wetlands. Second, wetlands are drained and occupied because of the expansion of agricultural or urban land; the larger the expansion of agricultural land and population, the greater the risk of disappearing wetlands.
- *Magnitude of wastewater load.* The ability of wetlands and other aquatic ecosystems to detoxify wastewater can be overwhelmed by high waste loading rates (see MA *Current State and Trends,* Chapter 15). For freshwater ecosystems, this means the higher the loads of wastewater, the higher the risk that the ecosystem's waste processing ability will be overloaded.

9.5.3.2 Comparison of Water Purification Capacity among Scenarios

Under Global Orchestration, geographically we expect little net change in water purification capacity in wealthy countries. Dilution capacity of most rivers increases because higher precipitation leads to increases in runoff in most river basins. However, some smaller regions have decreasing precipitation and hence their rivers have decreasing runoff and dilution capacity. Wetland areas decrease because of the expansion of population and agricultural land, but this is a small change compared with in the other scenarios.

Under this scenario, wastewater flows increase by 40% (and hence increase the risk of overloading the detoxification ability of freshwater systems), but this is the second lowest increase among the scenarios. These factors may lead to a reduction in the ability of freshwater systems to handle wastewater loadings, but the reduction may be lower than in Order from Strength and Adapting Mosaic. Moreover, under this scenario the wealth of rich countries is used to repair breakdowns in water purification as they occur. In poorer countries, however, there are net losses in water purification by ecosystems. The pace of ecosystem degradation, the overtaxing of ecosystems by high waste loads, the decline of wetland area because of the expansion of population and agricultural land all tend to drive a deterioration of water purification.

Water purification declines in all countries under Order from Strength. In this scenario, the expansion of agricultural land and population is the largest of all the scenarios and poses the greatest risk to the state and extent of wetlands (and hence their capacity to process wastes). Likewise, the magnitude of wastewater discharges is the largest. In wealthy countries, lack of international coordination complicates the management of transnational watersheds, leading to further deterioration of water purification. In poorer countries, losses of water regulation capacity of ecosystems are more severe than during Global Orchestration.

The expansion of agricultural land and population (and risk to wetlands) is large under Adapting Mosaic, but not as large as in Order from Strength. The magnitude of wastewater discharges is second largest among the scenarios. Although these factors tend to reduce the ability of freshwater ecosystems to purify water, society gives local water management special priority and therefore ensures that wetlands are protected and wastewater discharges are treated. Hence in all countries we expect an improvement in the water purification capacity of ecosystems.

Under TechnoGarden, re-engineering advances in wealthy countries are slow because of existing ecological problems, such as the high levels of nutrients in soils and lags in ecosystem regrowth and turnover of infrastructure. On the other hand, this scenario has the smallest increase in pressure on the environment (smallest expansion of population and agricultural land, and smallest increase in volume of wastewater discharges). The net result is little change in water regulation by 2050. In poorer countries, there are improvements by 2050 because the time lags for ecosystem engineering are shorter, and in some cases the countries learn from, and avoid, errors made earlier rich countries.

9.5.4 Coastal Protection

9.5.4.1 Methodology and Assumptions

"Storm protection" describes the role of ecosystems in protecting society from storm damage. Here we focus on the ecosystem service of coastal protection. Although many different factors influence the level of coastal protection in a particular scenario, we take into account the adaptive capacity of nature, the adaptive capacity of society, and the extent of sea level rise.

The adaptive capacity of nature depends largely on the existence of natural buffers against storms such as coral reefs, mangrove forests, and sand bars (see MA *Current State and Trends,* Chapter 16). Meanwhile, the adaptive capacity of society (in the sense of coastal protection) is a function of many economic, social, and political factors, including the priority society gives to preserving or restoring natural buffers. The extent of sea level rise will depend on various tectonic processes over geologic time, but more so on climate change over the time horizon of the MA scenarios.

9.5.4.2 Comparison of Coastal Protection among Scenarios

Coastal protection remains about the same in wealthy countries during Global Orchestration. Under the reactive ecosystem management that prevails in this scenario, it is thought to be more cost-effective to address storm damage after it occurs than to maintain ecosystem configurations that mitigate storm damage. In poorer countries, coastal protection declines due to degradation of ecosystems. A similar viewpoint leads to little change in coastal protection by ecosystems in wealthy countries during Order from Strength. In poorer countries, ecosystem degradation leads to extensive losses of coastal protection during Order from Strength.

Under Adapting Mosaic, society emphasizes a configuration of ecosystems to meet regional goals. Storm protection is likely to be one of those goals, leading to improvements under this scenario. In TechnoGarden, ecosystems are deliberately engineered to provide ecosystem services such as coastal protection. This leads to improved coastal protection in wealthy countries. In poorer countries, improvements are sometimes offset by unforeseen responses of ecosystems. The net result is little overall change in coastal protection from ecosystems.

Earlier in this chapter we described the sea level rise that is expected (*with high certainty*) to accompany climate change in the MA scenarios. IPCC assessments indicate that sea level will rise under climate change because warmer air temperatures will cause ocean water to expand, and warmer air temperatures will melt the ice and snow that now persist on the ice caps and glaciers from year to year. Furthermore, climate change may cause stronger and more persistent winds in the landward direction along some parts of the coastline, and this will also contribute to rising sea level at these locations. In the four scenarios (given a medium climate sensitivity), the global-mean sea level is expected to increase in the range of 50 centimeters (in TechnoGarden) to 70 centimeters (in Global Orchestration) between 1995 and 2100 (but there is a considerable uncertainty attached to these numbers).

While the precise impact of sea level rise on reducing coastal protection is difficult to assess, we estimate (*with medium to high certainty*) that populated coastal areas under all scenarios will require new coastal protection measures such as stronger and higher dikes or flood gates in estuaries. These are all expensive undertakings and they might be affordable only in the world's richer countries. Hence, for all scenarios we expect (*with medium certainty*) a higher storm risk to coastal populations because of sea level rise and a relatively higher risk in poorer than in wealthy countries.

9.5.5 Other Regulating Ecosystem Services

Here we briefly address the trends of two other processes that fit in the category Regulating Ecosystem Services.

9.5.5.1 Comparison of Pollination among Scenarios

The MA *Current State and Trends* volume describes the deterioration of pollination due to species losses, use of biocides, climate change, and diseases of pollinators. This trend will continue during the Global Orchestration, Order from Strength, and TechnoGarden scenarios. In addition, the continuing deforestation and urbanization in these scenarios is likely to be accompanied by landscape fragmentation (that is, the degree to which natural landscapes are broken up by different land uses of society), which will further reduce the effectiveness of pollinators. In TechnoGarden, there are some successful efforts to engineer pollination and produce crops that do not need pollinators—for example, development of self-pollinated strains.

During Adapting Mosaic, maintenance of pollinators is a goal of some regional ecosystem management programs. Some of these succeed in maintaining populations of pollinators or in adapting to shifting ranges of pollinators as the climate changes. Thus in some regions the pollination capacity is maintained or even improves. On balance, pollination is maintained during Adapting Mosaic.

