Chapter 6

Food and Ecosystems

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Main Messages

There exists a fundamental trade-off between the need to increase food production and the need to sustain, in the long run, the capacity of the ecosystems to support food production. Food production is by far the largest user of ecosystems and their provisioning services. It has the largest impact on ecosystems and biodiversity. Intensive exploitation of ecosystems to satisfy needs for food might erode the productive capacity of these ecosystems through soil degradation, water depletion or contamination, collapse of fisheries, and biodiversity loss. While the recent trends in the slowdown of demographic growth and potential advances in agricultural technology are encouraging, there are also increased pressures on the resource base (land, water, fisheries, and biodiversity), extensive habitat destruction, deforestation, and loss of biodiversity and agrobiodiversity, and potentially serious long-term effects from the regional impacts of climate change.

The impacts on ecosystems from attempts to increase food production have resulted largely from secondary effects and, as such, they represent negative externalities. Expansion of agricultural land in many regions is difficult. Farming land is disappearing because of land degradation and urbanization. Water resources are under pressure because of excessive use and contamination. Governments are faced with the challenge of ensuring that the agricultural water supply is sustainable and that ecosystems contributing to that sustainability are protected. The substantial increase in the use of agrochemicals, such as pesticides, in developing-country agriculture has resulted in environmental contamination, severe health hazards to farmers, and unprofitable crop production. There are emerging problems of overgrazing and dry land degradation, rangeland fragmentation and loss of wildlife habitat, dust formation, bush encroachment, deforestation, nutrient overload through disposal of manure, and greenhouse gas emissions. Critical issues relate to human health arising from the threat of diseases such as bird flu in poultry and BSE in cattle. Capture fisheries are facing overexploitation and stock depletion.

The emergence of water pricing schemes and the establishment of water markets in different parts of the world shows that water pricing is a response that promotes efficient allocation and responsible use. In the context of negative externalities from excessive use of agrochemicals, integrated pest management, utilizing biological rather than chemical agents, provides avenues for sustainable production without damaging side effects. Organic farming can contribute to enhancing sustainability of production systems and agrobiodiversity. Agroforestry is a contributory technology for increased food production, using nitrogen-fixing trees to increase soil fertility and nutrient cycling. On overfishing, strict regulatory mechanisms, enforcing fishing quota and fishing capacity reduction, are urgently needed. Aquaculture has an important role to play in meeting fish food demand. In that context, government support in combination with private sector investments is important. However, given the potential detrimental environmental impacts of aquaculture, appropriate regulatory mechanisms need to supplement polices.

The information and communication revolution has a significant role in mitigating impacts on ecosystems and sustaining their capacity for future generations through evolving national and international agricultural knowledge systems. The design of policies needs to cautiously take into account "worst-case" scenarios and abrupt changes in ecosystems, because many impacts of ecological trade-offs in increased food production are uncertain. Comprehensive knowledge of the natural resources and the environment, science, and technology, as well as the socioeconomics of sustainable agricultural development, is essential to design policy frameworks. It calls for comprehensive assessments, education, and knowledge dissemination at the local, national, and international level, in order to ensure that farmers can produce food in a manner that is environmentally, economically, and socially sustainable and that consumers have the opportunities to make choices regarding food that is nutritious and healthy, safe, and affordable.

Integrated agroecological approaches in scientific research, policy design, and appropriate regulatory frameworks at all levels from local to global are important for enhancing sustainability. New analytical approaches of decision-making, which integrate ecological and socioeconomic systems and environmental change, play an important role in generating science-based policy analysis to assess response options towards sustainable food and ecosystems. **New agricultural sciences combined with effective natural resource management could support a future agricultural revolution to meet worldwide food needs in the twenty-first century.**

