Chapter 3

Land

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Main messages

The demands of a burgeoning population, economic development and global markets have been met by unprecedented land-use change. The following are the main messages of this chapter:

During the last 20 years, the exponential expansion of cropland has slackened, but land is now used much more intensively: globally in the 1980s, on average a hectare of cropland produced 1.8 tonnes, but now it produces 2.5 tonnes. For the first time in history, more than half of the world's population lives in cities, which are growing rapidly, especially in developing countries. Cities draw upon extensive rural hinterlands for water and disposal of waste, while their demands for food, fuel and raw materials have a global reach.

Unsustainable land use is driving land degradation. Land degradation ranks with climate change and loss of biodiversity as a threat to habitat, economy and society, but society has different perspectives on various aspects of land degradation, according to political visibility. Inaction means a cumulative addition to a long historical legacy of degradation, from which recovery is difficult or impossible.

Harmful and persistent pollutants, such as heavy metals and organic chemicals, are still being released to the land, air and water from mining, manufacturing, sewage, energy and transport emissions; from the use of agrochemicals and from leaking stockpiles of obsolete chemicals. This issue is politically visible, effects on human health are direct and increasingly well understood, and better procedures and legislation to address chemical contamination are being developed. There has been progress in dealing with pollution in the industrialized countries, where the problem first emerged, but the shift of industry to newly-industrialized countries is yet to be followed by implementation of adequate measures to protect the environment and human health. Achievement of an acceptable level of safety, worldwide, requires strengthening of institutional and technical capacity in all countries, and the integration and effective implementation of existing controls at all levels. There remains an unacceptable lack of data, even for proxies, such as total production and application of chemicals.

Forest ecosystem services are threatened by increasing human demands. Exploitation of forests has been at the expense of biodiversity and natural regulation of water and climate, and has undermined subsistence support and cultural values for some peoples. These issues are increasingly acknowledged, prompting a range of technical responses, legislation and non-binding agreements (such as the United Nations Forum on Forests) to conserve forests, and financial mechanisms to support them. The historical decline in the area of temperate forest has been reversed, with an annual increase of 30 000 km^2 between 1990 and 2005. Deforestation in the tropics, having begun later, continued at an annual rate of 130 000 km^2 over the same period. The decline in forest area may be countered by investment in planted forest and more efficient use of wood. More forest is being designated for ecosystem services, but innovative management is required to maintain and restore ecosystems. There is an urgent need to build institutional capacity, in particular community-based management; the effectiveness of this response depends on good governance.

Land degradation in the form of soil erosion, nutrient depletion, water scarcity, salinity and disruption of biological cycles is a fundamental and persistent problem. Land degradation diminishes productivity, biodiversity and other ecosystem services, and contributes to climate change. It is a global development issue – degradation and poverty are mutually reinforcing – but is politically invisible and largely ignored. The damage can be arrested, even reversed, but this requires concerted, long-term investment across sectors, by all levels of government and by individual land users, research to provide reliable data, and adaptation of technologies appropriate to local circumstances. Such a package of measures has rarely been attempted.

Depletion of nutrients by continued cropping with few or no inputs limits productivity over vast tropical and subtropical upland areas. Research has shown the benefits of biological nutrient cycling by integration of legumes into the cropping system, improved fallows and agroforestry. However, widespread adoption is yet to be achieved, and for severely nutrient-deficient soils, there is no remedy except external nutrient inputs. The simple addition of manure or fertilizer may raise crop yields from as little as 0.5 to between 6 and 8 tonnes of grain/ha. In contrast to intensive farming systems that pollute streams and groundwater by excessive fertilizer application, many smallholders in poor countries do not have the means to purchase fertilizer, despite favourable benefit-cost ratios.

Increasing water scarcity is undermining development, food security, public health and ecosystem services. Globally, 70 per cent of available freshwater is held in the soil and accessible to plants, whereas only 11 per cent is accessible as stream flow and groundwater. Better soil and water management can greatly increase the resilience of farming systems and the availability of water downstream, but nearly all investment goes into the withdrawal of water, of which 70–80 per cent is used for irrigation. Meeting the Millennium Development Goal on hunger will require doubling of water use by crops by 2050. Even with much-needed improvements in efficiency, irrigation cannot do it alone. A policy shift is needed towards greater water-use efficiency in rain-fed farming, which will also replenish water supplies at source.

Desertification occurs when land degradation processes, acting locally, combine to affect large areas in drylands. Some 2 billion people depend on drylands, 90 per cent of them in developing countries. Six million km^2 of drylands bear a legacy of land degradation. It is hard to deal with the problem, because of cyclical swings in rainfall, land tenure that is no longer well adjusted to the environment, and because local management is driven by regional and global forces. These forces have to be addressed by national, regional and global policies. Local responses need to be guided by consistent measurement of indicators of long-term ecosystem change.

Demands on land resources and the risks to sustainability are likely to intensify. There are opportunities to meet this challenge, and to avoid potentially unmanageable threats. Population growth, economic development and urbanization will drive demands for food, water, energy and raw materials; the continued shift from cereal to animal products and the recent move towards biofuels will add to the demand for farm production. At the same time, climate change will increase water demands, and increasing variability of rainfall may increase water scarcity in drylands. Opportunities to meet these challenges include application of existing knowledge, diversification of land use, in particular to farming systems that mimic natural ecosystems and closely match local conditions instead of ignoring them, technological advances, harnessing markets to the delivery of ecosystem services, and independent initiatives by civil society and the private sector. Potentially unmanageable threats include runaway biological cycles, climate-related tipping points, conflict and breakdown of governance.

INTRODUCTION

Twenty years ago, *Our Common Future*, the report of the World Commission on Environment and Development, stated: "If human needs are to be met, the Earth's natural resources must be conserved and enhanced. Land use in agriculture and forestry must be based on a scientific assessment of land capacity and the annual depletion of topsoil." Such a scientific assessment has yet to be undertaken and significant data uncertainties remain; the fundamental principles of sustainable land management, established at the 1992 UN Conference on Environment and Development (UNCED), notably in the Agenda 21 Programme of Action for Sustainable Development, are yet to be translated into globally effective policies and tools. Sustainable development remains one of the greatest challenges, although there have been some successes: at regional scales there are the rehabilitation of much of the Loess Plateau in China and the Great Plains of the United States, as a result of long-term, concerted action.

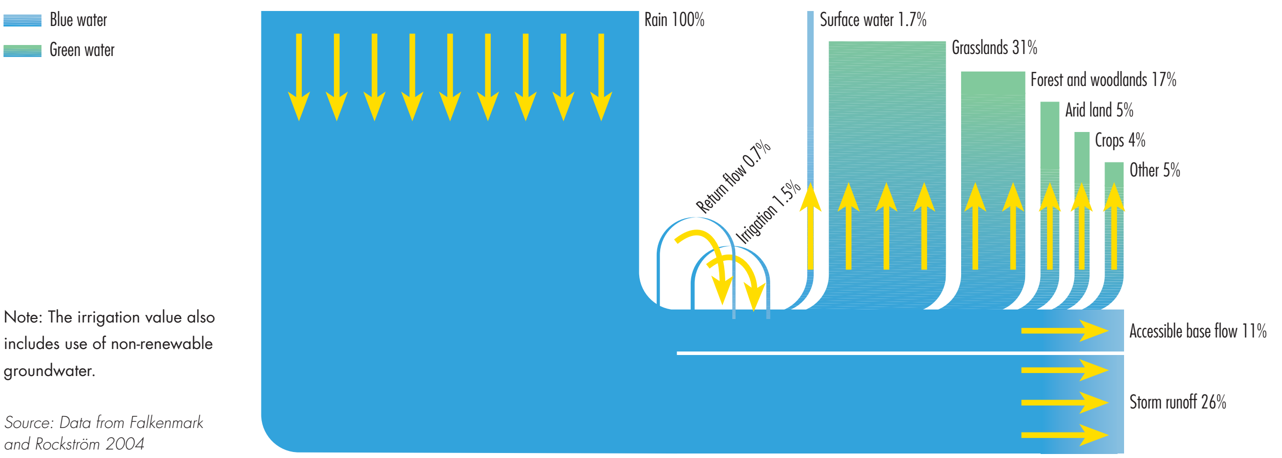
Over the last 20 years, increasing human population, economic development and emerging global markets have driven unprecedented land-use change. Anticipated human population increases and continued economic growth are likely to further increase exploitation of land resources over the next 50 years (see Chapter 9). The most dynamic changes have been in forest cover and composition, expansion and intensification of cropland, and the growth of urban areas. Unsustainable land use drives land degradation through contamination and pollution, soil erosion and nutrient depletion. In some areas there is an excess of nutrients causing eutrophication, and there can be water scarcity and salinity. Beneath land degradation lies disturbance of the biological cycles on which life depends, as well as social and development issues. The term desertification was coined to convey this drama of pressing and interconnected issues in drylands, but human-induced land degradation extends beyond drylands or forests.

Many issues interact with the atmosphere or water, or both. This chapter covers those aspects of water resources that are intimately linked to land management, ranging from rainfall to run-off, infiltration, storage of water in the soil and its use by plants (*green* water), as well as the uptake of salt, agrochemicals and suspended sediment. Aspects related to the recharge of groundwater and stream flow (*blue* water) are covered in Chapter 4, while carbon storage and emissions are dealt with mainly in Chapter 2. The *green-blue* water flows are highlighted in Figure 3.1, below.

DRIVERS OF CHANGE AND PRESSURES

Drivers of land-use change include great increases in the human population and density, increased productivity, higher incomes and consumption patterns, and technological, political and climate change. Individual land-use decisions are also motivated by collective memory and personal histories, values, beliefs and perceptions. Table 3.1 summarizes pressures and drivers of land-use change, distinguishing between slow drivers that result in gradual impacts over decades, and fast drivers that may have impacts in one year (see the section on desertification).

Figure 3.1 *Green* and *blue* water, global flows



Note: The irrigation value also includes use of non-renewable groundwater.

Source: Data from Falkenmark and Rockström 2004

Drivers of land-use change themselves change over time. For instance, the Brazilian Amazon was exploited from the late-19th to mid-20th century to supply rubber to the world market. In the second half of the 20th century, the region was drawn into the national economy, with large areas cleared for cattle ranching. Currently, it is responding to national and international markets, resulting in more intensive land use and continued forest conversion, mainly to farmland, including grassland for beef production.

Land-use change is influenced by local needs, as well as by nearby urban demands and remote economic forces (see Box 3.1 under Forests). At the global level, reliable historical data are scarce, but the available information indicates that the greatest changes over the last 20 years have been in forests, especially by conversion to cropland, woodland or grassland and also by new planted forests. Estimates of global land-use changes since 1987 are shown in Table 3.2 in terms of area change by category (the table does not show change of composition within these categories).

Since 1987, the largest forest conversions have occurred in the Amazon Basin, South East Asia, and Central and West Africa. Forest area increased in the Eurasian boreal forest, and in parts of Asia, North America, and Latin America and the Caribbean, mainly due to new planted forests (FAO 2006a). Forest degradation, from both human and natural causes, is widespread. For instance, 30 000 km^2 of forest in the Russian far east have been degraded over the past 15 years by illegal logging and fires (WWF 2005).

Cropland has expanded significantly in South East Asia, and in parts of West and Central Asia, the

Table 3.1 Pressures and drivers of land-use change

	Changes in human population and management	Changing opportunities created by markets	Policy and political changes	Problems of adaptive capacity and increased vulnerability	Changes in social organization, resource access and attitudes
Slow	Natural population growth; subdivision of land parcels Domestic life cycles that lead to changes in labour availability Excessive or inappropriate use of land	Commercialization and agro-industrialization Improvement in accessibility through road construction Changes in market prices for inputs or outputs, such as erosion of prices of primary products, unfavourable global or urban-rural terms of trade Off-farm wages and employment opportunities	Economic development programmes Perverse subsidies, policy-induced price distortions and fiscal incentives Frontier development (for example, for geopolitical reasons, or to promote interest groups) Poor governance and corruption Insecurity in land tenure	Financial problems, such as creeping household debts, no access to credit, lack of alternative income sources Breakdown of informal social networks Dependence on external resources, or on assistance Social discrimination against ethnic minorities, women, members of lower classes or castes	Changes in institutions governing access to resources by different land managers, such as shifts from communal to private rights, tenure, holdings and titles Growth of urban aspirations Breakdown of extended families Growth of individualism and materialism Lack of public education, and poor flow of information about the environment
Fast	Spontaneous migration, forced population displacement Decrease in land availability due to encroachment of other uses, such as natural reserves	Capital investments Changes in national or global macro-economic and trade conditions that lead to changes in prices, such as a surge in energy prices, or global financial crisis New technologies for intensification of resource use	Rapid policy changes, such as devaluation Government instability War	Internal conflicts Diseases, such as malaria, and illnesses, such as HIV/AIDS Natural hazards	Loss of entitlements to environmental resources through, for example, expropriation for large-scale agriculture, large dams, forest projects, tourism and wildlife conservation

Source: Adapted from Lambin and others 2003

Table 3.2 Global land use – areas unchanged (thousands km²) and conversions 1987–2006 (thousands km²/yr)

From \ To	Forest	Woodland/ Grassland	Farmland	Urban areas	Losses	Gains	Net change
Forest	39 699	30	98	2	–130	57	–73
Woodland/Grassland	14	34 355	10	2	–26	50	24
Farmland	43	20	15 138	16	–79	108	29
Urban areas	n.s.	n.s.	n.s.	380	0	20	20
Total					–235	235	

n.s. = not significant; farmland includes cropland and intensive pasture

Source: Holmgren 2006

Great Lakes region of Eastern Africa, the southern Amazon Basin, and the Great Plains of the United States. In contrast, some croplands have been converted to other land uses: to forests in the southeastern United States, eastern China and southern Brazil, and to urban development around most major cities. Viewed in a wider historical context, more land was converted to cropland in the 30 years after 1950, than in the 150 years between 1700 and 1850 (MA 2005a).