9.5.5.2 Comparison of Biological Pest and Disease Control among Scenarios

Biological control is expected to change little in wealthy countries during Global Orchestration, since increased wealth should improve biological control research and practices, but the spread of invasive species will present new challenges. In poorer countries, losses of biodiversity during Global Orchestration will compromise the capacity for biological control. In Order from Strength, biological control is expected to deteriorate in all countries due to the decline in local ecosystems and biodiversity. In Adapting Mosaic, there is emphasis on adjusting ecological feedbacks to meet local goals for ecosystem management. This is likely to lead to improvements in biological control in at least some regions of both rich and poorer countries. In TechnoGarden, society invests in engineering of biological controls, but as ecosystems are simplified the biological controls become more difficult to implement. On balance, there is little net change in the capacity of ecosystems to provide biological control in this scenario.

9.6 Supporting Ecosystem Services

Supporting ecosystem services are those that are necessary for the production of all other ecosystem services. Their impacts on people are indirect or occur over a long time frame. Examples of supporting ecosystem services are soil formation, primary production, nutrient cycling, and provisioning of habitat. Since the impacts of these services occur over such a long time period, management does affect many of them in a time period relevant for 50-year scenarios. However, even small changes in the provision of these services will eventually affect all other types of ecosystem services.

In general, the scenarios in which people handle environmental problems in a reactive manner more often than not—Global Orchestration and Order from Strength—do not focus on maintaining supporting services. The short-term approach to fixing the most immediate problems does not allow for full consideration of long-term services like the ones in this category. Thus supporting services undergo a slight, gradual decline in these two scenarios. This decline is likely to go unnoticed until it causes major surprises. On the other hand, the two scenarios in which some environmental actions are proactive, Adapting Mosaic and TechnoGarden, may give some consideration to the management of certain supporting services, causing them to remain steady throughout these scenarios.

9.7 Cultural Ecosystem Services

Cultural ecosystem services are nonmaterial benefits obtained from ecosystems. The conceptual framework of the MA lists the following clusters of cultural services:

- cultural heritage and diversity,
- spiritual and religious,
- knowledge systems (diversity and memory),
- educational and aesthetic values,
- inspiration,
- sense of place, and
- recreation and ecotourism.

This section describes some of the possible changes in these services under the four MA scenarios on the basis of the qualitative assessment. (See Table 9.21.) The presentation focuses on the services where differentiation between scenarios can be achieved, based on either calculations with numerical models or on our best qualitative assessment derived from the scenarios and an assessment of recent scientific literature. In general, global models have been less successful at quantitatively estimating changes in cultural ecosystem services (see Chapters 4 and 12); therefore, most of the discussion here will focus on a qualitative assessment of changes in cultural ecosystem services across the four scenarios.

Overall, cultural services decline slightly in Global Orchestration. People have less contact with nature and therefore have less personal familiarity with it. This lack of personal experience generally reduces the benefits of cultural services. The world in this scenario experiences some loss of indigenous knowledge systems and other cultural diversity, but recreation possibilities do increase, particularly in poorer countries. On the other hand, cultural services generally decline in Order from Strength, especially in poorer countries. People in wealthy countries have far less contact with nature and less familiarity with it. Adapting Mosaic shows a different pattern: an increase in basically all cultural services. This scenario, with its focus on preservation of local knowledge and innovation, prizes cultural ecosystem services and emphasizes retaining or improving them. TechnoGarden is focused on education and knowledge but ignores local or traditional knowledge in favor of global technologies. Thus, the results for cultural ecosystem services under this scenario are mixed. Knowledge shifts away from traditional knowledge to technological information, leading to a loss of cultural diversity.

When we consider the many particular types of cultural ecosystem services, it seems that each scenario offers a different mix, so that there are no really strong consistent patterns of decline or improvement in cultural services across all scenarios. Overall, it appears that the details of each particular path into the future have a considerable, but path-specific, impact on the provision of cultural ecosystem services.

The cultural services associated with a sense of place—inspiration, aesthetic values, cultural heritage, social relations, knowledge systems, and sense of place itself—follow approximately the same pattern across the scenarios. These cultural services stay the same as they were in the year 2000 in Global Orchestration, mostly stay the same in wealthy countries in Order from Strength, improve in Adapting Mosaic, and stay the same or decline somewhat in TechnoGarden. The declines in poorer countries in Order from Strength are largely due to the difficulty of simply meeting

Table 9.21. Qualitative Expectations for Cultural Ecosystem Services in MA Scenarios. Ecosystem services are defined in the MA conceptual framework volume (MA 2003: 56–59). "Industrialized Countries" stands for nations that are relatively developed and wealthy in 2000; "Developing Countries" stands for nations that are relatively underdeveloped and poor in 2000. Note that any particular nation could switch categories between 2000 and 2050. Scores pertain to the endpoint of the scenarios, 2050. A score of +1 means that the ecosystem service is in better condition than in 2000. A score of 0 means that the ecosystem service is in about the same condition as in 2000. A score of −1 means that the ecosystem service is in worse condition than in 2000.

	Global Orchestration		Order from Strength		Adapting Mosaic		TechnoGarden	
Ecosystem Service	Industrial Countries	Developing Countries	Industrial Countries	Developing Countries	Industrial Countries	Developing Countries	Industrial Countries	Developing Countries
Cultural diversity	−1	−1	−1	−1	+1	+1	−1	−1
Spiritual and religious values	0	0	0	−1	+1	+1	−1	−1
Knowledge systems (diversity and memory)	0	−1	−1	−1	+1	+1	0	0
Educational values	0	0	−1	−1	+1	+1	+1	+1
Inspiration	0	0	0	−1	+1	+1	0	0
Aesthetic values	0	0	0	−1	+1	+1	0	0
Social relations	0	0	0	−1	+1	+1	−1	−1
Sense of place	−1	0	0	−1	+1	+1	−1	−1
Cultural heritage values	0	0	−1	−1	+1	+1	0	0
Recreation and ecotourism	−1	+1	−1	+1	−1	−1	+1	+1
Comment on cultural services	loss of some indigenous knowledge systems; people have less contact with nature and therefore less personal familiarity with it		loss of many indigenous knowledge systems; emphasis on security inhibits innovation in ecosystem management; ecotourism is less safe in the developing countries; especially in industrial countries, people have less contact with nature and therefore less personal familiarity with it; there is an increase in fundamentalism with respect to spiritual and religious values		emphasis on preservation of local knowledge for ecosystem management, and innovation of new ways of managing ecosystems		shift of knowledge from traditional forms of technological information; changing knowledge through spiral of technical innovation; tourism in engineered ecosystems is fundamentally different from that in wilderness; designer ecosystems should increase perceived value of nature; people have less contact with nature and therefore less personal familiarity with it	

basic needs in these areas. The declines in TechnoGarden, on the other hand, are due to the tendency in this scenario to engineer ecosystems that are similar despite differences in location.