Modern methods of biotechnology, such as market-assisted methods of breeding, as well as molecular methods for the preservation of germplasm diversity, are important scientific tools. Responses need to determine the level of risks to human health and the environment for their optimal deployment. Response polices need to be gender sensitive. Women play a substantive role in food production and food preparation. **The national and international public research needs to be substantially strengthened to meet the challenge of environmentally sound food production, especially in view of the growing role of the private sector and the privatization of agricultural research, which often lacks an environmental focus and whose profit orientation has thus far excluded the needs and crops of poor farmers.**

Agricultural research needs to give high priority to developing mitigation and adaptation options related to climate change and variability in tropical areas, particularly the developing countries with the least capacity to cope. **Changes in international agricultural trade, as well as the conditions of access to world markets offer both obstacles and opportunities to developing countries, which are particularly vulnerable.** Different approaches to trade and production have opened huge gaps within the developing world in terms of productive capacity and international marketing. The challenge is to make agricultural knowledge support efficient and policies environment friendly through the integration of biological, biochemical, agroecological and environmental, socioeconomic, and information sciences.

The Common Agricultural Policy constitutes a major response from the European Union aimed at securing food supply and enhancing the well-being of the rural communities. The introduction of an environmental dimension into the CAP shows direct recognition of the fact that agricultural policies need to correct undesirable environmental pressures. **Government policies developed around food production (price supports and various types of payments, or taxes) can have adverse economic, social, and environmental effects.** This issue is highlighted in the case of the international sugar market, one of the most heavily distorted international markets due to EU and U.S. support policies.

6.1 Introduction

The purpose of this chapter is to (1) present the important drivers associated with the provisioning of food (crops, livestock, fish) and the main issues related to the food provisioning services of ecosystems, (2) analyze and assess major responses, mainly in the form of economic, technological, and institutional interventions, undertaken in order to enhance and/or secure food provisioning services, (3) present through case studies the structure and the major impacts of selected responses on ecosystems and human well-being, and (4) provide some conclusions derived from the analysis and assessment.

The main issues associated with the food sector relate to the structure of consumption and production. Consumption patterns relate to both hunger and overconsumption, directly affecting human well-being. The structure of production systems directly affects food supply and also, through the production processes and the inputs used, has important impacts on resource availability and the state of the ecosystems. This section examines important direct and indirect drivers, as well as consumption patterns, production systems, and likely impacts on ecosystems associated with cropping, fisheries, and livestock husbandry.

A number of drivers affect the current and future capacity of ecosystems associated with food provisioning services. They also affect food needs and food provisions as determinants of human well-being. The focus here is on important drivers, which are interrelated and are within the wider system—drivers that are endogenous, depending on the spatial and temporal scale of analysis. Thus responses affect direct drivers such as changes in resource availability (land, water, fish biomass, biodiversity), intensification of production, and climate change, but also indirect drivers such as population growth or international trade regimes.

6.1.1 Population

An issue of great importance is the challenge of tripling the global food production in the poorest societies, some of which have been doubling their numbers in as little as thirty years. The generally accepted point (Arrow et al. 2004; Ehrlich and Ehrlich 2002) is that population and consumption jointly impose increasing strains on the ecosystems which are supporting them. (For more extensive information on population developments, see MA *Scenarios,* Chapter 7.)

Long-term predictions, on the other hand, regarding world population growth (UN 2003; IIASA 2004) indicate a slowdown in the annual population growth rate. This might imply a possible slowdown in the growth of demand for food. FAO (2003b) projects progress in raising food consumption levels, in improving nutrition, and in reducing the proportion of undernourished people. However, initially, this might not show as a decline in the number of undernourished people, due to population growth. Also, rapid population growth in some regions not only pushes up demand for food, but may also cause the agricultural resource base to diminish due to overexploitation and conversion of arable land for residential, infrastructure, and industrial uses. As a result, the developing world's capacity to expand food production may well be shrinking in some regions rather than expanding. In many developing countries, with limited prospects of bringing additional land into production, intensification will be required to enable higher productivity and at the same time ensure the sustainability of ecosystems and services.