Even more significant than the change in cropland area, is that land-use intensity has increased dramatically since 1987, resulting in more production per hectare. Cereal yields have increased by 17 per cent in North America, 25 per cent in Asia, 37 per cent in West Asia, and by 40 per cent in Latin America and the Caribbean. Only in Africa have yields remained static and low. Globally, adding together production of cereals, fruit, vegetables and meat, output per farmer and unit of land has increased. In the 1980s, one farmer produced one tonne of food, and one hectare of arable land produced 1.8 tonnes, annually on average. Today, one farmer produces 1.4 tonnes, and one hectare of land produces 2.5 tonnes. The average amount of land cultivated per farmer remained the same, at about 0.55 ha (FAOSTAT 2006). However, world cereal production per person peaked in the 1980s, and has since slowly decreased despite the increase in average yields.

Towns and cities are expanding rapidly. They occupy only a few per cent of the land surface, but their demand for food, water, raw materials and sites for waste disposal dominate the land around them. Urban expansion occurred at the expense of farmland rather than forest, and is currently highest in developing countries.

ENVIRONMENTAL TRENDS AND RESPONSES

Land-use changes have had both positive and negative effects on human well-being, and on the provision of ecosystem services. The enormous increase in the production of farm and forest products has brought greater wealth and more secure livelihoods for billions, but often at the cost of land degradation, biodiversity loss and disruption of biophysical cycles, such as the water and nutrient cycles. These impacts create many challenges and opportunities. Table 3.3 summarizes positive and negative links between changes in land and human well-being.

Table 3.3 Links between land changes and human well-being

Change in land	Environmental impact	Material needs	Human health	Safety	Socio-economic
Cropland expansion and intensification	Loss of habitat and biodiversity; soil water retention and regulation; disturbance of biological cycle; increase of soil erosion, nutrient depletion, salinity, and eutrophication	Increased food and fibre production – such as doubling world grain harvest in last 40 years Competing demands for water	Spread of disease vectors related to vegetation and water (such as irrigation associated with schistosomiasis) Exposure to agrochemicals in air, soil and water	Increased hazards from flood, dust and landslides during extreme weather	More secure livelihoods and growth in agricultural output Changes in social and power structures

<table>
<tr><th colspan="7">Table 3.3 Links between land changes and human well-being, continued</th></tr>
<tr><th colspan="2">Change in land</th><th>Environmental impact</th><th>Material needs</th><th>Human health</th><th>Safety</th><th>Socio-economic</th></tr>
<tr><td colspan="2">Loss of forest, grassland and wetlands</td><td>Loss of habitat, biodiversity, stored carbon, soil water retention and regulation

Disturbance of biological cycles and food webs</td><td>Diminished variety of resources

Diminished water resources and water quality</td><td>Loss of forest ecosystem services, including potential new medicinal products</td><td>Increased hazard of flooding and landslides during extreme weather and tsunamis</td><td>Loss of forest products, grazing, fisheries and drought reserves

Loss of livelihood, cultural values and support for traditional lifestyles of indigenous and local communities

Loss of recreation opportunities and tourism</td></tr>
<tr><td colspan="2">Urban expansion</td><td>Disruption of hydrological and biological cycles; loss of habitat and biodiversity; concentration of pollutants, solid and organic wastes; urban heat islands</td><td>Increased access to food, water and shelter; increased choice, but satisfaction of material needs highly dependent on income</td><td>Respiratory and digestive-tract diseases due to air pollution, poor water supply and sanitation

Higher incidence of stress- and industry-related diseases
Higher incidence of heat stroke</td><td>Increased exposure to crime

Traffic and transport hazards

Increased hazard of flooding caused by soil sealing and occupation of hazardous sites</td><td>Increased opportunity for social and economic interaction and access to services

Increased competition for financial resources

Diminished sense of community; increased sense of isolation</td></tr>
<tr><td rowspan="5">Land Degradation</td><td>Chemical contamination</td><td>Polluted soils and water</td><td>Water scarcity and non-potable water</td><td>Poisoning, accumulation of persistent pollutants in human tissue with potential genetic and reproductive consequences</td><td>Increased risk of exposure and of contamination of food chains; in severe cases, areas become uninhabitable</td><td>Loss of productivity due to ill health

Diminished productivity of contaminated systems</td></tr>
<tr><td>Soil erosion</td><td>Loss of soil, nutrients, habitat and, property; siltation of reservoirs</td><td>Loss of food and water security</td><td>Hunger, malnutrition, exposure to diseases due to weakened immune system

Turbidity and contaminated water</td><td>Risk of floods and landslides

Accidents due to damage to infrastructure, particularly in coastal and riverine areas</td><td>Loss of property and infrastructure

Decreasing hydro-power generation due to siltation of reservoirs

Diminished development in farm and forest sectors</td></tr>
<tr><td>Nutrient depletion</td><td>Impoverished soils</td><td>Diminished farm and forest production</td><td>Malnutrition and hunger</td><td></td><td>Lack of development in farm sector, poverty</td></tr>
<tr><td>Water scarcity</td><td>Diminished stream flow and groundwater recharge</td><td>Loss of food and water security</td><td>Dehydration
Inadequate hygiene, water-related diseases</td><td>Conflict over water resources</td><td>Lack of development, poverty</td></tr>
<tr><td>Salinity</td><td>Unproductive soils, unusable water resources, loss of freshwater habitat</td><td>Diminished farm production</td><td>Non-potable water</td><td></td><td>Loss of farm production
Increased industrial costs of corrosion and water treatment

Damage to infrastructure</td></tr>
</table>

Change in land	Environmental impact	Material needs	Human health	Safety	Socio-economic
Desertification	Loss of habitat and biodiversity Reduced groundwater recharge, water quality and soil fertility Increased soil erosion, dust storms, and sand encroachment	Diminished farm and rangeland production Loss of biodiversity Water scarcity	Malnutrition and hunger Water-borne diseases, respiratory problems	Conflict over land and water resources Increasing flash floods, dust hazard	Poverty, marginalization, decreased social and economic resilience, population movements
Carbon cycle	Climate change, acidification of ocean surface waters (see mainly Chapter 2)	Shift from fossil fuels to biofuels conflicts with food production Shift in growing seasons and risk of crop failure	Respiratory diseases related to air pollution	Risk of flood-related damage to property, particularly in coastal and riverine areas	Up to 80 per cent of energy supply is derived through manipulation of the carbon cycle
Nutrient cycles	Eutrophication of inland and coastal waters, contaminated groundwater Depletion of phosphate resources		Health effects from bioaccumulation of N or P in food chains Non-potable water		Benefits of food security and biofuel production
Acidifying cycles	Acid depositions and drainage damaging land and water ecosystems Acidification of ocean and freshwaters	Freshwater fish resources declining; risk of further collapse of marine fisheries	Poisoning from increased plant and animal uptake of toxic metals		Economic damage to forests, fisheries and tourism Corrosion of infrastructure and industrial facilities

Table 3.3 Links between land changes and human well-being, *continued*

FORESTS

Forests are not just trees, but part of ecosystems that underpin life, economies and societies. Where forests are privately owned, they are often managed mainly for production. Yet, in addition to directly supporting such industries as timber, pulp and biotechnology, all forests provide a wide range of ecosystem services. These services include prevention of soil erosion, maintenance of soil fertility, and fixing carbon from the atmosphere as biomass and soil organic carbon. Forests host a large proportion of terrestrial biodiversity, protect water catchments and moderate climate change. Forests also support local livelihoods, provide fuel, traditional medicines and foods to local communities, and underpin many cultures. The harvesting of forest products is putting severe stress on the world's forests. Box 3.1 describes some of the main pressures that drive changes in forest ecosystems.

Changes in forest ecosystems

Between 1990 and 2005, the global forest area shrank at an annual rate of about 0.2 per cent. Losses were greatest in Africa, and Latin America and the Caribbean. However, forest area expanded in Europe and North America. In Asia and the Pacific, forest area expanded after 2000 (see the FAO data in Figure 3.2 and in Figure 6.31 on annual forest change in the biodiversity and ecosystems section of Latin America and the Caribbean in Chapter 6).

In addition to the changes in global forest area, significant changes also occurred in forest composition, particularly in the conversion of primary forest to other types of forests (especially in Asia and the Pacific). It is estimated that over the past 15 years there has been an annual loss of 50 000 km^2 of primary forest, while there has been an average annual increase of 30 000 km^2

Box 3.1 Drivers and pressures affecting forest ecosystems

Changes in forest ecosystems, particularly the conversion from forest to other land uses and vice-versa, are driven by the harvesting of forest products and associated management activities, as well as by natural forest dynamics such as changes in age class and structure, and natural disturbance. Other drivers include climate change, diseases, invasive species, pests, air pollution and pressures from economic activities, such as agriculture and mining.

There are a number of drivers and pressures causing changes in forests.

- Demographic trends include changes in human population density, movement, growth rates, and urban-rural distribution. These trends exert pressures on forests through demands for goods such as timber and firewood, and for services such as regulation of water resources and recreation. The demand for services is increasing faster than the supply.
- Economic growth is reflected in the prices of forest products and international trade. The relative contribution of the forestry sector to global GDP declined in the last decade, from 1.6 per cent in 1990 to 1.2 per cent in 2000.
- Cultural preferences are shifting demands towards cultural services provided by forests.
- Science has helped to improve forest management, while both science and technology have improved the productivity and the efficiency of production and utilization of forests.

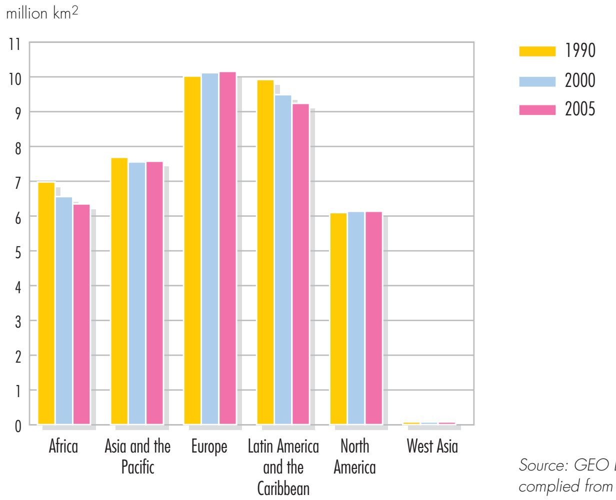
Sources: Bengeston and Kant 2005, FAO 2004, FAO 2006a

of planted and semi-natural forests. Primary forests now comprise about one-third of global forest area (see Figure 3.3).

Forests are managed for various functions (see Figure 3.4): in 2005, one-third of global forests were managed primarily for production, one-fifth for conservation and protection, and the remaining forests for social and multiple services. The proportion allocated primarily for production is largest in Europe (73 per cent) and least in North America (7 per cent) and West Asia (3 per cent). Of the total wood production, 60 per cent was industrial wood and 40 per cent was fuel; 70 per cent of industrial wood is produced in North America and Europe, while 82 per cent of fuelwood is produced in the developing world (FAO 2006a). Non-wood forest products, including food, fodder, medicine, rubber and handicrafts, are increasingly acknowledged in forest assessments and, in some countries, are more valuable than wood products.

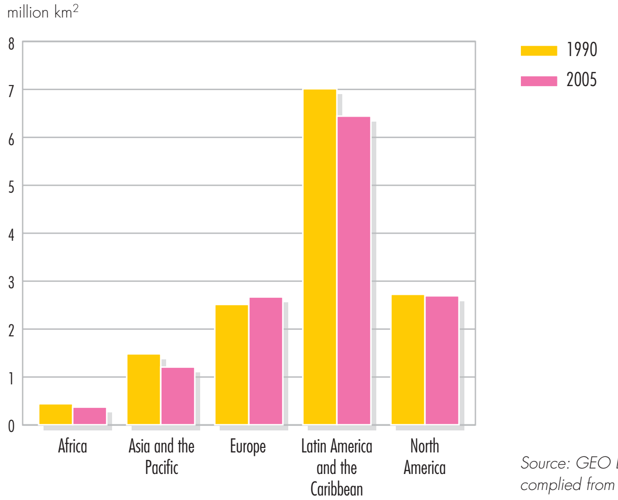
More and more forest areas are being designated for conservation and protection, partly in recognition of their valuable ecosystem services such as soil and water protection, absorption of pollution, and climate regulation through carbon fixation. However, these services have been reduced by the decline in total forest area and by continued forest degradation, especially in production and multipurpose forests. For example, the rate of decline in fixed carbon has been greater than the rate of decline in forest area (see Figure 3.5).