Other types of services follow different patterns across the scenarios. For example, cultural diversity declines under all scenarios except Adapting Mosaic, where it improves.

9.8 Cross-cutting Synthesis

The MA scenarios about the future of ecosystem services, as presented in this chapter, have been developed using multiple quantitative and qualitative methods, each of which comes with its own assumptions and uncertainties. In most cases, a rigorous assessment of this uncertainty is not yet possible. Here, we provide a synthetic analysis of ecosystem change based on a comparison of results across the four scenarios.

9.8.1 What Drives the MA Scenarios?

The key driving forces of the MA scenarios include population, income, technological development, changes in consumption patterns, land use change, and climate change. (Other driving forces are described in the early part of this chapter.) The future trends of these driving forces are quite different under the storylines of the four scenarios.

Change in population is important because population size directly influences the demand for future ecosystem services. Global population estimates for 2050 range from approximately 8 billion (Global Orchestration) to 9 billion (Order from Strength). Assumptions about future income affect the amount of ecosystem services required or consumed per person. The low estimate (Order from Strength) implies that global annual average income levels per person (as measured on market exchange basis) increase by a factor of two between now and 2050. Under the high estimate

(Global Orchestration), the increase is more than a factor of four during the same period. The income gap between the richest and the poorest world regions remains about the same under Order from Strength but narrows under the other three scenarios.

The rate of technological change affects the efficiency by which ecosystem services are produced or used. For example, a higher rate of technological change leads to more-rapid increase in the yield of crops per hectare or in the efficiency of water use by power plants. The rate of technological change in general is highest under the Global Orchestration scenario and lowest under the Order from Strength scenario. With respect to environmental technology (such as control of emissions, efficiency of water use) developments under TechnoGarden are as rapid as under Global Orchestration.

Consumption patterns also form an important driver determining the provision of ecosystem services. Consumption patterns are strongly affected by development pathways (and therefore, all other factors being equal, by economic growth). Relative to the overall trends, however, consumption patterns can be assumed to be more oriented toward low ecological impacts in the two environmentally proactive scenarios, TechnoGarden and Adapting Mosaic, and to be more material-intensive under the other two scenarios. One example of this is the consumption of meat products.

For land use change, results critically depend on the scenario results for food production and trade. The amount of land used by humans has been increasing significantly at the expense of natural biomes (such as forest and grasslands). In the MA scenarios, expansion of agricultural land slows down and even stabilizes in TechnoGarden, but continues to grow under Order from Strength. Critical factors include population size, diets (in particular consumption of meat products), and development of agricultural yields. Climate change, finally, takes place in all four scenarios. The increase of global mean temperature ranges from 1.6° to 2.0° Celsius in 2050, and from 2.0° to 3.5° Celsius in 2100.

9.8.2 Patterns in Provisioning and Regulating Ecosystem Services across the Scenarios

In the world of Global Orchestration, outcomes for ecosystem services are mixed. There is a very rapid increase in demand for provisioning services, such as food and water. As the means for investments exists, it can be expected that there is a simultaneous improvement in the provisioning services for food, fiber, and fuel. However, there is also degradation of ecosystem services related to biodiversity, such as biochemical discoveries and biological control. The ad hoc approach to the management of ecological issues that comes from addressing each issue as it becomes important leads to neglect of the underlying causes of watershed degradation. Degradation of watersheds leads to breakdowns in freshwater availability, water regulation, erosion control, water purification, and storm protection. Particularly in poorer countries, there is degradation of regulating ecosystem services. In general, the tendency to neglect the underlying processes that provide ecosystem services creates vulnerability during Global Orchestration. Probably one of the most important threats to sustainability under this scenario is climate change. The increase of global mean temperature is the largest of the four scenarios.

Under Order from Strength, there is a major risk of collapsing ecosystem services. These are maintained only for a few cases in wealthy countries. In poorer countries, all provisioning and regulating ecosystem services are in worse condition in 2050 than they were in 2000. Nationalism and lack of international cooperation make it difficult to address transnational ecosystem problems. Overarching concerns about security push ecosystem issues into the background for policy-makers, except for times when ecosystem services such as food or freshwater supply fail catastrophically. These failures have greatest impact in poorer countries. In rich countries, disaster-relief efforts address the short-term consequences of ecosystem breakdowns but rarely tackle underlying causes or reduce vulnerabilities. In all countries, the vulnerability of ecosystem services is greater in 2050 than it was in 2000.

There will be a strong focus under the Adapting Mosaic and TechnoGarden scenarios to maintain (or even improve) provisioning and regulating ecosystem services.

In Adapting Mosaic, ecosystem management focuses on comanagement of local or regional resources. People attempt to reduce vulnerability of ecosystem services using approaches that ''design with nature.'' These attempt to achieve an optimal balance among local social, ecologic, and economic needs. They involve ongoing adjustments of management practices to changing conditions and opportunities. The adjustments sometimes require experiments that are inconsistent with management for maximizing the production of desired ecosystem services. The approaches of Adapting Mosaic tend to maintain or increase both genetic resources and the diversity of landscapes. They decrease vulnerability of ecosystem services, particularly those related to food and fresh water. Moreover, the lack of focus on global ecological change means a great risk of leaving these unaddressed. For instance, under this scenario a considerable increase in global mean temperature is expected to occur.

In TechnoGarden, the prevailing approach to ecosystem management seeks innovative environmental technologies that allow the supply of desired ecosystem services to be increased. This approach enables the production of more food and fiber per unit land area, thereby reducing the footprint on wild lands of agriculture and forestry. The technological emphasis also provides advances in manipulating genetic resources, utilizing natural biochemicals, and introducing ecological engineering of air quality, fresh water, and climate. These approaches are efficient, but they create vulnerabilities because they neglect the ecological infrastructure and diversity that ensure production of ecosystem services. Some of the vulnerabilities are discovered only when they trigger breakdowns. Some of the breakdowns are catastrophic and require expensive re-engineering of ecosystem service systems. Only under this scenario have we assumed climate policies to be implemented. As a result, global mean temperature increase is limited to 2° Celsius above preindustrial levels.

9.8.3 Hotspot Regions with Particularly Rapid Changes in Ecosystem Services

In three regions, several different pressures on ecosystems and human well-being seem to be relatively high under all the scenarios.