Food security is also affected by patterns of trade and protection. The removal of trade barriers to developing countries, especially in the agricultural products that they have a comparative advantage in producing, along with reduced tariffs for processed agricultural commodities is expected to benefit them. Globalization of markets is also a stimulus to competitiveness and local forms of production. It will be important for developing countries to promote production systems for which their agroecosystems are suited and which can be sustained.

6.1.2 Natural Resources

Arable Land: About 4 billion hectares of the world's land is suitable for arable agriculture. (FAO 2003b), and nearly all land well suited for intensive agriculture is currently in cultivation (MA *Current State and Trends,* Chapter 26). In developing countries, population growth resulted in a substantial decline of arable land per capita. Furthermore, farming land is lost because of land degradation and urbanization. Land degradation is mainly due to soil erosion, loss of nutrients, damages from inappropriate farming practices, and misuse of agricultural chemicals (FAO 1995a). Urbanization affects food production by converting arable land, and by reducing labor input to the agricultural sector. China, for example, lost around one million hectares of arable land between 1987 and 1995, due to construction (Fischer et al. 1998).

Water: Approximately 70% of all fresh water withdrawals is currently used for agriculture. While rain-fed croplands might consume more or less water than the natural vegetation/soil conditions they replaced, irrigated areas consume significantly more. Irrigation systems divert 20–30% of the world's available water resources, but chronic inefficiencies in distribution mean that only some 40–50% of that water is actually used in crop growth (MA *Current State and Trends,* Chapters 7, 26). According to a study by the International Water Management Institute, irrigation water withdrawals will need to increase by 17% (Seckler 2000) as the area of irrigated land expands by a further 22 % in order to feed the population of 2025. Other projections based on different scenarios vary widely, with some even predicting a decrease (Cosgrove and Rijsberman 2000). Of greater concern than increased demands for irrigation water alone are the far higher increases in municipal and industrial water demands that compete for the limited resource and often draw water away from agriculture. The same IWMI projection predicts increases of 60% for industrial and 80% for municipal withdrawals.

In 1999, the irrigated area as a proportion of irrigation potential was 50% for the developing world, where most irrigation development is expected to occur. The figure is 13% for sub-Saharan Africa and more than 80% for South Asia, excluding India. By 2030, 60% of all land with irrigation potential in developing countries will be in use (FAO 2003b). Poor drainage and irrigation practices have led to water logging and salinization of approximately 30% of the world's irrigated lands (FAO 2001a). Groundwater from shallow aquifers is an important source of irrigation water, but its sustainable use is at risk due to over-pumping of aquifers, pollution from agrochemicals and the mining of fossil groundwater (FAO 2001a). Fertilizers and pesticides are a major cause of water pollution generally, and the nutrients from fertilizers are causing severe problems of eutrophication in surface waters worldwide.

About 10% of irrigation water in developing countries comes from reused wastewater. For irrigation use, wastewater should receive treatment, but in lower-income countries, raw sewage is often used directly, leading to a variety of health and environmental problems. Also, crops grown using untreated wastewater cannot be exported and access to local markets, at least partially, is restricted.

Fisheries: FAO estimates that currently 71–78% of fish stocks are fully exploited, overexploited, or recovering from depletion. The increase of the world's fish catches during 1950 to 1990 was followed by a decline in productivity due to overfishing (Jackson 2001). Overexploitation occurred due to rapid expansion of the world's fishing fleet, enormous advances in fishing technologies, poor understanding of fish population dynamics (or little concern for ensuring sustainable yields), and a failure to introduce effective management systems (see Alverson et al. 1994).