Figure 3.2 Total forest area by region



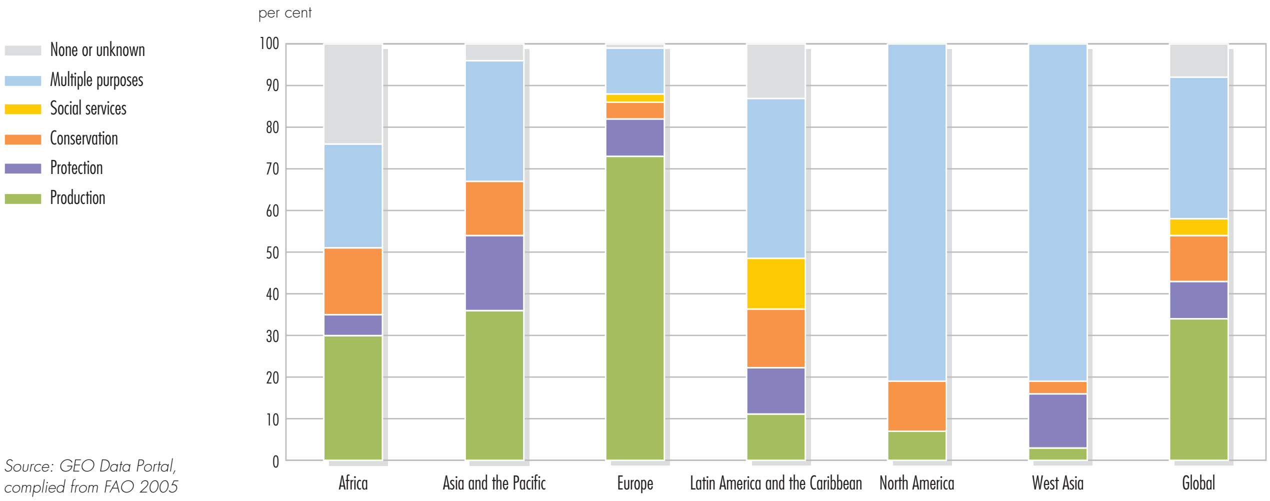
Source: GEO Data Portal, complied from FAO 2005

Figure 3.3 Primary forest area by region



Source: GEO Data Portal, complied from FAO 2005

Figure 3.4 Designation of forests by region, 2005



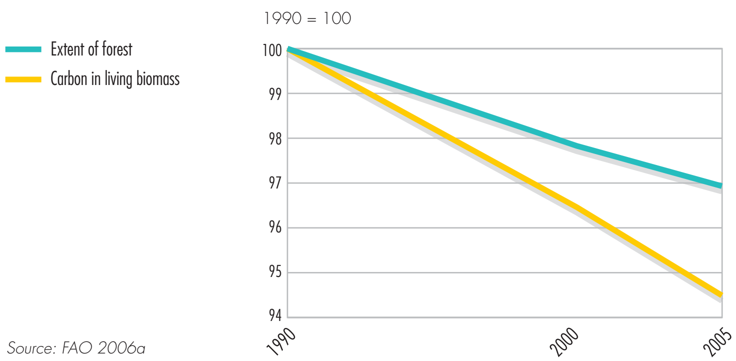
Source: GEO Data Portal, complied from FAO 2005

Ensuring a continued flow of goods-and-services from forests is essential for human well-being and national economies. Greater emphasis on conservation of biodiversity may lead to increased benefits in terms of resilience, social relations, health, and freedom of choice and action (MA 2005a, FAO 2006a). Many of the world's poor are directly and intensely affected by changes in forest use. A recent synthesis of data from 17 countries found that 22 per cent of rural household income in forested regions comes from harvesting wild food, firewood, fodder and medicinal plants, generating a much higher proportion of income for the poor than for wealthy families. For the poor, this is crucial when other sources of income are scarce (Vedeld and others 2004).

Managing forests

Despite the extensive impacts of changes in forest cover and use, forest issues continue to be addressed piecemeal in multilateral conventions and other legally and non-legally binding instruments and agreements. However, some regional initiatives in forest law enforcement and governance break new ground in addressing illegal activities. Regional ministerial conferences on forests have taken place in East Asia (2001), Africa (2003), and Europe and North America (2005), jointly organized by the governments of producing and consuming countries (World Bank 2006).

Figure 3.5 Declines in carbon in living biomass and in extent of forest



Source: FAO 2006a

The concept of sustainable forest management has evolved over the last two decades, but remains hard to define. The Forest Principles developed for UNCED state: "Forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations." Alternative frameworks to assess and monitor the status and trends of different elements of sustainable forest management include criteria and indicators, forest certification and environmental accounting. At the methodological level, it is difficult to integrate information on forest state and trends, and the contribution of non-marketed, non-consumptive and intangible forest goods-and-services. A further difficulty lies in defining thresholds beyond which changes in values can be regarded as being significant. At the practical level, spatial and temporal data for assessing sustainability are often incompatible, inconsistent and insufficient. Policies to promote the fixing of atmospheric carbon by agricultural, pastoral and forest systems have been more seriously considered, because fixing carbon by forest plantations is

Table 3.4 Progress towards sustainable forest management

Thematic element	Trends in FRA 2005 variables or derivatives	Data availability	1990–2005 Annual change rate (per cent)	1990–2005 Annual change	Unit
Extent of forest resources	(Yellow) Area of forest (Yellow) Area of other wooded land (Yellow) Growing stock of forests (Yellow) Carbon stock per hectare in forest biomass	H M H H	–0.21 –0.35 –0.15 –0.02	–8 351 –3 299 –570 –0.15	1 000 ha 1 000 ha million m^3 tonnes/ha
Biological diversity	(Red) Area of primary forest (Green) Area of forest designated primarily for conservation of biological diversity (Yellow) Total forest area excluding area of productive forest plantations	H H H	–0.52 1.87 –0.26	–5 848 6 391 –9 397	1 000 ha 1 000 ha 1 000 ha
Forest health and vitality	(Yellow) Area of forest affected by fire (Red) Area of forest affected by insects, diseases and other disturbances	M M	–0.49 1.84	–125 1 101	1 000 ha 1 000 ha
Productive functions of forest resources	(Yellow) Area of forest designated primarily for production (Green) Area of productive forest plantations (Yellow) Commercial growing stock (Yellow) Total wood removals (Green) Total NWFP removals	H H H H M	–0.35 2.38 –0.19 –0.11 2.47	–4 552 2 165 –321 –3 199 143 460	1 000 ha 1 000 ha million m^3 1 000 m^3 tonnes
Protective functions of forest resources	(Green) Area of forest designated primarily for protection (Green) Area of protective forest plantations	H H	1.06 1.14	3 375 380	1 000 ha 1 000 ha
Socio-economic functions	(Green) Value of total wood removals (Green) Value of total NWFP removals (Red) Total employment (Green) Area of forest under private ownership (Green) Area of forest designated primarily for social services	L M M M H	0.67 0.80 –0.97 0.76 8.63	377 33 –102 2 737 6 646	million US$ million US$ 1 000 pers. yrs 1 000 ha 1 000 ha

FRA = FAO Global Forest Resources Assessment NWFP = non-wood forest products

(Green) = Positive change (greater than 0.5 per cent) (Yellow) = No major change (between –0.5 and 0.5 per cent) (Red) = Negative change (less than –0.5 per cent)

Source: FAO 2006a

eligible for trading under the Kyoto Protocol. Table 3.4 summarizes progress towards sustainable forest management against measures of forest extent, biodiversity, forest health, and productive, protective and socio-economic functions.

At the local level, there are many examples of innovative management, especially community-based approaches that are arresting trends in forest degradation and loss of forest ecosystem services (see Box 3.2).

Box 3.2 Sustainable forest management by smallholders in the Brazilian Amazon

Since 1998, Brazilian farmers have had to maintain 80 per cent of their land as forest (50 per cent in some special areas) as a legal forest reserve. Small-scale forest management enables smallholders to make economic use of their forest reserves.

Since 1995, a group of smallholders in the state of Acre, supported by Embrapa (the Brazilian Agricultural Research Corporation), has developed sustainable forest management systems based on traditional forest practices as a new source of income. Forest structure and biodiversity are maintained by low-impact disturbance at short intervals, combined with silvicultural practices, matching the circumstances of the smallholders (small management area, limited labour availability and investment) with appropriate management techniques (short cutting cycles, low intensity harvesting and animal traction).

The system described here is practised in forest holdings averaging 40 ha each. Cooperative agreements among neighbours facilitate the acquisition of oxen, small tractors and solo-operated sawmills, yielding higher prices in local markets and reducing transportation costs. As a result, farmers' incomes have risen 30 per cent. In 2001, the smallholders created the Association of Rural Producers in Forest Management and Agriculture to market their products nationwide and, in 2003, they won Forest Stewardship Council certification from SmartWood. Surveys have been conducted to monitor biodiversity. IBAMA (the Brazilian Environment and Renewable Natural Resource Institute) and BASA (the Bank of the Amazon) use the sustainable forest management system as a benchmark for development and financial policies for similar natural resource management schemes.

Sources: D'Oliveira and others 2005, Embrapa Acre 2006

LAND DEGRADATION

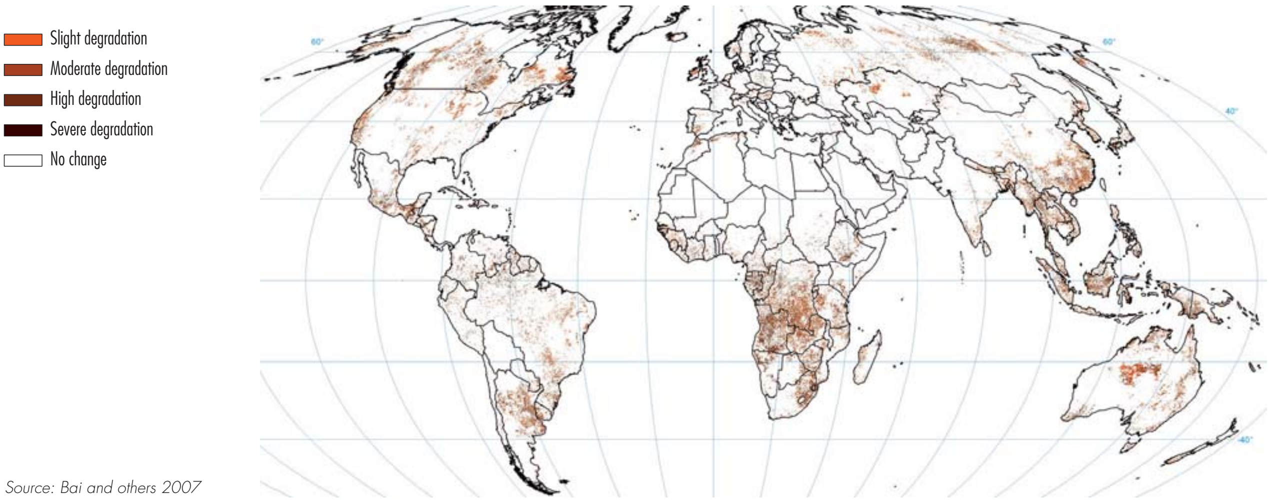
Land degradation is a long-term loss of ecosystem function and services, caused by disturbances from which the system cannot recover unaided. It blights a significant proportion of the land surface, and as much as one-third of the world's population – poor people and poor countries suffer disproportionately from its effects. Established evidence links land degradation with loss of biodiversity and climate change, both as cause-and-effect (Gisladottir and Stocking 2005). Direct effects include losses of soil organic carbon, nutrients, soil water storage and regulation, and below-ground biodiversity. Indirectly, it means a loss of productive capacity and wildlife habitat. For instance, in rangelands it disrupts wildlife migration, brings changes in forage, introduces pests and diseases, and increases competition for food and water. Water resources are diminished by disruption of the water cycle, off-site pollution and sedimentation. The threat to sustainable development posed by land degradation has been recognized for decades, including by the 1992 Earth Summit and the 2002 World Summit on Sustainable Development, but responses have been hamstrung by weaknesses in available data, particularly in relation to the distribution, extent and severity of the various facets of degradation.

The only comprehensive source of information has been the Global Assessment of Human-induced Soil Degradation (GLASOD), which assessed the severity and kind of land degradation for broadly-defined landscape units at a scale of 1:10 million (Oldeman and others 1991). It was compiled from expert judgements and, while invaluable as a first global assessment, it has since proven to be not reproducible and inconsistent. In addition, the relationships between land degradation and policy-relevant criteria, such as crop production and poverty, were unverified (Sonneveld and Dent 2007).

A new, quantitative global assessment under the GEF/UNEP/FAO project Land Degradation Assessment in Drylands (LADA) identifies black spots of land degradation by trends analysis of the last 25 years' net primary productivity (NPP or biomass production). NPP is derived from satellite measurements of the normalized difference vegetation index (NDVI or greenness index). A negative trend in NPP does not necessarily indicate land degradation, since it depends on several other factors, especially rainfall. Figure 3.6 combines the recent trend of NPP with rain-use efficiency (NPP per unit of rainfall). Critical areas are identified as areas with a declining trend of NPP and declining rain-use efficiency over the past 25 years, excluding the simple effects of drought. For irrigated areas, only the biomass is considered and urban areas are excluded. The case study on Kenya highlights some of the results of the study (see Box 3.3).

By contrast with previous assessments, such as GLASOD, this new measure does not compound the legacy of historical land degradation with what is happening now. It shows that between 1981

Figure 3.6 Global land degradation using biomass production and rain-use efficiency trends between 1981–2003



Source: Bai and others 2007

and 2003 there was an absolute decline in NPP across 12 cent of the global land area, with a strong negative change in a further 1 per cent of the land area. In respect of rain-use efficiency, there was an absolute decrease on 29 per cent of the land area and strong negative change on 2 per cent. The areas affected are home to about 1 billion people, some 15 per cent of the global population. Apart from the loss of farm and forest production, the degraded areas represent a loss of NPP of about 800 million tonnes of carbon over the period, meaning this amount was not fixed from the atmosphere. In addition, there were emissions to the atmosphere of one or two orders of magnitude more than this from the loss of soil organic carbon and standing biomass (Bai and others 2007).

Areas of concern include tropical Africa south of the equator and southeast Africa, southeast Asia (especially steeplands), south China, north-central Australia, Central America and the Caribbean (especially steeplands and drylands), southeast Brazil and the Pampas, and boreal forests in Alaska, Canada and eastern Siberia. In areas of historical land degradation around the Mediterranean and West Asia, only relatively small areas of change are visible, such as in southern Spain, the Maghreb and the Iraqi marshlands. Comparison of black spots with land cover reveals that 18 per cent of land degradation by area is associated with cropland, 25 per cent is in broad-leaved forests and 17 per cent in boreal forests. This is consistent with trends in forest degradation, even as the area of boreal forests has increased (see section on Drivers and pressures). This preliminary analysis will need to be validated on the ground by the country-level case studies being undertaken by LADA, which will also determine the different types of degradation.