- *Central Africa*—The African region sees a rapidly increasing population in all four MA scenarios. As a result, the demand for provisioning services such as food and water also increases rapidly, in fact in some cases even beyond the potential of this region to supply these services. Increased food imports will be an important strategy to deal with these problems. Nevertheless, in most of the MA scenarios the area for natural biomes will be strongly reduced. Moreover, to meet its needs for development, the central part of Africa will need to rapidly expand its withdrawal of water, and this will require an unprecedented investment in new water infrastructure. Under some scenarios, this rapid increase in withdrawals could also cause a similarly rapid increase in untreated return flows to the freshwater systems, which could endanger public health and aquatic ecosystems. The further expansion of agriculture would lead to losses of ecosystem services provided by forests in this region and to undesirable side effects of agricultural intensification, such as contamination of surface and groundwaters.
- *Middle East*—The MA scenarios tend to indicate that rapid increases in population and (secondary) rising incomes in MENA countries will lead to greater demand for food (including meat), which could lead to a still higher level of dependence on food imports. Rising incomes will also put further pressures on limited water resources, which will either stimulate innovative approaches to water conservation or possibly limit development.
- *South Asia*—The MA scenarios point toward continuing deforestation in these areas, increasingly intensive industrial-type agriculture, rapidly increasing water withdrawals and return flows, and further intensive water stress. This may be a region where the pressure on ecosystems causes breakdowns in these ecosystems, and these breakdowns could interfere with the well-being of the population and its further economic development.

9.8.4 Trade-offs between Ecosystem Services

A robust preliminary conclusion is that all scenarios in general depict an intensification of the trade-offs already observed between different ecosystem services. In particular, the demand for services increases rapidly under each of the four scenarios (but with a wide range across them). This increase in demand could place significant pressure on ecosystems.

9.8.4.1 Possible Gains in Provisioning Services

- World agricultural production increases. For example, world total production of grains increases around 50% for all scenarios, with larger differences between scenarios for poorer regions. However, per capita consumption of grain (for food and feed) remains near its current level of around 300 kilograms per year. Consumption in the sub-Saharan region does not substantially increase under any scenario.
- Domestic water use per person per year grows in the sub-Saharan and other poorer regions by a factor of five or more (depending on the scenario and region), and this implies increased access of the population in these regions to fresh water. In OECD countries, there is a decline in domestic water use per person because of more-efficient usage. Because of stabilization of food consumption and gains in access to water supply and other factors, the percentage of malnourished children falls by 40% in sub-Saharan Africa under the Global Orchestration scenario. The decline is much smaller under the Order from Strength scenario.
- The amount of wood extracted from remaining forests for fuelwood and fuel products is likely to increase greatly up to 2050 (despite a loss of land) under all scenarios. The sustainability of this wood extraction has not been analyzed.
- The demand for the provisioning service of fish production increases under all scenarios. Whether this demand can be met depends critically on assumptions on the sustainability of aquaculture.

9.8.4.2 Possible Losses in Provisioning Services

- Some of the gains in agriculture will be achieved through expansion of agricultural land and at the expense of uncultivated natural land. This applies to all scenarios. A rough estimate is that, by 2050, 10–20% of current grassland and forestland will be lost, mainly due to the expansion of agriculture (and secondarily because of the expansion of cities and infrastructure). The provisioning services associated with this land (genetic resources, wood production, habitat for terrestrial biota and fauna) will also be lost. The loss of wood production on this land might be compensated for by more-intensive production elsewhere.
- Although gains are made in access to fresh water, all scenarios also indicate a likely increase in the volume of polluted fresh water (especially in poorer countries if the capacity of wastewater treatment is not greatly expanded). Moreover, the expansion of irrigated land (which contributes to the increased production of grains) leads to substantial increases in the volume of water consumed in arid regions of Africa and Asia. These and other changes in the freshwater system are likely to cause a reduction in the provisioning services now provided by freshwater systems in developing countries (such as genetic resources, fish production, and habitat for other aquatic and riparian animals).

9.8.4.3 Uncertain Changes in Regulating Services

- It is not clear whether climate regulation will be increased or decreased under the scenarios. On one hand, the warmer, moister climate will, on average, increase primary productivity and the uptake of CO_2 in the atmosphere. On the other hand, the depletion of natural forest and grassland may lead to a decrease in standing biomass on Earth. Uncertain factors are the longer-term direct influence of CO_2 on plant growth and soil carbon pools, as well as the uncertainty of rainfall changes in water-limited regions. This question must be further analyzed.

9.8.4.4 Possible Changes in Regulating Services

- All scenarios assume an increase in per capita income and imply an increase in material well-being. This is likely to lead to higher consumption of electricity and fuel for transport, as well as to a higher production of industrial products. The result will be a decline in air quality maintenance, as indicated by a substantial rise in the emissions of SO_2 and NO_x, especially in poorer countries. While wealthy countries are expected to maintain or expand their control of local and regional air pollution, the same is not expected for poorer regions. The loss of natural land will also affect the regulating services it provided (erosion control, regulation of human diseases, and water regulation).
- Reduction in the size of natural ecosystems might have strong repercussions for regulation services associated with these ecosystems (such as erosion control, regulation of human diseases, and water regulation).

9.8.5 Uncertainty

Uncertainty in the assessment of this chapter arises from two principal sources: the methods being applied (primarily numerical models, expressing currently available understanding in mathematical formalisms), and the scenario storylines themselves.

9.8.5.1 How Certain Are the Model Results Used to Quantify the Scenarios?

As discussed in Chapter 6, all model results transport uncertainty since they make assertions about complex ecosystems over several decades into the future. A typical problem arises when output from one model is used as input for another model, and the uncertainty of the models propagates and multiplies. However, this problem can be lessened by interpreting modeling results in a conservative way.[9] Another drawback with current modeling approaches for ecosystem services is the lack of connections and feedbacks between human and environmental systems.

Despite these uncertainties, numerical models are a useful tool that allows us to combine complex ideas and data from the social and natural sciences in a consistent way. It is evident that this combination provides useful information to supplement the storylines presented in Chapters 5 and 8. Indeed, the modeling results show certain tendencies that can help us anticipate coming risks to ecosystem services. Moreover, they can provide information that is useful for developing policies to lessen these risks. In many areas, qualitative assessment methods can supply further valuable information.

9.8.5.2 Do the Scenarios Cover the Entire Range of Possible Futures?

The quantitative scenarios do not cover the entire range of possible futures because they do not include major surprises that we know from history will have a profound effect on ecosystem services (such as breakthroughs in technology, unexpected migration movements, and major industrial accidents). The models used to quantify the scenarios also rarely generate plausible ''breaking points'' in which ecological thresholds are exceeded (such as rapid changes in water quality or pest outbreaks over large agricultural areas). Exceeding these thresholds could have important consequences on the future of the world's ecosystems. Models do not generate breaking points because they poorly represent global feedbacks and linkages. This reflects the state of the art of global modeling, which needs to be improved to address urgent MA-relevant questions. On the other hand, the scenario storylines do include many examples of surprises and breaking points.

9.8.5.3 Likelihood of Surprises in Different Scenarios

Each scenario carries a certain risk of surprising disturbances. The level of risk is based on the pressures on ecosystems and on society's concern for learning about how ecosystems work and understanding threshold behaviors in ecosystems. Societies also have different vulnerabilities to these surprises based on aspects of well-being, including social networks, education, flexibility, and economic well-being. (The risk of extreme events is discussed in more detail in Chapter 5.)