Biodiversity: Species extinction and biodiversity loss is caused by habitat destruction due to a variety of economic and social driving forces including poverty, human population growth, unsustainable human production and consumption patterns, as well as legal, institutional, and cultural aspects (Folke et al. 1992). In relation to food production, there are two aspects of biodiversity loss that can be regarded as constraining feedbacks to the attainment of food security. One is associated with habitat destruction due to expansion of cropland, pastures, and aquaculture; the other is loss of genetic diversity in agriculture due to specific crop choices and cultivation practices. Habitat destruction is also associated with tropical deforestation.

Loss of genetic diversity in agriculture is associated with changes due to factors such as domestication and development of genetically uniform varieties, the preference of farmers and consumers for certain breeds or varieties, global consolidation of the seed grain industry, and the adoption of high-yield varieties as part of the Green Revolution (Heal et al. 2002).

6.1.3 Agrobiodiversity

The analysis of the history of breeding of major crops such as wheat, maize, or rice shows that conventional breeding focused on objectives of increased productivity, increased resistance to diseases and pests, and enhanced quality with respect to nutrition and food processing. After the spread of crop ancestors from centers of origin and diversification of lines, breeding made use of natural variations and, later on, of the traits found in different lines or close relatives.

Modern methods of breeding have significantly increased yields of cereal crops in general. However, yield growth has slowed in the most intensively cultivated irrigated areas, and land quality has also declined.

To overcome these problems, scientists and farmers considered new ways to attain the overall objectives of improved yields and sustainable agricultural systems. They also looked for methods for improvements in health risks and environmental problems created by the need for high amounts of chemicals in many areas. Additional breeding objectives are stress tolerances, for example, drought or salt tolerance, or improved pest tolerance. Research programs have been implemented to arrive at an improved understanding of basic physiology and genomics.

International efforts to conserve agroecological diversity are required, along with wild gene pools, on which further genetic enhancement may depend. However, gene banks, without continuous propagation of races, do not suffice to conserve diversity. Presently, (for example, for rice) tens of thousands of land races are known in many areas worldwide. Additionally, some species (for example, some tree species) cannot yet be conserved ex situ.

6.1.4 Climate Change and Extreme Events

Climate change, climate variability, and extreme events will have significant impacts on global and regional food production, supply, and consumption. The impacts of climate change on natural and human systems have been classified according to the concepts of: *vulnerability*—the extent to which climate change may damage or harm a system; *sensitivity*—the degree to which a system will respond to a climate change; and *adaptability*—the degree to which practices, processes, or structures can be adapted to climate change.

A recent report by the International Institute for Applied Systems Analysis (Fischer et al. 2002b) commissioned by the United Nations for the World Summit on Sustainable Development, with a global coverage of all countries, integrates spatial agroecological potentials into a world economic and trade policy model framework. It evaluates the impact of climate change projections by some major climate models (General Circulation Models), as well as the socioeconomic development portrayed in the special report on emission scenarios of the IPCC Third Assessment. The results highlight that by the 2080s, the world's boreal and arctic ecosystems are likely to shrink by as much as 60% due to a northward shift of thermal regimes, and the unfavorable semiarid and arid land areas in developing countries may increase by up to 10%. Also, potential agricultural land will increase in North America (up to 30%) and the Russian Federation (up to 55%), but significant losses are projected for Africa, particularly in northern (up to 75%) and southern Africa (55%).

Analyses of the effects of climate change on food production potential show that there is actually a possibility of improvement in industrial countries. However, many developing countries, where food production is already insufficient, would suffer a further decline, resulting in aggravated malnutrition and famine problems.

While future food security depends mainly on political and socioeconomic conditions, climate change might affect the availability and distribution of food production and people's access to food. Mitigation measures are mainly reflected in the discussion about the Kyoto Protocol. However, it is crucial for adaptation measures to be elaborated, especially in developing countries, which are expected to suffer the most from climate change.

On the other hand, since land use change and agriculture are responsible for about a fifth of greenhouse gas emissions, agriculture could play an important role in mitigating climate change (FAO 2003c). Mitigation measures include mainly changes in cultivation patterns, reduction of fertilizer use, improvement of livestock diet and better manure management, alternatives to slash and burn land expansion, more efficient use of water resources, and promotion of carbon sequestration.