Changes in land

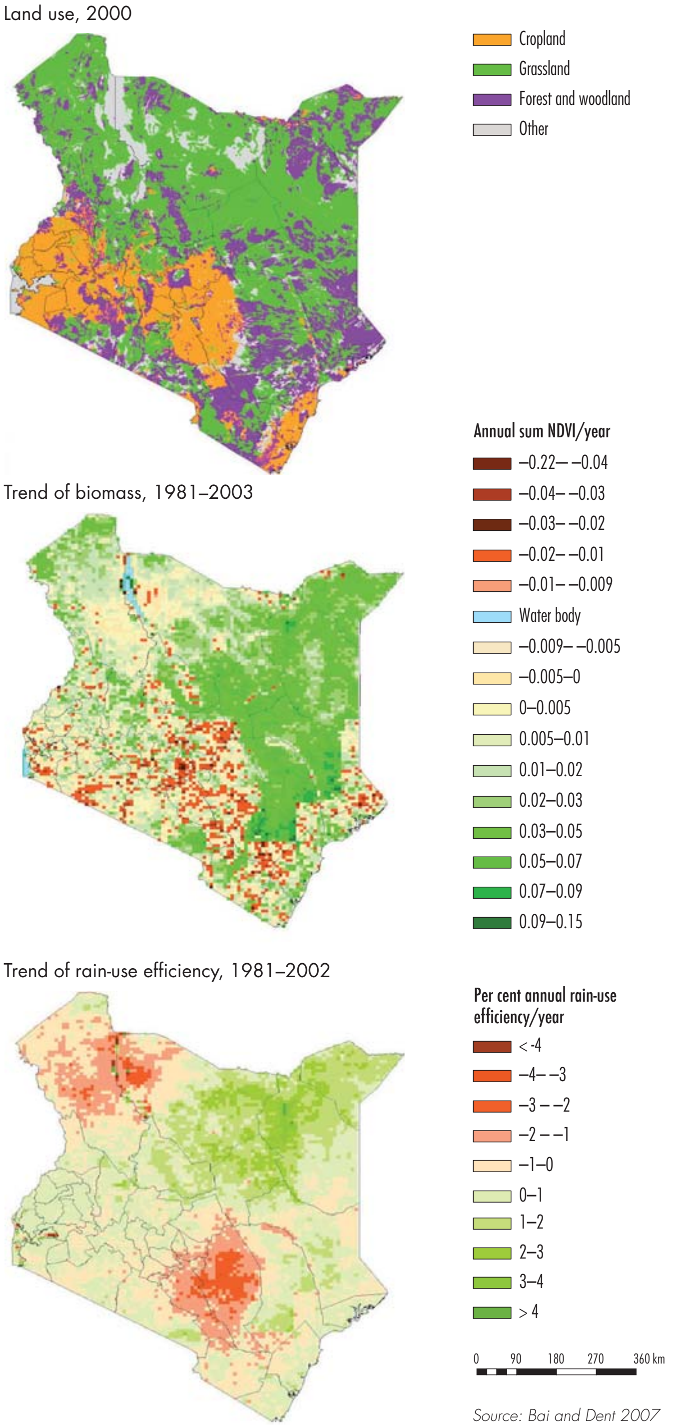
Chemical contamination and pollution

Chemicals are used in every aspect of life, including industrial processes, energy, transport, agriculture, pharmaceuticals, cleaning and refrigeration. More than 50 000 compounds are used commercially, hundreds are added every year, and global chemical production is projected to increase by 85 per cent over the next 20 years (OECD 2001). The production and use of chemicals have not always been accompanied by adequate safety measures. Releases, by-products and degradation of chemicals, pharmaceuticals and other

Box 3.3 Land degradation in Kenya

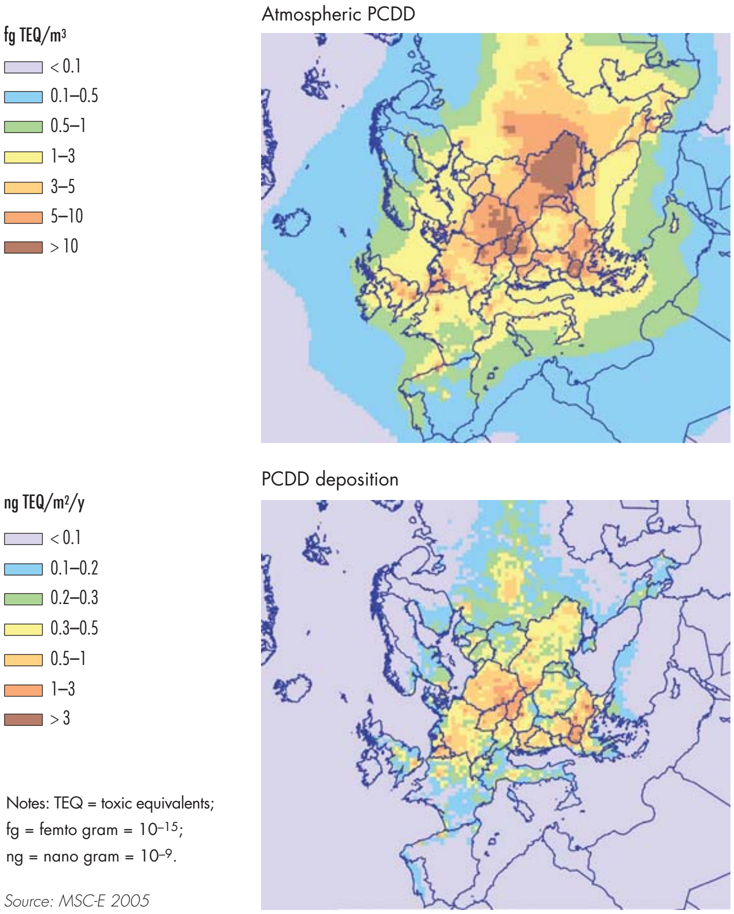
About 80 per cent of Kenya is dryland. The 25-year trends of biomass and rain-use efficiency highlight two *black spots* of land degradation: the drylands around Lake Turkana, and a swath of cropland in Eastern Province, corresponding to the recent extension of cropping into marginal areas (see the red areas in the bottom map).

Figure 3.7 Kenya land use, biomass and rain-use efficiency



Source: Bai and Dent 2007

Figure 3.8 PCDD (dioxin) in the atmosphere and deposition, 2003



Notes: TEQ = toxic equivalents;
fg = femto gram = 10^{-15};
ng = nano gram = 10^{-9}.

Source: MSC-E 2005

commodities contaminate the environment, and there is growing evidence of their persistence and their detrimental effects on ecosystems and on human and animal health.

Currently, there is insufficient information on the amounts released, their toxic properties, effects on human health and safe limits for exposure to fully evaluate their environmental and human health impacts. The magnitude of chemical contamination can be measured or estimated by the residue levels and spatial concentration of substances, but data are incomplete globally and for many regions. Proxies that provide some indication include total production of chemicals, total use of pesticides and fertilizers, generation of municipal, industrial and agricultural wastes, and the status of implementation of multilateral environmental agreements relating to chemicals.

Land is subjected to a wide range of chemicals from many sources, including municipalities, industries and agriculture. There are persistent organic pollutants (POPs) such as DDT, brominated flame retardants and polyaromatic hydrocarbons heavy metals, such as lead, cadmium and mercury, and oxides of nitrogen and sulphur. In mining, for instance, toxic substances such as cyanide, mercury and sulphuric acid are used to separate metal from ores, leaving residues in the tailings. Toxic chemicals may be emitted from identifiable point sources, such as stockpiles of hazardous waste, power generation, incineration and industrial processes. They also come from diffuse sources, such as vehicle emissions, the agricultural application of pesticides and fertilizers, as well as in sewage sludge containing residues of process chemicals, consumer products and pharmaceuticals.

Many chemicals persist in the environment, circulating between air, water, sediments, soil and biota. Some pollutants travel long distances to supposedly pristine areas (De Vries and others 2003). For example, POPs and mercury are now found in high concentrations in both people and wildlife in the Arctic (Hansen 2000) (see Figure 6.57 in the Polar section of Chapter 6). Chemical emissions to the atmosphere often become fallout on land or water. Figure 3.8 shows modelling results of the distribution of polychlorodibenzodioxins (PCDD) emissions and deposition in Europe for 2003.

Chemical wastes from industry and agriculture are a big source of contamination, particularly in developing countries and countries with economies in transition. The concentrations of persistent toxic substances observed in many parts of sub-Saharan Africa indicate that this contamination is widespread across the region. Stockpiles containing at least 30 000 tonnes of obsolete pesticides were recorded in Africa (FAO 1994). These stockpiles, often leaking, are up to 40 years old, and contain some pesticides banned long ago in industrialized countries. Environmental levels of toxic chemicals will increase in countries still using them in large quantities (such as Nigeria, South Africa and Zimbabwe), and in countries without effective regulation of their use (GEF and UNEP 2003). In addition, toxic wastes are still being exported to and dumped in developing countries. The dumping of hazardous wastes, such as the 2006 dumping of poisonous oil refinery waste containing hydrogen sulphide and organochloride in Abidjan, Ivory Coast, is still a major problem. This is despite such efforts as the 1991 Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa.

A legacy of contaminated industrial and urban sites is common to all old industrial heartlands, particularly in the United States, Europe and the former Soviet Union. Across Europe, it is estimated that there may be more than 2 million such sites, containing hazardous substances such as heavy metals, cyanide, mineral oil and chlorinated hydrocarbons. Of these, some 100 000 require remediation (EEA 2005). See Chapter 7 for additional information on exposing people and the environment to contaminants.

Increasingly, some of the chemical waste stream comes from everyday products; increasing consumption remains coupled to increased generation of wastes, including chemical wastes. Most domestic waste still goes into landfills, although in Europe there is a shift to incineration (EEA 2005).

There are growing differences in pollution trends between industrialized and developing countries. Between 1980 and 2000, control measures resulted in lower emissions of pollutants into the atmosphere and reduced deposition over most of Europe. Now, pollution as a result of consumer activities is outpacing pollution from primary industrial sources. While OECD countries are still the largest producers and consumers of chemicals, there has been a shift of chemical production to newly industrializing countries that, 30 years ago, had little or no chemicals industry. This shift in production has not always been accompanied by control measures, increasing the risks of release of hazardous chemicals into the environment.

The last 25 years have seen accumulating evidence of the serious consequences of chemicals for the environment and human well-being. In addition to directly harming human health, atmospheric pollutants have been implicated in increasing soil acidity and forest decline, and acidification of streams and lakes (see section on acidifying cycles), and have been linked to the burden of chronic diseases such as asthma. WHO estimates that each year, 3 million people suffer from severe pesticide poisoning, with as many as 20 000 unintentional deaths (Worldwatch Institute 2002). (See Chapter 2 under effects of air pollution).

Soil erosion

Erosion is the natural process of removal of soil by water or wind. Soil erosion becomes a problem when the natural process is accelerated by inappropriate land management, such as clearance of forest and grasslands followed by cropping which results in inadequate ground cover, inappropriate tillage and overgrazing. It is also caused by activities such as mining, infrastructural and urban developments without well-designed and well-maintained conservation measures.

Loss of topsoil means loss of soil organic matter, nutrients, water holding capacity (see section on water scarcity) and biodiversity, leading to reduced production on-site. Eroded soil is often deposited where it is not wanted, with the result that the off-site costs, such as damage to infrastructure, sedimentation of reservoirs, streams and estuaries, and loss of hydropower generation, may be much higher than the losses in farm production.

Although there is consensus that soil erosion is often a severe problem, there are few systematic measurements of its extent and severity. Indicators include barren ground, removal of topsoil as sheet erosion over a wide area or concentrated as rills and gullies, or through landslides. Wind erosion is the major problem in West Asia, with as much as 1.45 million km^2 – one-third of the region – affected. In extreme cases, mobile dunes encroach upon farmland and settlements (Al-Dabi and others 1997, Abdelgawad 1997). Regional or even global estimates have, quite wrongly, scaled up measurements made on small plots, arriving at huge masses of eroded soil that would reshape whole landscapes within a few decades. Erosion rates reported from Africa range from 5–100 tonnes/ha/yr, depending on the country and assessment method (Bojö 1996). Authors including den Biggelaar and others (2004) estimate that globally, 20 000–50 000 km^2 is lost annually through land degradation, chiefly soil erosion, with losses 2–6 times higher in Africa, Latin America and Asia than in North America and Europe. Other global and regional spatial data present vulnerability to erosion, modelled from topographic, soil, land cover and climatic variables, but vulnerability is not the same thing as actual erosion: the most important factor determining actual erosion is the level of land management (see Box 3.4).

Nutrient depletion

Nutrient depletion is a decline in the levels of plant nutrients, such as nitrogen, phosphorous and potassium, and in soil organic matter, resulting in declining soil fertility. It is commonly accompanied by soil acidification, which increases the solubility of toxic elements, such as aluminium. The causes and consequences of nutrient depletion are well-established: in a wet climate, soluble nutrients are leached from the soil, and everywhere crops take up nutrients. The removal of the harvest and crop residues depletes the soil, unless the nutrients are replenished by manure or inorganic fertilizers (Buresh and others 1997). Nutrient mining refers to high levels of nutrient removal and no inputs.

Deficiency of plant nutrients in the soil is the most significant biophysical factor limiting crop production across very large areas in the tropics, where soils are inherently poor. Several studies in the 1990s indicated serious nutrient depletion in many tropical countries, particularly in sub-Saharan Africa. Most calculations drew up nutrient budgets in which fluxes and pools were estimated from published data at country or sub-regional level. For example, the influential 1990 study by Stoorvogel and Smaling calculated budgets for nitrogen, phosphorus and

Box 3.4 Soil erosion in the Pampas

Soil erosion by water is the main form of land degradation in Latin America. The more extensive the area under cultivation, the more serious the erosion, even in the fertile Pampas. It has been an intractable problem, leading to the abandonment of farmland, for example, in northwest Argentina.