For most services, the pressure on ecosystems is greatest from the Order from Strength scenario because of the combination of slow, unrelenting growth of population, slower development of new technologies, and a lack of interest in environmental management. Consequences include increases in global energy use throughout the century and an acceleration of current deforestation rates, with near depletion of forests in Africa and parts of Asia and the Amazon by the end of the century. High demand for ecosystem services, combined with a lack of concern for the ecosystems providing these services, leads to a high likelihood of situations in which society is surprised by sudden changes in ecosystems.

In Global Orchestration, the world may be confronted with major unexpected consequences of climate change, since here the average rate of change of temperature and precipitation is likely to be the fastest in the first half of the century. Of all the scenarios, this world could see the greatest consequences of climate change on water resources, changing natural vegetation, and crop yield. Intensification of agriculture is also extreme. Fast economic growth and a focus on reducing poverty lead to high levels of consumption of ecosystem services. This, combined with a lack of concern for understanding the ecosystems that provide these services, again leads to a high likelihood of surprise. This is offset by a high potential to respond to surprise due to higher incomes and economic well-being.

TechnoGarden also has a high risk of surprise. TechnoGarden's focus on new technologies leads to a high risk of technological failure. The risk is that each new technology can lead to a new and unexpected problem, which is then solved by another new technology. People in the TechnoGarden scenario are able to reduce their risk through a focus on understanding ecosystems and maintaining supporting and regulating ecosystem services. This scenario features high levels of agricultural intensification, which may yield unexpected outcomes for ecosystem services. Moreover, the assumptions on climate change policy in this scenario rely on strong technological development and continuous support to bear the costs that are associated with these policies. There is a risk that one of these conditions might not be met.

The Adapting Mosaic scenario has the lowest risk of surprising events. Moreover, expansion of agricultural land in poorer countries is lowest in this scenario. Nevertheless, the major risk factor in this scenario is represented by major ecological changes that occur at the global scale, as environmental management is oriented at the local scale. The most obvious example is climate change (we have not assumed climate policies under this scenario), but other examples could include disturbance of the global nitrogen cycle.

9.8.6 Outlook

Using four major storylines and a set of numerical models to investigate the potential risks for the future provision of ecosystem services may appear an impossible task under conditions of scientific rigor and quality standards. However, it must be noted that uncertainty in itself is not a factor disqualifying systematic analysis. Advances in global ecological research can only be achieved on the basis of searching for the limits of our understanding. Areas for improvement, in fact, could include the following: better coverage of provisioning, regulating, and supporting ecological services; better coverage of the feedbacks for ecosystem change on human development; better insights into the sustainability of some provisioning services, such as water supply and wood production; and further disaggregation of the analysis, for instance by using local-scale models within the global context laid out by the tools used in this chapter.

Appendix 9.1. Selected Drivers of the Ecosystem

Crop Area and Livestock Numbers Growth

Exogenous assumptions were made for crop area and livestock number development by scenario. Crop area and livestock numbers are then further adjusted endogenously based on other parameters (yield growth, population, income growth, and so on) to meet effective food demands. The ranking resulting from effective crop area growth over the projections period is (1) Order from Strength, (2) Adapting Mosaic, (3) TechnoGarden, and (4) Global Orchestration, where crop area expansion is largest under Order from Strength and lowest under Global Orchestration. Total livestock population is a function of the livestock's own price and the price of competing commodities, the prices of intermediate (feed) inputs, and a trend variable reflecting growth in the number of livestock slaughtered. Numbers and weight growth for the group of livestock products is heavily influenced by the increasing share of chicken (low weight, large numbers) in total livestock production and the correspondingly declining share of beef and pig (larger weight and relatively lower numbers) in total production. Whereas for crop production, yield growth is the major contributor to future production increases, for livestock products, growth in numbers will remain dominant for production increases into the future.

Crop area expansion under the Order from Strength scenario is driven by a combination of high population growth and low yield improvements. Increased food demand coupled with low output per unit area induces farmers to expand cultivation on marginal lands. In terms of regional implications, between the base year and 2050 sub-Saharan Africa sees the largest expansion, with an overall increase in harvested cereal area of 70%, followed by Latin America with an increase of 36%, and MENA at 30%. Cereal area is projected to increase in Asia by 8%, in the former Soviet Union by 17%, and in the OECD region by 11%. The evolution is similar for livestock numbers. Over the 1997–2050 period, the number of slaughtered cattle is expected to increase by 75%, that of pigs by 34%, and that chicken by 100%, with numbers growth accounting for 78%, 74%, and 83% of total production growth respectively.

Similarly, under the Adapting Mosaic scenario, high population and relatively low crop yield growth also lead to substantial crop area expansion, led by sub-Saharan Africa, with 50%, followed by Latin America, 21%; MENA, 16%; former Soviet countries, 2.8%; and Asia, 1.5%. Area is projected to slightly decline in the OECD region, however (−0.1%). Livestock numbers growth under Adapting Mosaic is much slower compared with the Order from Strength scenario, with the slaughtered cattle numbers increasing by 47%, pigs by 29%, and chicken by 104%, with numbers growth accounting for 66%, 67%, and 80% of production growth, respectively.

Rather than expanding in all MA regions, as in the case of Order from Strength, crop areas in TechnoGarden and Global Orchestration are projected to contract considerably in certain countries and regions. The decline under TechnoGarden is mainly due to an increase in conservation programs to retire land for biodiversity, improved land use through improved technology applications on existing areas, and sufficient yield enhancements making expansion into marginal areas unnecessary. By 2050, cereal crop areas are expected to decline in the OECD region by 10%, in the former Soviet Union by 7%, and in Asia by 6%. On the other hand, harvested areas are set to rise 37% in sub-Saharan Africa, 9% in Latin America, and 7% in MENA. Under the TechnoGarden scenario, the global number of buffaloes and other cattle increases by 48%, the number of pigs rises by 26%, and the number of chickens goes up by 73% from 1997–2050. Numbers growth is projected to account for 65%, 61%, and 73% of livestock production growth, respectively.

Under the Global Orchestration scenario, cereal areas also decline in some regions, but less so than under TechnoGarden, due to higher income growth in poorer regions and more demand for meatier diets. Globally, cereal-harvested area still expands slightly. By 2050, cereal-harvested area in the OECD and former Soviet regions is 10% and 6% lower than in the base year, and in Asia, it is 6% lower. On the other hand, expansion in cereal-harvested area in sub-Saharan Africa will still be considerable, at 45%. The area in Latin America is projected to expand by 12% and in MENA by 2%. Driven by rapid increase in demand for livestock products, the number of buffaloes and other cattle is projected to expand by 101%, the number of pigs by 71%, and the number of chickens by 172%, with growth in numbers accounting for 72% (beef), 74% (pigs), and 80% (poultry) of production growth.