Extreme weather events—floods, droughts and cyclones—have emerged as the biggest threats to crop production, food availability and security in some developing countries. Here climate variability and weather fluctuations can create famine-like situations. Even in industrial countries farmers often go bankrupt because of crop losses due to extreme weather events.

6.2 Food Systems

The challenge of meeting safe and healthy food needs comprises the effective and sustainable functioning of the range of systems from production to consumption. The performance of agriculture over the last 100 years has been phenomenal. World population has increased almost four-fold. Today, global food production is sufficient to meet the world's food needs, and yet there is concern with regard to unhealthy food consumption, be it too little to too much. On the production side, the increasing degradation of land, water, and biological resources poses a major challenge of mobilizing agricultural science and technology. These need to manage natural resources and reduce social and economic vulnerability.

6.2.1 Food Consumption

Food is a basic human right and everyone should have access to nutritious, safe, and affordable food for a healthy and productive life. Although, at the global level, there has been significant progress in increasing average food consumption over the last 30 years, there are still some 840 million chronically undernourished people, mainly in the developing countries. At the same time, there is an emerging problem of overconsumption and changing lifestyles, resulting in obesity that is affecting more than 500 million people worldwide. The driving forces of changes in food consumption include demographic changes, urbanization, increasing levels of income, globalization and international trade, as well as rapidly changing consumer preferences.

The challenge in the developing world is to eradicate hunger, as some 15% of the total population is consuming 10–20% less food than the recommended minimum requirement. A priority focus on meeting food needs from domestic production is also important with regard to supporting domestic producers and reducing dependence on scarce foreign exchange. In the industrial and transition countries, the majority of the population already lives in urban environments, served by food supermarkets with a wide variety of domestic food products, as well as products from around the world. The number of people living alone has increased dramatically in developed countries and the traditional home family meal is declining. Health concerns are becoming predominant among rapidly aging populations. Food processors, distributors, and retailers are targeting and changing food consumption patterns, using the media and labeling, to market more and more processed and easy-to-cook foods. Campaigns that selectively highlight links between food and health, labor, and time saving often fail to give information about issues such as unhealthy levels of salt, sugar, and fat contents.

Cereals account for about half of total food energy consumption in the developing countries. Wheat consumption has increased the most, and many developing countries are meeting this demand through imports from the industrial countries, which continue to heavily subsidize producers. In the next 30 years, wheat imports by developing countries from temperate industrial countries are projected to increase some 2.5-fold to a total value of some $25 billion. Global food consumption of coarse grains continues to decline, but it is nutritionally of critical importance in many sub-Saharan countries, often accounting for over 70% of total calorie consumption. Demand for cereals in sub-Saharan Africa is expected to change with growing urbanization: demand is expected to increase for easy-to-prepare cereals like rice, and cereal products like bread, and expected to decrease for the local sorghum and millet, whose preparation is time-consuming (FAO 2003b).

Consumption of meat in developing countries more than doubled over the last two decades. Milk consumption in developing countries also increased considerably. It is more than triple the increase in the industrial countries. These trends, taken together, have been dubbed a ''Livestock Revolution'' (Delgado et al. 1999; Delgado et al. 2003). Although the massive increases in animal product consumption in the developing world are impressive, these countries still have a long way to go before they approach consumption levels of industrial countries. For instance, animal products comprised only 13% of calories consumed in the developing world in 2000, compared to 26% in developed countries (FAO 2000). Nonetheless, it is clear that diets are diversifying rapidly, with increasing consumption and production of animal products in developing regions. Poultry consumption will grow faster than other meats. Animal source foods have a positive impact on the quality and nutrient enhancement of the diet and can prevent or ameliorate many nutrient deficiencies. They are one of the few instruments for addressing the ''hidden hunger'' of nutrient deficiencies that exact a heavy toll on both societies and individuals in terms of mental ability late in life, energy levels, and susceptibility to diseases (Neumann et al. 2002). Alternatives to animal source foods for improving nutrition are few in the vast areas of poor developing countries, where distributing daily nutritional supplements is not feasible and green leafy vegetables are only available in local markets a few weeks a year.