The most promising development has been the large-scale adoption of conservation tillage, which increases infiltration of rain into the soil compared to conventional ploughing. The area under conservation tillage in Latin America increased from almost zero in the 1980s to 250 000 km^2 in 2000, with an adoption rate of 70–80 per cent among large, mechanized farms in Argentina and Brazil, although the adoption rate by small farms is lower.

Sources: FAO 2001, KASSA 2006, Navone and Maggi 2005

In the Pampas, rills form during rainstorms when ground cover is sparse, and gradually turn into large gullies.

Credit: J.L. Panigatti

Poor crop performance due to nutrient deficiency compared with enhanced fertility around a farmstead, Zimbabwe.

Credit: Ken Giller

potassium for the cropland of 38 countries in sub-Saharan Africa for the years since 1983, and projected the data to 2000. In nearly every case, the nutrient inputs were less than the outputs. Some 950 000 km^2 of land in the region is threatened with irreversible degradation if nutrient depletion continues (Henao and Baanante 2006).

There has been criticism of the basis for such calculations, and debate on the extent and impact of nutrient depletion (Hartemink and van Keulen 2005), but broad agreement on the phenomenon. In some areas, nutrients have been depleted because of reduced fallow periods in shifting cultivation systems, and little or no inorganic fertilizer inputs. In other areas, soil fertility of cropland may be maintained or improved through biomass transfer at the expense of land elsewhere. Where such differences are explored in more detail, there are complex explanations including non-agronomic factors, such as infrastructure, access to markets, political stability, security of land tenure and investments.

Across most of the tropics, the use of inorganic fertilizers is limited by availability and cost, although inorganic fertilizers often have favourable value-to-cost ratios (van Lauwe and Giller 2006). In parts of sub-Saharan Africa, as little as 1 kilogramme of nutrients is applied per hectare. This compares with nutrient additions around 10–20 times higher in industrialized countries – and also much higher rates in most other developing countries (Borlaug 2003), where there is established evidence that leaching of nitrates into surface and groundwater, and wash-off of phosphates into streams and estuaries, can cause eutrophication (see Chapter 4).

Water scarcity

By 2025, about 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under conditions of water stress – the threshold for meeting the water requirements for agriculture, industry, domestic purposes, energy and the environment (UN Water 2007). This will have major impacts on activities such as farming (see Chapter 4).

The source of all freshwater is rainfall, most of which is held in the soil, and returns to the atmosphere by evapotranspiration (*green water*). Globally, only 11 per cent of the freshwater flow is available as usable stream flow and groundwater that can be tapped for irrigation, urban and industrial use, potable and stock water (see Figure 3.1). Yet, nearly all investment goes into the management of the water withdrawn from streams and groundwater. While irrigated agriculture is overwhelmingly the biggest user of freshwater, and already draws substantially on groundwater that is not being replenished, it faces increasing competition from other claims (see Figure 4.4). To meet the Millennium

Development Goal (MDG) of halving the proportion of people suffering from hunger by 2015, it will be necessary to manage freshwater resources from the moment that rainwater hits the land surface. This is where soil management determines whether rain runs off the surface, carrying topsoil with it, or infiltrates the soil to be used by plants or to replenish groundwater and stream flows.

Ecosystems and farming systems have adapted to water scarcity in various ways (see Table 3.5). Outside arid and semi-arid areas, absolute lack of water is not the issue; there is enough water to produce a crop in most years. For example in Eastern Africa, meteorological drought (a period when there is not enough water to grow crops because of much below average rainfall) happens every decade. Dry spells of 2–5 weeks in the growing season happen every 2–3 years (Barron and others 2003). Agricultural drought (drought in the root zone) is much more frequent, while political drought, where various failings are attributed to drought, is commonplace. Agricultural drought is more common than meteorological drought because, on cultivated land, most rainfall runs off the surface, and soil water storage is diminished by soil erosion, resulting in poor soil structure, loss of organic matter, unfavourable texture and impeded rooting. Farmers' field water balances show that only 15–20 per cent of rainfall actually contributes to crop growth, falling to as little as 5 per cent on degraded land (Rockström 2003).

Rainfall may not be the main factor limiting crop production. Tracts of land also suffer from nutrient deficiency (see section on nutrient depletion). While commercial farmers maintain nutrient status by applying fertilizer, risk-averse subsistence farmers do not invest in overcoming other constraints unless the risk of drought is under control.

Irrigation is arguably the most successful insurance against drought. Irrigated land produces 30–40 per cent of global farm output, and a far higher proportion of high-value crops, from less than 10 per cent of the farmed area. Water withdrawals for irrigation have increased dramatically, to about 70 per cent of global

Table 3.5 Ecosystem and farming system responses to water scarcity

Zone	**Extent** (per cent of global land surface)	**Rainfall** (mm) **(Aridity index)** (Rainfall/Potential evaporation)	**Growing season** (days)	**Water-related risks**	**Ecosystem type**	**Rain-fed farming system**	**Risk management strategies**
Hyper-arid	7	<200 (<0.05)	0	Aridity	Desert	None	None
Arid	12	<200 (0.05–0.2)	1–59	Aridity	Desert- desert scrub	Pastoral, nomadic or transhumance	Nomadic society, water harvesting
Semi-arid	18	200–800 (0.2–0.5)	60–119	Drought 1 year in 2, dry spells every year, intense rainstorms	Grassland	Pastoral and agro-pastoral: rangeland, barley, millet, cow-pea	Transhumance, water harvesting, soil and water conservation, irrigation
Dry sub-humid	10	800–1 500 (0.5–0.65)	120–179	Drought, dry spells, intense rainstorms, floods	Grassland and woodland	Mixed farming: maize, beans, groundnut, or wheat, barley and peas	Water harvesting, soil and water conservation, supplementary irrigation
Moist sub-humid	20	1 500–2 000 (0.65–1)	180–269	Floods, waterlogging	Woodland and forest	Multiple cropping, mostly annuals	Soil conservation, supplementary irrigation
Humid	33	>2 000 (>1)	>270	Floods, waterlogging	Forest	Multiple cropping, perennials and annuals	Soil conservation, drainage

Note: Drought-susceptible drylands are highlighted (see Figure 3.9)

Source: Adapted from Rockström and others 2006 water withdrawals (see Figure 4.4). One-tenth of the world's major rivers no longer reach the sea during some part of the year, because water is extracted upstream for irrigation (Schiklomanov 2000). However, limits to the growth of irrigation are in sight, and much of further development is likely to be marginal in terms of returns on investment (Fan and Haque 2000), and in terms of trade-offs against salinity (see section on *Salinity*) and ecosystem services.

Salinity

Soils, streams and groundwater in drylands contain significant amounts of naturally-occurring salt, which inhibits the absorption of water by plants and animals, breaks up roads and buildings, and corrodes metal. Soils containing more than 1 per cent soluble salt cover 4 million km^2, or about 3 per cent of the land (FAO and UNESCO 1974–8). Salinity is defined by the desired use of land and water; it is salt in the wrong place when found in farmland, drinking and irrigation water, and in freshwater habitats. It is caused by inappropriate forms of land use and management. Irrigation applies much more water than rainfall and natural flooding and, nearly always, more than can be used by crops. The added water itself contains salt, and it mobilizes more salt that is already in the soil. In practice, leakage from irrigation canals, ponding because of poor land levelling and inadequate drainage raise the water table. Once the water table rises close to the soil surface, water is drawn to the surface by evaporation, further concentrating the salt, which may eventually create a salt crust on the soil surface.

Increasing water withdrawals for irrigation increase the likelihood of salinity (see Box 3.5) when there is inadequate drainage to carry the salt out of the soil. This is a threat to livelihoods and food security in dry areas, where most farm production is from irrigation and farmers use whatever water is available, however marginal, even on land with a high, saline water table. In the long run, this renders the land unproductive. Salinity will increase unless the efficiency of irrigation networks, in particular, is greatly improved.

Salinity induced by irrigation in the Euphrates basin in Syria.

Credit: Mussaddak Janat, Atomic Energy Commission of Syria

Dryland salinity, as distinct from irrigation-induced salinity, is caused by the replacement of natural vegetation with crops and pastures that use less water, so that more water infiltrates to the groundwater than before. The rising, saline groundwater drives more salt into streams, and, where the water table comes close to the surface, evaporation pulls salt to the surface.

Worldwide, some 20 per cent of irrigated land (450 000 km^2) is salt-affected, with 2 500–5 000 km^2

Box 3.5 Irrigation and salinity in West Asia

Saline soils cover up to 22 per cent of the arable land in West Asia, ranging from none in Lebanon to 55–60 per cent in Kuwait and Bahrain. Salinity is increasing through both excessive irrigation and seawater intrusion into depleted coastal aquifers.

Over the last 20 years, irrigated land in West Asia increased from 4 100 to 7 300 km^2, raising food and fibre production, but at the expense of rangelands and non-renewable groundwater. Agriculture consumes 60–90 per cent of the accessible water, but contributes only 10–25 per cent of GDP in Mashriq countries, and 1–7 per cent in Gulf Cooperation Council countries.

Generally, water is used inefficiently in flood and furrow irrigation systems, and for crops with high water demand. Field water losses, combined with leakage from unlined canals, exceed half of the water withdrawn for irrigation. In some areas, withdrawals are far greater than rates of recharge, and aquifers have been rapidly depleted. Yet, the main measures adopted have been largely limited to the introduction of costly sprinkler and drip irrigation systems.

Sources: ACSAD and others 2004, Al-Mooji and Sadek 2005, FAOSTAT 2006, World Bank 2005 lost from production every year as a result of salinity (FAO 2002, FAO 2006b). In Australia, for example, the National Land and Water Resources Audit (NLWRA 2001) estimated 57 000 km^2 of land to be at risk of dryland salinity, and projected three times as much in 50 years. There is underlying concern about the inexorable increase in river water salinity driven by rising water tables; it is predicted that up to 20 000 kilometres of streams may be significantly salt-affected by 2050 (Webb 2002).

Disturbances in biological cycles

Water, carbon and nutrient cycles are the basis of life. The integrity of these cycles determines the health and resilience of ecosystems, and their capacity to provide goods-and-services. Agriculture depends on manipulating parts of these cycles, often at the expense of other parts of the same cycle. Links between the carbon cycle and climate change are now well established (see Box 3.6). While the burning of fossil fuels has greatly disturbed the carbon cycle, land-use change has been responsible for about one-third of the increase in atmospheric carbon dioxide over the last 150 years, mainly through loss of soil organic carbon. Also well established are the links between soil erosion and sediment deposition, between fertilizers and eutrophication, and between emissions of sulphur and nitrogen oxides to the atmosphere and acid contamination of land and water.

Box 3.6 Disturbances in the carbon cycle due to losses of soil organic matter

Land-use change over the past two centuries has caused significant increases in the emissions of CO_2 and methane into the atmosphere. There are large uncertainties in the estimates, though, especially for soils. Clearance of forests causes a significant initial loss of biomass, and, where native soil organic content is high, soil organic carbon declines in response to conversion to pasture and cropland. Under cultivation, soil organic matter declines to a new, lower equilibrium, due to oxidation of organic matter.

Significant emissions also result from drainage of wet, highly organic soils and peat, as well as from peat fires. Higher temperatures, for example associated with forest fires and climate change, increase the rate of breakdown of soil organic matter and peat. Half of the organic carbon in Canadian peatlands will be severely affected, and permafrost carbon is likely to be more actively cycled. Warming will also release significant stores of methane presently trapped in permafrost.

While there has been a decline in the emissions from Europe and North America since the mid-20th century, emissions from tropical developing countries have been increasing, resulting in continued increases in overall global emissions due to land use change. The region of Asia and the Pacific accounts for roughly half of global emissions.

Sources: Houghton and Hackler 2002, Prentice and others 2001, Tarnocai 2006, UNFCCC 2006, Zimov and others 2006

Nutrient cycles: Soil fertility and chemistry are closely interwoven. Many elements in the soil participate in cycles of plant nutrition and growth, decomposition of organic matter, leaching to surface water and groundwater, and transport to the oceans. Nitrogen and phosphorus are the nutrients required in largest amounts, and there is concern about both the prospects of continued availability of chemical supplements and the resulting disturbance of these cycles.

The tiny fraction of atmospheric nitrogen made available to biological cycles through natural fixation restricted plant production until the industrial production of nitrogen fertilizers in the early 20th century. Today, the food security of two-thirds of the world's population depends on fertilizers, particularly nitrogen fertilizer. In Europe, 70–75 per cent of nitrogen comes from synthetic fertilizers; at the global scale, the proportion is about half. Some nitrogen is also fixed by legumes, with the balance of nitrogen coming mostly from crop residues and manure. However, crops take up only about half of the applied nitrogen. The rest is leached into streams and groundwater, or lost to the atmosphere. Losses of nitrogen from animal wastes account for 30–40 per cent, half of this escaping into the atmosphere as ammonia. Very high emissions are recorded from the Netherlands, Belgium, Denmark and the province of Sichuan in China. Annual emissions of reactive nitrogen from combustion of fossil fuels amount to about 25 million tonnes (Fowler and others 2004, Li 2000, Smil 1997, Smil 2001).

Enhanced levels of reactive nitrogen are now found from deep aquifers to cumulonimbus clouds, and even in the stratosphere, where N_2O attacks the ozone layer. There are concerns that elevated levels of nitrates in drinking water are a health hazard, particularly to very young children. Established evidence links enhanced concentrations of nitrates and phosphates to algal blooms in shallow lakes and coastal waters. Two of the largest blooms are in the Baltic Sea (Conley and others 2002) and in the Gulf of Mexico, off the mouth of the Mississippi River (Kaiser 2005). By-products of the algae are toxic to animals, while the decomposition of these huge masses of organic matter depletes the oxygen dissolved in water, causing fish kills (see Chapter 4).