Crop Yield Improvement

In IMPACT, crop yield is a function of the commodity price, the prices of labor and capital, and a projected non-price exogenous trend factor reflecting technology improvements. The non-price trend reflecting technological change is affected by a number of indirect determinants. These include public and private R&D, agricultural extension and farmers' schooling, development of infrastructure and markets, and irrigation capacity. The MA storylines provide different descriptions for the development of individual components of these technological trends depending on the scenario, with the two major determinants of the trend being changes in (agricultural) investment levels and water and energy use efficiency.

In Global Orchestration, crop yield improvement over time is assumed to range from medium to high for both rich and poorer countries. Improvements in water use efficiency and energy use efficiency, as well as large investments in agricultural research and supporting infrastructure, particularly in poorer countries, are major drivers behind the crop yield improvement for Global Orchestration. The greatest yield increases are seen in sub-Saharan Africa, with increases of 159% over the base levels, followed by Latin America at 114%, Asia at 84%, and MENA at 74%, compared with 49% for the former Soviet states and 47% for the OECD region.

Under TechnoGarden, crop yield improvement over time is assumed to be lower in the wealthy world due to a greater focus on organic farming. However, investments in biotechnology and other crop innovations are sufficient enough to bring about significant crop yield growth. Under TechnoGarden, the OECD and former Soviet Union are expected to experience cereal yield growth up to 2050 of about 45%; Asia, 72%; Latin America, 93%; sub-Saharan Africa, 106%; and MENA, 70%.

For Order from Strength, crop yield improvement is assumed low in all countries, as are improvements in water use and energy use efficiency, resulting from low investments in these sectors. In the OECD and former Soviet countries, yield improvements are only 20% and 24% over base levels, respectively. In sub-Saharan Africa, by 2050 cereal yield levels are still below 2 tons per hectare, after yield increases of 90% over base levels. In Latin America, yield levels are 54% higher; in MENA, 40%; and in Asia, 36%.

For Adapting Mosaic, crop yield improvement is assumed to start out at a medium level and then decrease over time in the rich world due to the adoption of organic farming. In the OECD and former Soviet countries, cereal crop yields increase by 38% and 34%, respectively. In poorer countries, crop yield improvements are somewhat larger, due to successful local adaptation mechanisms. Regionally, sub-Saharan Africa will lead with improvement in cereal yields of 103% by 2050. Latin America, Asia, and MENA follow with 69%, 49%, and 50% improvements respectively over base year cereal yields.

Average final cereal crop yields by 2050 are highest for Global Orchestration (4.7 tons per hectare), followed by TechnoGarden (4.3 tons), Adapting Mosaic (3.8 tons), and Order from Strength (3.5 tons).

Changes in Livestock Slaughtered Weight

Livestock slaughtered weight in the model is affected mainly by expected changes in technological development, without additional price effects. The assumptions made in terms of technological change in this case are along the same lines as those made with respect to crop yield changes, and the same ranking of scenarios is observed as a result.

Livestock slaughtered weight improves most under Global Orchestration and least under the Order from Strength scenario. For example, by 2050 slaughtered weight of cattle is projected to reach 260 kilograms per head under Global Orchestration compared with 229 kilograms per head under Order from Strength, 242 kilograms under Adapting Mosaic, and 245 kilograms under TechnoGarden. Among regions, growth in slaughtered weight for cattle under Global Orchestration is projected to be particularly high in Asia, followed by sub-Saharan Africa and MENA.

Under TechnoGarden, livestock weight improvement over time is assumed to be low in wealthy countries due to the already high level of weights achieved and relatively lower demand for livestock products, while it will be medium to high in poorer nations due to innovations in livestock breeding.

In Order from Strength, yield improvement for livestock is assumed low in all countries. Finally, for Adapting Mosaic livestock yield improvement is assumed to start at a medium level and to decline in the wealthy world, and to start out from medium-low to reach a medium level in poorer nations, driven by locally adapted breeding and a lack of investments in modern techniques in both rich and poor countries.

Basin-level Irrigation Efficiency

Under the Order from Strength scenario, government budgetary problems are assumed to worsen, resulting in dramatic government cuts on irrigation system expenditures. Water users fight price increases, and a high degree of conflicts results in lack of local water-user cooperation for cost-sharing arrangements. The turnover of irrigation systems to farmers and farmer groups is accelerated but not accompanied by the necessary reform of water rights and necessary funding. Rapidly deteriorating infrastructure and poor management reduce system- and basin-level water use efficiency under this scenario. As a result, efficiency levels, which are already quite low in most of Asia, drop by 23–28% to reach levels of only 0.25–0.30 by 2050. In East and South Africa, levels decline slightly less, by about 20%, to reach 0.44 by 2050. Declines are similar in Latin America, to reach 0.32–0.34 by 2050. In MENA, where efficiency levels were very high in 2000, at 0.6–0.7, levels are expected to decline to 0.56 by 2050. Efficiencies are more resilient in wealthy countries as elites concentrate resources on some systems to maintain minimum food self-sufficiency levels. As a result, levels decline by about 8% in the OECD and slightly more, about 15%, in the former Soviet nations.

Under the Global Orchestration scenario, careful market-oriented reform in the water sector and more comprehensive and coordinated government action will lead to greater water management investments in efficiency-enhancing water and agricultural technology. The effective price of water for the agricultural sector is assumed to increase more rapidly to induce water conservation as well as to free up agricultural water for other environmental, domestic, and industrial uses. Large investments in poorer countries lead to rapid increases in efficiency levels in Asia and sub-Saharan Africa, where levels increase to as high as 0.4–0.5 and 0.56–0.74, respectively. Selected—economically viable—investments also enhance efficiency levels in those countries and regions, where relatively high efficiency had been achieved by 2000, including the OECD and MENA, although increases are small. The highest irrigation efficiency level is achieved in the region facing the greatest water scarcity, North Africa, at 0.8.

Under TechnoGarden, technological innovations for on-farm efficiency increases help boost irrigation efficiency levels across the world to previously unseen levels. Moreover, river basins make progress toward more integrated basin management through real-time measuring and management of water resources. Gradual introduction of water price increases in some agricultural areas induce farmers in these regions to use water more efficiently. As a result, high efficiency levels are reached, particularly in regions where little or no further improvement had been expected, like the OECD and MENA. There, levels increase to 0.75–0.9 by 2050. Advances are also significant in Asia, reaching 0.5 by 2050, and in sub-Saharan Africa, where levels of 0.75 can be reached.

Under the Adapting Mosaic scenario, local adaptations, including expansion of water harvesting and other water conservation technologies, as well as the increased application of agro-ecological approaches, help boost efficiency levels in some regions and countries. Successful efficiency increases—although important—remain scattered in areas and regions within countries, and the global and regional impacts are smaller than under TechnoGarden and Global Orchestration. In Asia, the results are mixed, with increases in efficiency in East Asia balanced by declines in South Asia. In sub-Saharan Africa, the outcomes are more favorable, with conservation strategies boosting efficiency levels by 2–11%. The former Soviet Union is less successful with efficiency-enhancing methods, experiencing a slight decline in efficiency levels. The OECD region, as a whole, does successfully apply locally developed methods to enhance irrigation efficiency, with increased efficiency levels in some countries more than balancing declines in other ones.