Acidifying cycles: Oxides of carbon (CO_2), nitrogen (NO_X) and sulphur (SO_X) are released to the atmosphere by decomposing organic matter and burning fossil fuels (see Chapter 2). SO_X are also produced by the smelting of sulphidic ores. Total emissions of SO_X from human activities are about equal to natural production, but they are concentrated in northern mid-latitudes. Large areas of eastern North America, western and central Europe, and eastern China experience SO_X deposition in the range of 10–100 kg S/ha/yr. In addition, NO_X deposition now exceeds 50 kg/ha/yr in central Europe and parts of North America.

As a result of such emissions, the pH of rainfall in polluted areas can be as low as 3.0–4.5. Where soils are weakly buffered, this translates to more acid streams and lakes, associated with increased solubility of toxic aluminium and heavy metals. Since 1800, soil pH values have fallen by 0.5–1.5 pH units over large parts of Europe and eastern North America. They are expected to fall by a further pH unit by 2100 (Sverdrup and others 2005). Canada and Scandinavia have been most severely affected by acidic precipitation in recent decades, suffering loss of phytoplankton, fish, crustaceans, molluscs and amphibians. Emission controls and rehabilitation efforts have slowed or even reversed freshwater acidification in some areas (Skjelkvåle and others 2005). The jury is still out on the forest decline predicted in the mid-1980s for Europe and North America, but acidification may be contributing to the biomass losses in boreal forests indicated in Figure 3.3. However, the risks of acidification from coal-powered industry are rising elsewhere, particularly in China and India.

Acidification is not just a problem arising from air pollution. Extreme cases develop when soils and sediments rich in sulphides are drained and excavated, for example, through the conversion of mangroves to aquaculture ponds or urban developments. In these acid sulphate soils, sulphuric acid produces pH values as low as 2.5, mobilizing aluminium, heavy metals and arsenic, which leak into the adjacent aquatic environment, causing severe loss of biodiversity (van Mensvoort and Dent 1997).

Managing land resources

Chemical contamination and pollution

Increasing awareness of the negative effects of chemical contamination and pollution is leading to stringent regulations in many industrialized countries. Since the 1992 UN Conference on Environment and Development, the risks associated with chemicals and the transboundary movements of pollutants have been widely recognized. Chemicals management is now addressed by 17 multilateral agreements and 21 intergovernmental organizations and coordination mechanisms. The Basel Convention on the International Movement of Hazardous Wastes, the Rotterdam Convention on Certain Hazardous Chemicals in International Trade, and the Stockholm Convention on Persistent Organic Pollutants aim to control international traffic of hazardous chemicals and wastes that cannot be managed safely. Regional agreements include the Bamako Convention, which was adopted by African governments in 1991 and the European Union's REACH (see Box 3.7).

There has been a significant reduction in the use of some toxic chemicals, and safer alternatives are being identified. Voluntary initiatives, such as the chemical industry's Responsible Care programme encourage companies to work towards continuous improvement of their health, safety and environmental performance. A number of major chemical industries have made significant reductions in their emissions.

A Strategic Approach to International Chemicals Management (SAICM) was agreed to by more than 100 environment and health ministers in Dubai in 2006, following the ninth Special Session of the UNEP Governing Council/Global Ministerial Environment Forum. It provides a non-binding policy framework for achieving the goal of the Johannesburg Plan of Implementation: that, by 2020, chemicals are produced and used in ways that minimize adverse effects on the environment and human health. This requires responsibility for and reductions in pollution.

Box 3.7 Soil protection from chemicals in the European Union

In the European Union, evaluation of the effects of chemical pollutants on soil communities and terrestrial ecosystems provides a basis for soil protection policy. The Soil Framework Directive will require member states to take appropriate measures to limit the introduction of dangerous chemicals to the soil, and to identify and remediate contaminated sites.

The new REACH legislation (Registration, Evaluation, Authorisation and Restriction of Chemicals), that entered into force in June 2007, requires manufacturers and importers of chemicals to prove that substances in widely-used products, such as cars, clothes or paint, are safe, while the properties of chemicals produced or imported into the European Union have to be registered with a central agency.

Source: European Commission 2007

Chemicals and materials are to be selected for use on the basis of their non-toxicity, waste should be minimized, and products at the end of their useful life should re-enter production as raw materials for the manufacture of new products.

All these instruments depend on institutional capacity and political will. They are undermined by limited political commitment, legislative gaps, weak inter-sectoral coordination, inadequate enforcement, poor training and communication, lack of information, and failure to adopt a precautionary approach. (Until the 1990s, chemicals were considered "innocent" until proven "guilty"). While regulations to control environmental loadings have established maximum allowable limits for releases of certain chemicals, observed concentrations are often still much higher than the set limits. In addition, there are areas of uncertainty that argue for a precautionary approach. These areas of uncertainty include trigger mechanisms that may suddenly cause potentially toxic contaminants to become more harmful; triggers include a change of location, for instance through the rupture of a retaining dam, or change of chemical state, such as through oxidation of excavated materials.

Existing multilateral and regional agreements offer an opportunity to arrest and eventually reverse the increasing releases of hazardous chemicals. Prerequisites for success include:

- full integration of a precautionary approach in the marketing of chemicals, shifting the burden of proof from regulators to industry;
- development of adequate chemicals management infrastructure in all countries, including laws and regulations, mechanisms for effective enforcement and customs control, and capacity to test and monitor;
- substitution with less-hazardous materials, adoption of best available technologies and environmental practices, and easy access to these approaches for developing countries and countries with economies in transition;
- encouragement of innovation in manufacturing, non-chemical alternatives in agriculture, and waste avoidance and minimization; and
- inclusion of environmental issues related to chemicals in regular educational curricula, and in partnership processes between academia and industry.

Soil erosion

Widespread attempts to mitigate soil erosion have met with mixed success. National responses have been directed towards legislation, information, credits and subsidies, or specific conservation programmes. Local responses have been generated by land users themselves (Mutunga and Critchley 2002), or introduced by projects. At the technical level, there is a wealth of proven approaches and technologies, from improved vegetation cover and minimum tillage to terracing (see photos on facing page). These useful experiences (both positive and negative) are not well documented. The World Overview of Conservation Approaches and Technologies network (WOCAT 2007) aims to fill this gap through collection and analysis of case studies from different agro-ecological and socio-economic conditions. But the usual focus on technical aspects misses the more complex, underlying political and economic issues that must also be addressed, an issue already advocated since the early 1980s (Blaikie 1985).

Substantial investment in soil conservation over past decades has yielded some local successes, but, except for conservation tillage (see Box 3.4), adoption of recommended practices has been slow and seldom spontaneous. A historic success story is the programme undertaken in the United States following the Dust Bowl in the 1930s, when drought triggered massive soil erosion in the US Midwest, and millions of people lost their livelihoods and were forced to migrate (see Box 3.8). The way the issue was handled provides an object lesson and inspiration for today. The clear message is that effective prevention and control of soil erosion needs knowledge, forceful social and economic policy, well-founded institutions maintaining supporting services, involvement of all parties, and tangible benefits to the land users. Nothing less than the whole package, continuing over generations, will be effective (see Box 3.10 and the section on responses to desertification).

Nutrient depletion

There is no remedy for soils that are deficient in nutrients other than adding the necessary inputs. Efforts to improve soil fertility have focused on the replenishment of nutrients by the judicious use of inorganic fertilizers and organic manure. This has been very successful in many parts of the world, and is responsible for a very large increase in agricultural production. Yields may be doubled or tripled on a sustained basis by even modest

Soil and water management measures against erosion and water scarcity.
Left: Micro-basins;
Centre: Mulch;
Right: Conservation tillage.
Credit: WOCAT

application of fertilizer (Greenland 1994). In Niger, for instance, sorghum yields without fertilizer (about 600 kg/ha) were doubled by application of 40 kg/ha of nitrogen fertilizer (Christianson and Vlek 1991). However, the use of inorganic fertilizers requires cash, which can be an insurmountable barrier for most smallholders in developing countries, where inputs are rarely subsidized.

There are myriad indigenous practices to mitigate nutrient constraints, such as bush fallow, biomass transfer to home fields, and adding compost and manure on favoured plots. However, these are failing to keep up with production needs in the face of increasing population pressure, and lack of adequate funds for labour or mechanization. In recent years, significant research efforts have focused on biological processes to optimize nutrient cycling, minimize external inputs and maximize nutrient use efficiency. Several techniques have been developed, including the integration of multipurpose legumes, agroforestry and improved fallows, but scientific breakthroughs and large-scale adoption by smallholder farmers are yet to materialize.

Nutrient depletion is not the same everywhere, because it depends on a series of interacting causes, and depletion processes are different for

Box 3.8 The success story of the Dust Bowl

In the United States in the late 1920s, good crop yields and high prices for wheat encouraged a rapid increase in the cropped area. When drought hit in the following decade, there was catastrophic soil erosion, and many were driven from the land; by 1940, 2.5 million people had left the Great Plains.

During the 1930s, the US Government responded with a comprehensive package of measures, both to give short-term relief, mitigating economic losses, and providing for long-term agricultural research and development. Examples of these initiatives include:

- the Emergency Farm Mortgage Act – to prevent farm closures by helping farmers who could not pay their mortgages;
- the Farm Bankruptcy Act – restricting banks from dispossessing farmers in times of crisis;
- the Farm Credit Act – a system of local banks to provide credit;
- stabilizing the prices of agricultural commodities;
- Federal Surplus Relief that directed commodities to relief organizations;
- the Drought Relief Service – buying cattle in emergency areas at reasonable prices;
- the Works Progress Administration – which provided employment for 8.5 million people;
- the Resettlement Administration – buying land that could be set aside from agriculture; and
- the Soil Conservation Service, set up within the Department of Agriculture, which developed and implemented new soil conservation programmes underpinned by a detailed, nationwide soil survey.

As a result of this long-term, comprehensive package of responses, natural, social, institutional and financial capital has been rebuilt. Combined with the good use of science and technology, subsequent droughts have been ridden out and the US Midwest is now a prime agricultural region.

Source: Hansen and Libecap 2004

different nutrients. There is a need for much better spatial information at regional and local scales, and for better soil management technologies to improve responses. Techniques to reduce nutrient depletion and enhance soil fertility vary, depending on the soils and farming systems. Improved soil management, including rotation of annual with perennial crops, and the integration of trees into farming systems, can improve the efficiency of nutrient cycling by maintaining the continuity of uptake, and reducing leaching losses. Nitrogen stocks can be maintained through biological nitrogen fixation (by integrating legumes into cropping systems), but nitrogen fixing is limited by available phosphorus, which is very low in many tropical soils. For severely nutrient-deficient soils, there is no remedy other than additions from outside sources.

Water scarcity

Achieving the MDG on reducing hunger will require an increase of 50 per cent in water use by agriculture by 2015, and a doubling by 2050, whether by farming more land or by withdrawing more water for irrigation (SEI 2005). For developing countries, FAO (2003) projects an increase of 6.3 per cent in rain-fed cropland area between 2000 and 2015, and of 14.3 per cent by 2030. It also projects an increase in irrigated area of almost 20 per cent from 2000 to 2015, and to just over 30 per cent by 2030. Large dams continue to be built, because they promise certainty of supply of water and power to downstream interests, but the same investment has not gone into the catchments that supply the water. On the contrary, the last 20 years have seen continued squandering of the *green water* resource through soil erosion, and higher rates of run-off, which has increased floods at the expense of base flow. This has also resulted in siltation of reservoirs, such as those behind the Victoria Dam on the Mahaweli River in Sri Lanka (Owen and others 1987) and the Akasombo Dam on the Volta River in Ghana (Wardell 2003).

While irrigated yields will always be higher than rain-fed yields, there is much scope for improving rain-fed farming on vast areas. In Africa, average cereal yields range from 0.91 tonnes/ha in Western Africa to 1.73 tonnes/ha in Northern Africa (GEO Data Portal, from FAOSTAT 2004), while commercial farmers operating in the same soil and climatic conditions achieve 5 tonnes/ha or more. Established, though incomplete evidence, suggests that two-thirds of the necessary increase in production needed from rain-fed farming can be achieved through better rain-use efficiency (SEI 2005). Analysis of more than 100 agricultural development projects (Pretty and Hine 2001), found a doubling of yields in rain-fed projects, compared with a 10 per cent increase for irrigation (see Box 3.9).

More crop production means more water use by crops, whether through irrigation or increase in the cropped area. However, established evidence also shows that investment in water productivity

Box 3.9 Gains can be made through better water use efficiency

Low yields with sparse ground cover result in a large, unproductive loss of water by run-off and evaporation from bare soil. In semi-arid areas, doubling of yield from 1–2 tonnes/ha may increase water productivity from 3 500 m^3/tonne of grain to 2 000 m^3/tonne. Improvements in water use efficiency may be achieved in various ways, some of which are illustrated, under responses to soil erosion.

- Short-duration, drought-resistant crops can be matched to a short growing season.
- Water can be funnelled to crops from micro-catchments in the field, which can increase crop water use by 40–60 per cent without any loss in groundwater recharge, simply by reducing evaporation and allowing micro-basins to hold run-off until it can infiltrate.
- Mulch can be used to absorb raindrop impact, and provide organic matter and insulation against high surface temperatures, enabling soil animals to create a permeable soil structure.
- Conventional ploughing can be replaced by deep ripping with minimum disturbance of the topsoil; such conservation tillage improves infiltration while greatly reducing draught-power requirements.
- Dramatic improvements in yield and water-use efficiency may be achieved by supplementary irrigation, not to provide the crop's full water requirements but to bridge dry spells. At Aleppo, Syria, application of 180, 125 and 75 mm of water in dry, median and wet years, respectively, increased wheat yield by 400, 150 and 30 per cent. Such volumes of water can be harvested in micro-catchments outside the cropped area, using many local systems that can be affordable as household or small community ventures.

Sources: Oweis and Hachum 2003, Rockström and others 2006

– achieving more crop per drop – can help maintain water supply downstream (Rockström and others 2006), and appropriate land use and soil management can increase groundwater recharge and stream base flow (Kauffman and others 2007).

Responses to water scarcity have focused on run-off management, water abstraction, and demand management. New policies need to focus on rainwater management, and address the competing claims on water resources. In practice, a package of mutually supporting measures and concerted action from interested parties should include:

- capacity building for land and water management institutions;
- investment in education, and training of land and water managers; and
- a mechanism to reward land users for managing water supply at the source, involving payments for environmental services (Greig-Gran and others 2006).

Salinity

FAO and regional organizations have established collaborative programmes to reduce water losses from canals, match field application with the needs of the crop and drain surplus water to arrest rising water tables (FAO 2006b). However, investment in management and improvement of irrigation networks, especially in drainage and on-farm water use, has rarely been commensurate with the capital investment in water distribution.

Dryland salinity is caused by changes in the hydrological balance of the landscape, which are driven as much by fluctuations in rainfall as by land-use change. Piecemeal tree planting and crop management to reduce groundwater recharge has no chance of arresting groundwater flow systems that are orders of magnitude bigger. In both cases, successful intervention depends on information on the architecture and dynamics of groundwater flow systems (Dent 2007), and the technical capacity to act on this information. As with soil erosion, a focus on technical issues has diverted attention from wider issues of water rights and payments, the need for capacity building in managing institutions, and implementation of national and transboundary agreements. Salinity is sometimes only a symptom of underlying failures in management of common resources.

Disturbances in biological cycles

The excess of nutrients in regions such as Europe and North America has prompted the setting of legal limits on the application of manure and fertilizers. For instance, under the EU Nitrate Directive (Council Directive 91/676/EEC), the application of nitrate fertilizers has been restricted in some areas susceptible to groundwater pollution by nitrates. An evaluation 10 years after the directive went into force concluded that some farm practices have positive effects on water quality, but emphasized that there is a considerable time lag between improvements at farm level and measurable improvements in water quality (European Commission 2002).

The investment in the management and improvement of irrigation networks has rarely been commensurate with the capital investment in water distribution.

Credit: Joerg Boethling/ Still Pictures

Helicopter spreading lime over an acidified lake in Sweden.

Credit: Andre Maslennikov/ Still Pictures

The reductions in acid gas emissions in Europe and North America has been one of the success stories of recent decades. It involved domestic regulations, innovations by some industries and international coordination (see mainly Chapter 2). This included agreements such as the 1979 UN/ECE Convention on Large Transboundary Air Pollution and the Canada-US Air Quality Agreement. The ECE convention adopted the concept of critical loads in 1988, and the Gothenburg Protocol in 1999 regulated emissions of SO_X and NO_X, defining critical loads according to best current evidence.

Global emissions of SO_2 were reduced by about 2.5 per cent between 1990 and 2000 (GEO Data Portal, from RIVM-MNP 2005), as a result of clean air acts promoting a switch to cleaner fuels and flue gas desulphurization, and the demise of heavy industries, particularly in Eastern Europe and the former Soviet Union. However, many areas still receive acid deposition well in excess of critical loads (for example, Nepal, China, Korea and Japan) and total global emissions are rising again, driven by newly industrialized countries (see Figure 2.8). China alone accounts for about one-quarter of global SO_2 emissions (GEO Data Portal, from RIVM-MNP 2005), and its coal-fired industrial development is likely to significantly increase acid emissions (Kuylenstierna and others 2001). Long-term liming programmes are in place in several countries to mitigate enhanced acidic inputs into inland waters.

When it comes to controlling acid soil drainage, only Australia has enacted specific planning regulations to prevent the formation of acid sulphate soils. Any response to acid sulphate drainage from mines and soil has usually been restricted to liming of the acidified soil or spoil heaps but Trinity Inlet in North Queensland, Australia, provides a recent example of remediation through controlled restoration of tidal flooding, whereby existing acidity is neutralized by tidewater, and re-establishment of a tidal regime stops further acid generation (Smith and others 2003).

DESERTIFICATION

Extent and impacts

Desertification occurs when individual land degradation processes, acting locally, combine to affect large areas of drylands. As defined by the UN Convention to Combat Desertification (UNCCD), desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (UNGA 1994). It is most sharply expressed in poor countries where intertwined socio-economic and biophysical processes adversely affect both land resources and human well-being. Drylands cover about 40 per cent of the Earth's land surface (see Figure 3.9) and support 2 billion people, 90 per cent of them in developing countries (MA 2005b). But desertification is not confined to developing countries; one-third of Mediterranean Europe is susceptible (DISMED 2005) as well as 85 per cent of rangelands in the United States (Lal and others 2004). (See Chapter 7 for more information on issues related to drylands).

Desertification endangers the livelihoods of rural people in drylands, particularly the poor, who depend on livestock, crops and fuelwood. Conversion of rangelands to croplands without significant new inputs brings about a significant, persistent loss of productivity and biodiversity, accompanied by erosion, nutrient depletion, salinity and water scarcity. In 2000, the average availability of freshwater for each person in drylands was 1 300 m^3/year, far below the estimated minimum of 2 000 m^3/year needed for human well-being, and it is likely to be further reduced (MA 2005b). Measured by indicators of human well-being and development, dryland developing countries lag far behind the rest of the world. For instance, the average infant mortality rate (54 per thousand) is 23 per cent higher than in non-dryland developing countries and 10 times that of industrialized countries.

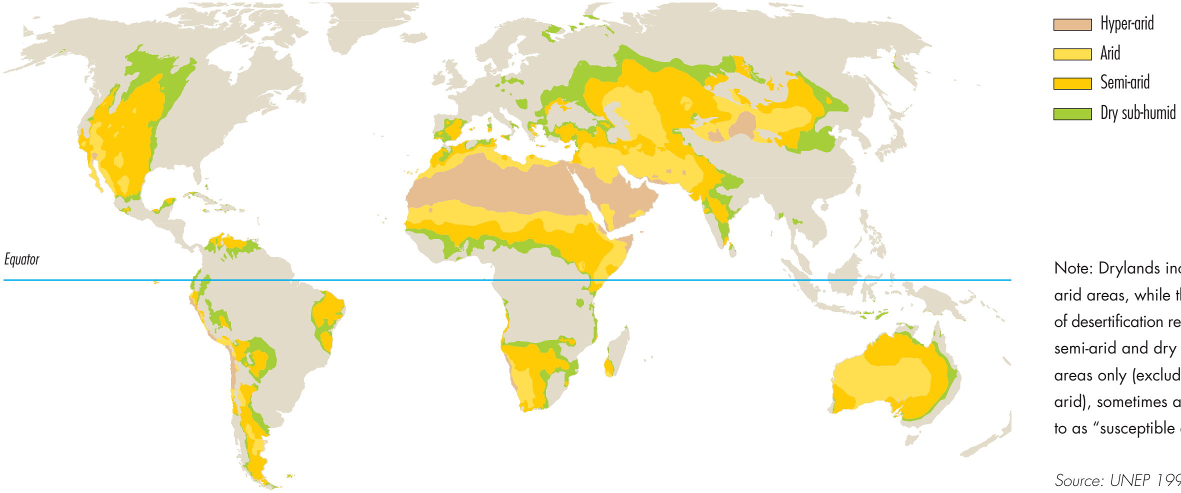
The seriousness of the issue is recognized by the UNCCD, the Convention on Biological Diversity (CBD) and the UN Framework Convention on Climate Change (UNFCCC). The New Partnership for Africa's Development also stresses the need to combat desertification as an essential component of poverty-reduction strategies. However, investment and action to combat desertification have been held back by the isolation of drylands from mainstream development, and even by controversy over the use of the term. Debate about desertification has been fuelled by alarming articles in the popular media about "encroaching deserts," reinforced by a series of droughts from the 1960s through the 1980s (Reynolds and Stafford Smith 2002).

Desertification is determined by various social, economic and biophysical factors, operating at local, national and regional scales (Geist and Lambin 2004). A recurring combination embraces national agricultural policies, such as land redistribution and market liberalization, systems of land tenure that are no longer suited to management imperatives, and the introduction of inappropriate technologies. Usually, the direct cause has been the expansion of cropping, grazing or wood exploitation. National and local policies to promote sustainable practices must take account of a hierarchy of drivers, from the household to the international level. This can be difficult where the indirect drivers, such as global trade imbalances, seem remote from these marginal lands, and when mechanisms for bottom-up decision-making are poorly developed.

Desertification is a continuum of degradation, crossing thresholds beyond which the underpinning ecosystem cannot restore itself, but requires ever-greater external resources for recovery. Resilience is lost when a disturbance, which a system used to be able to absorb, tips the system to a less desirable state from which it cannot easily recover (Holling and others 2002). Loss of ecosystem resilience is often accompanied by a breakdown in social resilience and adaptive capacity, when vulnerable people are forced to draw on limited resources with diminished coping strategies (Vogel and Smith 2002). For example, loss of resilience of parklands (integrated tree-crop-livestock systems) may result when the trees are cleared, exposing the land to erosion. Adaptive management aims to prevent ecosystems from crossing these thresholds by maintaining ecosystem resilience as opposed to seeking only narrow, production or profit objectives (Gunderson and Pritchard 2002).

Although indicators of desertification have been proposed ever since the term was introduced (Reining 1978), lack of consistent measurement over large areas and over time has prevented reliable assessment. Over the long term, ecosystems are governed by slowly-changing biophysical and socio-economic factors. Measurable indicators for these

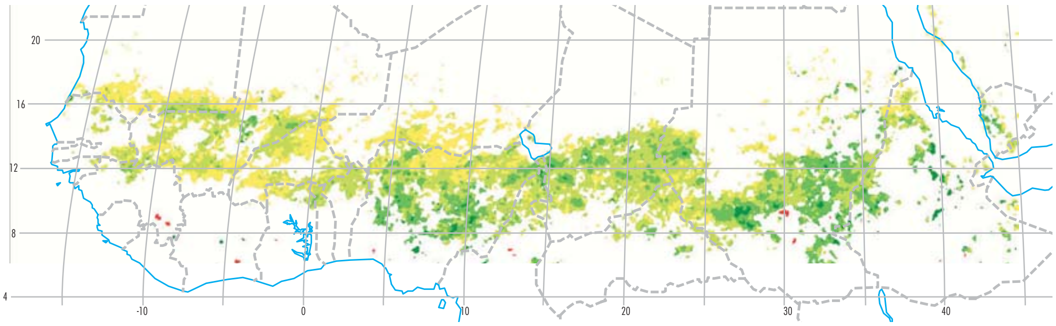
Figure 3.9 Drylands – defined by the long-term mean of the ratio of annual precipitation to potential evapotranspiration



Note: Drylands include hyper-arid areas, while the definition of desertification relates to arid, semi-arid and dry sub-humid areas only (excluding hyper-arid), sometimes also referred to as "susceptible drylands."

Source: UNEP 1992

Figure 3.10 Trends in greenness index in the Sahel, 1982–1999



Source: Adapted from Olsson and others 2005

slow variables (such as changes in woody vegetation cover and soil organic matter) better characterize the state of ecosystems than fast variables (such as crop or pasture yields), which are sensitive to short-term events. No systematic national or global assessment of desertification has been made using measurement of slow variables. Some areas thought to have been permanently degraded during droughts have subsequently recovered, at least in terms of the amount of green vegetation, although species composition may have changed. For instance in the Sahel, coarse-resolution satellite data show significant greening during the 1990s, following the droughts in the early 1980s (see Figure 3.10). This can be explained by increased rainfall in some areas but not in others; land-use changes as a result of urban migration and improved land management may have played a part (Olsson and others 2005). Systematic, interdisciplinary approaches are needed to provide more clarity and empirical evidence, which should enable more focused and effective interventions.

The argument that regional climate is affected by desertification through reduction in vegetation and soil water retention, and by the generation of dust (Nicholson 2002, Xue and Fennessey 2002), remains speculative. Desert dust has long-range impacts, both good and bad. It is a global fertilizer, as a source of iron and possibly phosphorus, contributing to the farmlands and forests of Western Africa (Okin and others 2004), the forests of the northeast Amazon Basin and Hawaii (Kurtz and others 2001), and the oceans (Dutkiewicz and others 2006). However, it has also been linked to toxic algal blooms, negative impacts on coral reefs, and respiratory problems (MA 2005b). Generally, dust from degraded farmland probably contributes less than 10 per cent to the global dust load (Tegen and others 2004). Natural processes create about 90 per cent of dust in areas like northern Chad and western China (Giles 2005, Zhang and others 2003).

Combating desertification

The international response to desertification has been led since 1994 by UNCCD, which has been ratified by 191 countries. It has evolved as a process seeking to integrate good governance, involvement of non-governmental organizations (NGOs), policy improvement, and the integration of science and technology with traditional knowledge. National action programmes have been drawn up by 79 countries, there are nine sub-regional programmes

Sand encroachment and land reclamation in China.

Left, 2000; right, 2004 planted with Xinjiang poplar (*Populus alba*).

Credit: Yao Jianming

Box 3.10 Responses needed to deal with desertification

Responses to desertification have focused on drought, shortfalls of food and the death of livestock, aspects that reflect inherently variable climatic cycles. Experience shows that policy and action must address long-term issues by combining a number of elements.

1. Direct action by governments
- Effective early warning, assessment and monitoring – combine remote sensing with field surveys of key indicators. Measure indicators consistently, at different scales, over the long-term.
- Integrate environmental issues into the mainstream of decision making at all levels – aim to increase system resilience and adaptive capacity, intervene before a system has crossed key biophysical or socio-economic thresholds (prevention is better and more cost-effective than cure). Include valuation of all ecosystem services in policy development.