Appendix 9.2. Additional Description of the Modeling Done for Chapter 9

Productivity Increase

Agricultural productivity growth can be due to area expansion or yield growth for crops and to an increasing number of animals slaughtered or improvement in slaughtered weight per head for livestock. In IMPACT, the factors influencing productivity growth include management research, conventional (plant) breeding, wide-crossing and hybridization breeding, and biotechnology and transgenic breeding. Other sources of growth considered include private-sector agricultural research and development, agricultural extension and education, markets, and infrastructure. In short, productivity drivers include greater public/private investment, better management practices, and improved technologies. Drivers were not further subdivided among technology, management, and infrastructure because the outcomes on the drivers are a function of all three of these factors. Area/numbers and yield/slaughtered weight growth were differentiated by scenario as deviations from our best estimates of future productivity and area increases for the 45 IMPACT countries and regions. Results from IMAGE on yield reduction factors from climate change were incorporated into IMPACT production growth assumptions for the four MA scenarios.

Dietary Preferences

Food demand is a function of the price of the commodity and the prices of other competing commodities, per capita income, and total population. Per capita income and population increase annually according to country-specific population and income growth rates by scenario.

Price elasticities of demand, which govern sensitivity of food consumption to a change in prices, are one important factor relating to price effects. The impact of changes in income on food demand is captured by the income elasticities of demand.

Price elasticities of demand are assumed to stay the same across the four MA scenarios. Income elasticities of demand, on the other hand, do vary by scenario. In general, income elasticities are considerably higher for high-valued commodities such as meat, milk, fruits, and vegetables compared with the elasticities for basic staple crops such as rice and wheat. With increasing incomes, the elasticity of demand for rice actually turns negative in some countries. In IMPACT, income elasticities of demand for meat and fish for wealthy countries is assumed to be lower than for poorer ones; as incomes increase, the elasticity of demand with respect to income declines.

The scenarios vary in their assumed income elasticities of demand for meat. (Income elasticities of demand for fish are not varied across scenario.) Among wealthy countries, demand for meat is assumed to be less sensitive to income changes for non-Global Orchestration scenarios. Between TechnoGarden and Order from Strength, income elasticities of demand are more inelastic for TechnoGarden in rich countries whereas they are similar for poorer countries. Adapting Mosaic is assumed to have the most inelastic income elasticities of demand for all countries.

Drivers Affecting Rates of Malnutrition in Addition to Caloric Consumption

IMPACT generates projections of the percentage and number of malnourished preschool children (0 to 5 years old) in poorer countries. Projections for the proportion and number of malnourished children are derived from an estimate of the functional relationship between the percentage of malnourished children, the projected average per capita kilocalorie availability of food, and non-food determinants of child malnutrition, including the quality of maternal and child care (proxied by the status of women relative to men as captured by the ratio of female to male life expectancy at birth), education (proxied by the share of females undertaking secondary schooling), and health and sanitation (proxied by the percentage of the population with access to safe drinking water). The equations used to project the percentage and numbers of malnourished children are as follows:

$$\begin{aligned}\%MAL_t = &-25.24 * \ln(KCAL_t) \\ &- 71.76\, LFEXPRAT_t - 0.22\, SCH_t \\ &- 0.08\, WATER_t\end{aligned} \tag{1}$$

and

$$NMAL_t = \%MAL_t \times POP5_t \tag{2}$$

where *%MAL* is the percentage of malnourished children, *KCAL* is per capita kilocalorie availability estimated in IMPACT, *LFEXPRAT* is the ratio of female to male life expectancy at birth, *SCH* is the percentage of females with secondary education, *WATER* is the percentage of the population with access to safe water, *NMAL* is the number of malnourished children, and *POP5* is number of children below five years of age.

Average per capita consumption per day is determined for the four different MA scenarios from IMPACT runs up to 2050 incorporating quantified parameters from the four storylines, including assumptions on area and yield growth, population and income growth, food preferences, investment levels, and assumptions regarding openness to trade. The non-food determinants of child malnutrition are synthesized from the storylines and assumed to improve the least under the Order from Strength scenario and the most under the TechnoGarden scenario.

Detailed Assumptions of the EwE Models for Fisheries Calculations

Appendix Table 9.1 shows the detailed assumptions that were made in the driving forces in each case study under the four MA scenarios.

Appendix Table A9.1. Summary of Harmonizing Storylines and Case Studies of Regional Marine Fisheries. Numbers in parentheses represent ratio of optimizing two or more policy options (EcoSim/EcoPath)

Time	Gulf of Thailand	North Benguela	Central North Pacific
Global Orchestration			
2000–10	optimize profits from shrimp and jobs (70/30); climate change medium-high	optimize profits and jobs (50/50); climate change medium	optimize profits from tuna and jobs (80/20); climate change low
2010–30	optimize profits, jobs, and then ecosystems (50/30/20); climate change impact reducing	optimize profits and jobs (30/70); climate change medium-low; increase catch of fish for fish food	optimize profits from tuna and jobs (70/30); climate change stable
2030–50	optimize profits and ecosystem (biomass) (50/50)	optimize profits, jobs, and ecosystems (50/20/30); increase the catch of small pelagics	optimize profits and ecosystems (50/50) through building of bigeye tuna
Order from Strength			
2000–10	optimize profits of the invertebrate fishery and jobs (50/50)	optimize profits and jobs (50/50) of high value fisheries; DWF increases effort (mod–high of current species as EU pushes for food security and African debts mount)	optimize profits from the tuna fishery as well as jobs (75/25); DWF effort remains stable since countries focused on national issues
2010–30	optimization mix continues (50/50) but effort increasing since Thailand feels the effects of national EEZs and despite agreements it has no room to expand DWF which is now concentrated in the Gulf	climate change starts low with build up over this decade to medium impact; rebuilding of biomass starts late in this period but there is still concern with maintaining jobs (30 profits/50 jobs/20 ecosystem)	optimize profit and jobs (85/15); Japan returns to drift netting; DWF has moderate increase as United States secures food and increases presence in Pacific for security
2030–50	climate change has significant impact (high impact) and ecosystem severely destabilized; rebuilding stocks of demersal species continues with objective of optimizing jobs rather than profits	mix of profit and job optimization (60/40) increased fishing effort with switch through time to fish meal species for domestic and international aquaculture operations and also internal food security	profit optimization not as important but jobs are (60/40); Japan stops drift netting by 2040, DWF effort remains stable
Adapting Mosaic			
2000–10	optimize profits of the invertebrate fishery and jobs (70/30)	optimize profits and jobs (40/60) and maintain food and fish meal fisheries	optimize profits from the tuna fishery; turtle exploitation ceases
2010–30	climate change starts in earnest (medium-high impact); optimize for profits; shift to rebuilding stocks of demersal species starts	climate change starts low with build up over this decade to medium impact; rebuilding of biomass starts late in this period but there is still concern with maintaining jobs (30/50/20)	climate change minimal if any impact; severe exploitation of bigeye tuna until close to 2030 when stock rebuilding commences at the same time as shift to optimizing for jobs with profit (70 profit/30 jobs)
2030–50	climate change has significant impact (high impact) and ecosystem severely destabilized; rebuilding stocks of demersal species continues with objective of optimizing jobs rather than profits	climate change continues to have high impact with some destabilization of the system; food security becomes an issue and therefore focus is on maximizing biomass for fish feed since it goes to aquaculture that ensures a stable supply of food (0 profits/100 jobs /0 ecosystems)	climate change has a low impact, bigeye tuna rebuilding continues; optimize for ecosystem, especially for top predators; international MPA to rebuild stocks (50 profits/50 jobs)
TechnoGarden			
2000–10	optimize profit	optimize profit	optimize profit
2010–30	optimize pelagic catch (cost of fishing lower) followed by ecosystem optimization (since impacts can be engineered)	optimize profits while increasing pelagics (50/50)for fish food since technology makes aquaculture widespread and demand for fish meal up despite artificial feed improvements	optimize profit, but with costs lowered since technology improves; possible to have more tuna caught younger for ranching (2015–2030)
2030–50	optimize pelagic catch—by 2040 ecosystem irrelevant due to technology advances—profits maximized by using Gulf to produce quality fishmeal for prawn aquaculture	optimize profits from fish used in fishmeal; basically supplies European demand for aquaculture	optimize profits, but fish changes to species for fishmeal since technology cracks tuna hatchery technology