2. Engagement of the public and private sectors
- Science and communication – integrate science, technology and local knowledge for better monitoring, assessment and adaptive learning, especially where uncertainty is impeding action. Communicate the knowledge effectively to all stakeholders, including youth, women and NGOs.
- Strengthen institutional capacity for ecosystem management – support institutions that can operate at the various scales at which ecosystems function (local catchments to river basins), and promote institutional learning, capacity building and the participation of all stakeholders. Create synergies among UNCCD, CBD, the Ramsar Convention, the Convention on International Trade in Endangered Species, Convention on Migratory Species and UNFCCC. Identify the overlaps, enhance capacity building and use demand-driven research.

3. Develop economic opportunities and markets
- Promote alternative livelihoods – grasp economic opportunities that do not depend directly on crops and livestock, but take advantage of the abundant sunlight and space in drylands, with approaches such as solar energy, aquaculture and tourism.

Sources: Reynolds and Stafford Smith 2002, UNEP 2006

targeting transboundary issues and three regional thematic networks (UNCCD 2005). Activities are now moving beyond awareness-raising and programme formulation to providing the financial resources for and implementing land reclamation projects (see sections on Africa and West Asia in Chapter 6). Starting much earlier, a national effort in reclamation of the severely degraded Loess Plateau in China now shows up in the Global Assessment of Land Degradation and Improvement as a 20-year trend of increasing biomass, in spite of a decrease in rainfall across the region during the same period (Bai and others 2005). In China in the 1990s, about 3 440 km^2 of land was affected annually by sand encroachment. Since 1999, 1 200 km^2 has been reclaimed annually (Zhu 2006).

Desertification is a global development issue, driving an exodus from the regions affected, yet policy and action are becalmed by uncertainty about the nature and extent of the problem, and about what policies and management strategies will be effective in different settings. Rigorous, systematic studies of the processes of desertification and the effects of intervention at different scales and different settings are urgently needed to guide future efforts. There is a great need to build local technical and management capacity (see Box 3.10) and applied science needs to focus on resolving the uncertainties that are impeding action, and on integrating science and technology with local knowledge to improve rigour in assessment, monitoring and adaptive learning.

CHALLENGES AND OPPORTUNITIES

Since the publication of *Our Common Future* (the Brundtland Commission report), economic growth has led to improvement of the environment in many ways, for instance by enabling investment in better technologies and some conspicuous improvements in developed countries. But many global trends are still strongly negative.

In the face of mounting evidence that much present development is unsustainable, global attention has focused on national strategies to promote sustainable development, foreshadowed at UNCED. The UN General Assembly Special Session Review Meeting in 1997 set a target date of 2002 for the introduction of such strategies. However, effective responses are still held back by limited access to information, inadequate institutional capacity faced with complex land-use issues, and the absence of broad participation or ownership of the responses. Future costs to others can be offset only by political cost to decision-makers now. Sustainability strategies need to be backed up by research to provide reliable data on biophysical, economic and social indicators of long-term change, and they require development or adaptation of technologies appropriate to local circumstances.

Strategies that are environment-driven, rather than focusing on sustainable development, rarely command the support needed to put them into action (Dalal-Clayton and Dent 2001). A successful approach deals not only with the environment, but also with the connections between environment and the economic and social issues to which people relate. For example, watershed development plans are being implemented in many places to secure water supplies and to protect hydropower facilities, and many multistakeholder projects on sustainable use of biosphere and forest reserves, some of which take account of the rights and needs of indigenous peoples.

The outlook to 2050 sees the emergence of two major sets of land-related challenges: dominating trends that are largely unavoidable, and caveats of risks that are very unpredictable, but which have serious implications for society that warrant precautions.

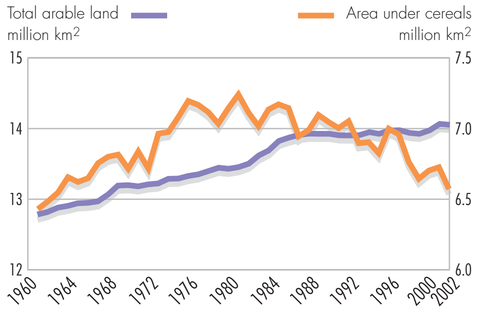
Challenges: Dominant land-use trends

Competing claims on the land

Given projections that the world's population will increase to over 9 billion by 2050, and to meet the MDG on hunger, a doubling of global food production will be required. In addition, a continuation of the shift from cereal to meat consumption, combined with overconsumption and waste, will increase food demand to between 2.5 and 3.5 times the present figure (Penning de Vries and others 1997). Yet, the production of cereals per person peaked in the 1980s and has since slowly decreased despite the increase in average yields. Reasons may include agricultural policies in regions of surplus, such as the European Union, ceilings to current technology, loss of farmland through land degradation and the growth of cities and infrastructure, and market competition from other land uses (Figure 3.11).

Our capacity to meet these future agricultural demands is contested. The main biophysical constraints are related to water, nutrients and land itself. Water scarcity is already acute in many regions, and farming already takes the lion's share of water withdrawn from streams and groundwater. Other claims on water resources are growing, particularly for urban water supplies (see section on Water scarcity).

Figure 3.11 Arable land and area under cereals



Source: FAOSTAT 2006

Increases in production over recent decades have come mainly from intensification rather than from an increase in the area under cultivation. Intensification has involved improved technologies, such as plant breeding, fertilizers, pest and weed control, irrigation, and mechanization; global food security now depends to a large extent on fertilizers and fossil fuels. Limits to current technologies may have been reached in mature farming systems, where they have been applied for several decades, and yields may have peaked. While there is land in poor countries that could respond to such technologies, most smallholders cannot afford fertilizers now, and the prices are being driven up by rising energy costs and the depletion of easily exploited stocks of phosphate. Food production is also constrained by the competing claims of other land uses, not least for maintenance of ecosystem services, and large areas may be reserved for conservation.

There is consensus that climate change over the next 20 years will affect farm production, with many regional differences in impacts. Changes may increase water requirements of crops, and increasing rainfall variability may exacerbate water scarcity in drylands (Burke and others 2006). Quantifying the current biological production for human consumption requires better estimates of global productivity of agricultural, grazed and human-occupied lands (Rojstaczer and others 2001). In the face of current uncertainty, it would be prudent to conserve good farmland, counteract tendencies of overconsumption, and undertake further needed research.

Bioenergy production

In most global energy scenarios that meet stringent carbon emissions constraints, biofuel is assumed to be a significant new source of energy. The World Energy Outlook 2006 (IEA 2006) forecasts an increase in the area devoted to biofuels from the current 1 per cent of cropland to 2–3.5 per cent by 2030 (when using current technologies). A major shift in agricultural production from food to biofuel presents an obvious conflict, which is already reflected in the futures market for food grains (Avery 2006). Forest products and the non-food cellulose component of food crops have a huge potential as an energy source, but technologies are still too costly to compete with fossil fuels at current prices, and the non-food component of crops also has a vital role in maintaining soil organic matter status.

Urbanization and infrastructure development

Half the world population now lives in urban areas, with positive and negative implications for the environment and human well-being. Densely populated cities use less land than do sprawling suburbs, they are easier to serve with public transportation, and can be more efficient in energy use, such as for transport and heating, and for waste reduction and recycling. The construction of housing and infrastructure in rural areas is often in conflict with other land uses, such as agriculture, recreation and other ecosystem services, particularly in rapidly industrializing countries (IIASA 2005).

However, cities are often built on prime farmland, and nutrients are being transferred from farms to cities with little or no return flow. The concentration of excrement and waste from food is often a source of pollution as well as a waste of resources. Urban areas become the source of sewage flows, run-off and other forms of waste that become environmental problems, often affecting the surrounding rural areas, as well as degrading water quality.

Challenges: Unpredictable risks to land

Tipping points

Tipping points occur when the cumulative effects of steady environmental changes reach thresholds that result in dramatic and often rapid changes. There is concern that a number of environmental systems may be heading toward such tipping points. One example is the bi-stability of the Amazon Basin, implying the possibility of a flip from a current wet phase to a dry phase, with profound implications beyond the basin (Schellnhuber and others 2006, Haines-Young and others 2006). Another very different tipping point with global implications might be simultaneous crop failures in different regions.

Runaway carbon cycle

The global carbon cycle is by no means fully understood. The missing sink for forty per cent of known carbon dioxide emissions is generally thought to be terrestrial ecosystems (Watson and others 2000, Houghton 2003). Vast areas of peat and tundra are reservoirs of stored organic carbon (one-third of all terrestrial organic carbon is peat) and methane, and they continue to fix carbon. With global warming, there is a risk of unexpected sudden increases in the atmospheric levels of carbon dioxide, if these sinks become saturated. The peat and tundra areas might transform from being a sink of carbon to become sources of greenhouse gases (Walter and others 2006).

Eutrophication

Rivers, lakes and coastal waters receive large amounts of nutrients from the land, and overloading of nutrients often results in algal blooms. If this increases in intensity and frequency, whole ecosystems may be subject to hypoxia (dead zones due to lack of oxygen) as seen already in the Gulf of Mexico (Kaiser 2005) and the Baltic Sea (Conley and others 2002).

Breakdown of governance, conflict and war

Land-use changes are usually associated with gains in livelihoods, income opportunities, food security or infrastructure. Illegal operations do not yield these long-term benefits, so good governance is vital to protect long-term values from short-term exploitation. Areas of exceptional environmental value, such as tropical rain forest and wetlands, as well as boreal forests, are in special need of strong structures of governance. War and civil conflict are always associated with rapid and far-reaching destruction of environmental values.

Opportunities to tackle these challenges

While the dominant trends are driven by demography, the global state of the environment and decisions already taken, there are several opportunities to steer or oppose them, not least by harnessing existing knowledge. Chapter 7 analyses successful strategies that offer opportunities for reducing human vulnerability, Chapter 8 goes further into biophysical and societal interlinkages that offer opportunities for more effective policy responses and Chapter 10 summarizes a range of innovative approaches to help improve responses. Some land-specific opportunities are described below.

Precision farming

Precision farming refers to optimizing production through site-specific choices of crop varieties, fertilizer placement, planting and water management, taking advantage of the variability of soil and terrain in a field rather than ignoring it. It is also describes the automation of techniques employed to do this, such as recording crop yields with a continuously recording monitor. However, the principle can be applied equally to low capital-input farming, where crops are intensively managed, manually: water harvesting is an example. Precise monitoring of crop performance will enable farmers to economize on their inputs in terms of labour, water, nutrients and pest management. The advent of reliable and inexpensive electronic devices offers the opportunity to extend advanced, information-based agriculture to new areas. Barriers to the wider application of precision farming include the scarcity and high cost of subtle management skills compared with using chemical inputs, and, among poor farmers, insecure tenure, lack of credit and low farm-gate prices.

Multifunctional landscapes

Agroforestry is one of several promising developments that can simultaneously generate livelihoods and preserve environmental quality. Successful examples include palm oil production in semi-natural rain forests, and gum arabic production in drylands. Carbon fixation through land management is another opportunity. Since fixing carbon by planted forests is eligible for trading under the Kyoto Protocol, most attention has been directed towards capturing carbon by forests and storing it as the standing crop. But carbon can also be stored in the longer term as soil organic matter, which is a much larger and more stable pool of carbon. At the same time, it would contribute to more sustainable agriculture by increasing resistance to erosion, add to water and nutrient reserves in the soil, and increase infiltration capacity. Low capital input farming systems may have a higher potential for net carbon accumulation than intensive forms of agriculture, where the inputs (such as fertilizer and energy) are associated with high carbon costs (Schlesinger 1999). Putting organic carbon back into soils, where it will be useful, is a challenge to soil science and management.

Uptake of agroforestry has slowly increased in recent years, and further development may be expected if soil carbon is recognized as an eligible sink by climate change legislation. Other market mechanisms, such as Green Water Credits for water management services in farmed landscapes, would be required to promote such multifunctional landscapes.

Ecosystem mimicry

Multiple cropping in the same field is well established in smallholder farming systems. However, very complex multi-layered perennial cropping systems, such as the Kandyan home gardens in Sri Lanka, demand rare skills and knowledge (Jacow and Alles 1987). Such biologically diverse systems provide both high productivity and better insurance against the risks of erosion, weather, pests and disease. Aquaculture is an important contribution to the world protein supply, but is often associated with high environmental costs and risks. One option to reduce the negative impact on aquatic ecosystems is to transfer such schemes to land, where tanks or reservoirs might be better suited for cultivation of protein (Soule and Piper 1992). There is also rich experience of fish and shrimp production in rice paddies (Rothuis and others 1998).

Crop breeding

One area with significant potential, but which is contested in several aspects, is the development and use of genetically modified (GM) crops (Clark and Lehman 2001). In contrast to the development of Green Revolution crops, the development of GM crops is almost exclusively privately funded, and focuses on crops with commercial potential. There are several sources of uncertainty, including unwanted environmental impacts, social acceptance of the technologies and their agronomic potential. Currently, there is polarization between proponents of the technology, mainly from the fields of genetics and plant physiology, and sceptics, mainly from the fields of ecology and environmental sciences. Outcomes to date mainly concern crop traits related to herbicide tolerance and resistance to pests. These may be significant, because losses due to insect pests have been estimated at about 14 per cent of total global farm production (Sharma and others 2004). Negatives include higher costs to farmers, dependency on big companies and specific agrochemicals, and the fact that, over time, cross-fertilization will mean that there will be no non-GM crops.

As an alternative to introducing new genes into crop species, the new technology of marker-assisted selection assists the location of desirable traits in other varieties, or in wild relatives of existing crops, which can then be cross-bred in the conventional way to improve the crop, halving the time required to develop new plant varieties (Patterson 2006) and avoiding the possible harm associated with GM crops. However achieved, salt- and drought-tolerance would be valuable for increasing food security in drylands, but we are far from understanding the mechanisms of such adaptations, let alone operational seed technologies (Bartels and Sunkar 2005).

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