Key: DWF = Distant Water Fleet; EEZ = Exclusive Economic Zone; MPA = Marine Protected Area

Notes

1. The WorldScan economic model has been set up to reproduce the GDP per capita numbers of the IPCC SRES scenarios at the level of the four aggregated IPCC regions, thus providing detailed information on a consistent macroeconomic trajectory for 12 WorldScan regions (Bollen 2004). In a next step, this information was further disaggregated into 17 IMAGE regions using simple desaggregation rules (See IMAGE-team 2001).

2. Gt C-eq is gigatons (thousand million tons) of greenhouse gas emissions, expressed in equivalent carbon dioxide emissions (in units of carbon). The conversion of different gases is done on the basis of ''global warming potential'' reported for 100 years, which measures the contribution of the different greenhouse gases over a 100-year-time period relative to carbon dioxide. The other greenhouse gases included in the numbers above are methane, nitrous oxides, HFCs, PFCs, and SF_6.

3. In assessing trends in land use and land cover change under the MA scenarios, we have used the IMAGE 2.2 model, with scenarios starting in 1970. For the historic 1970–95 period, land use (size of agricultural area) trends of IMAGE have been calibrated against FAO data. The size of 14 natural biomes (including ice, a large number of forest types, grasslands, desert, etc.) have been determined on the basis of the BIOME model that is included in IMAGE using climate and soil data. While the BIOME model represents overall patterns in existing land cover maps very well, the area of each biome type does not match exactly to available databases on land cover (typically, differences can be the order of 10–20% on the level of continents).

4. Here, we use the land use-change scenarios as calculated by IMAGE 2.2 under the MA storylines to assess the possible changes in land use. The changes in agricultural demand and agricultural management are derived from IMPACT as described in the section on provisioning of food. In addition, timber demand and demand for biofuels are taken into account. Climatic changes have been taken into account, as they drive changes in natural vegetation but also influence crop growth and thus yields.

5. Data on agricultural production for 1970–95 (FAO 2001) and for 2030 according to the AT 2030 projection (Bruinsma 2003) were implemented by Bouwman et al. (2005a) in the Integrated Model to Assess the Global Environment model (IMAGE-team 2001) to generate 0.5 by 0.5 degree global land cover maps. These were used to allocate fertilizer and animal manure inputs, ammonia volatilization, and crop nitrogen export. Country data on sanitation coverage, connection to sewerage systems, and wastewater treatment were taken from several sources (EEA 1998; EEA 2003; WHO/UNICEF 2000, 2001a, 2001b). For countries where data were lacking, the percentage of the population with connection to sewerage systems was estimated on the basis of the fraction of the urban population with improved sanitation and the degree of urbanization. In combination with the AT 2030 projection, target values for the year 2030 for the connection to sewerage systems and wastewater treatment were modified from WHO/UNICEF (2000) with adjustments for many countries on the basis of past developments or trends observed in other countries.

6. During the first steps in CO_2 assimilation, C3 plants form a pair of three carbon-atom molecules. C4 plants, on the other hand, initially form four carbon-atom molecules. An important difference between C3 and C4 species for rising CO_2 levels is that C3 species continue to increase photosynthesis with rising CO_2, while C4 species do not. So C3 plants can respond readily to higher CO_2 levels, and C4 plants can make only limited responses. C3 plants include more than 95 percent of the plant species on Earth. (Trees, for example, are C3 plants.) C4 plants include such crop plants as sugarcane and corn. They are the second most prevalent photosynthetic type.

7. The Gulf of Thailand is a shallow, tropical coastal shelf system that has been heavily exploited since the 1960s. This has caused the system to change from a highly diverse ecosystem with a number of large long-lived species (such as sharks and rays) to one that is now dominated by small, short-lived species that support a high-valued invertebrate fishery (Pauly and Chuenpagdee 2003). In the Central North Pacific, tuna fishing is one of the major economic activities. Recent assessments of the tuna fisheries indicate that top predators such as blue marlin and swordfish declined since the 1950s while small tunas, their prey, have increased (Cox et al. 2000). The North Benguella Current is an upwelling system off the west coast of Southern Africa. This system is highly productive, resulting in a rich living marine resource system that supports small, medium, and large pelagic fisheries (Heymans et al. 2004).

8. The water erosion index of Hootsman et al. (2001) can be compared with the erosion severity classes of GLASOD (Oldeman et al. 1991). The modeled estimates for the global land area for 1990 corresponded for approximately 85% with the GLASOD inventory.

9. For example, results from a simple climate model are input to a global water model to compute changes in runoff due to climate change. In this case, the uncertainties of the climate model are propagated to the water model. This problem can be reduced by recognizing that the uncertainty of the climate model is relatively high for computed spatial patterns of temperature and precipitation, but much less for the magnitude and direction of these changes. Therefore, statements about the changes in runoff at particular locations will be highly uncertain and should be avoided, whereas statements about the size of the area in a large region affected by increasing or decreasing runoff have a lower level of uncertainty and are appropriate for the MA scenario analysis. The key is to aggregate results either spatially or temporally because uncertainties that are important on the fine scale partly cancel out when data are aggregated.

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