Worldwide, more than 1 billion people rely on fish as an important source of animal protein. Fish provides at least 30% of their animal protein intake (FAO 2002a). Fish proteins are essential and critical in the diets of some densely populated countries where the total protein intake may be low. In countries such as Ghana, Indonesia, Sierra Leone, Bangladesh, Republic of Congo and Cambodia, it contributes to more than 50% of the total animal protein in the diet. In Japan, Iceland, and some small island states, fish is the major food source because of the lack of locally grown alternative protein foods. Besides, the people have developed and maintained a preference for fish. During the past decades, per capita fish consumption has expanded globally, along with economic growth and well-being. The consumption per capita of fish is larger in the United States and Europe than in Asia and Africa. In well-off industrial economies, the image of fish is changing. It is moving away from being a basic food and is becoming a culinary specialty. In industrial countries, economic growth has caused a growing proportion of fish to be consumed outside the home and in the form of ready-to-eat products. In volume terms, fish trade is still dominated by intermediate products, mostly in frozen form with a few standard categories of cured and canned products.

World food consumption has made substantial progress in terms of average daily per capita calorie consumption, rising from 2,400 calories to 2,800 in the last three decades. This has also been accompanied by major dietary changes comprising shifts toward increasing shares of meat, fat, and sugar, which in the developing countries rose from 20% of all food consumed to over 28% in the last four decades. The driving forces of these changes include transformation of lifestyles, traditions and culture, time pressures, demographic changes, economic growth, international trade and globalization of food markets—particularly through media targeting by the emerging transnational food companies. Major food safety incidents have also increased consumer concerns in recent years, leading to changes in consumer perceptions and food purchasing patterns.

Food consumption patterns vary from country to country and also within countries. Governments, civil society, particularly businesses, have to take responsibility to ensure that changes in food consumption patterns lead to good nutrition. Governments in industrial countries are already implementing standards for food quality, balanced nutritional content, labeling, etc., to reduce health risks. In contrast, many developing countries have few regulatory systems or public awareness campaigns to empower consumers to make the right food choices.

6.2.2 Food Production

Food production depends on natural resources (water, land, biodiversity), farm inputs (capital, power, chemical inputs, and seeds), and human inputs (labor, management skills, institutions).

Water: The greatest potential for increasing food production in developing countries lies in rain-fed agriculture. Low-cost technologies that allow judicious supplemental irrigation to bridge dry spells include treadle pumps. Trickle and seep-hose systems could substantially increase productivity of rain-fed agriculture. Irrigated agriculture has long been synonymous with high productivity. The 20% of the farmland that is irrigated produces 40% of the current food supply. In irrigated agriculture, the different types of irrigation used (surface or flood irrigation, sprinkler, drip, underground and sub-irrigation) have very important impacts on irrigation efficiency, the availability of water resources, and the state of ecosystems (for example, wetlands).

Land: The need to improve soil-water-plant nutrient management is addressed by Conservation Agriculture (Dixon et al. 2001). Conservation Agriculture contributes to environmental conservation with enhanced and sustained agricultural productivity. It ensures the recycling and restoration of soil nutrients and organic matter and optimal use of rainfall through retention and better use of biomass, moisture, and nutrients.

Biodiversity: The genetic resources for food and agriculture, which is the basis for world food security, have their base in biodiversity. Strong claims suggest that biodiversity promotes resilience and productivity of ecosystems. However, global biodiversity is changing at an alarming rate because of land conversion, inappropriate land use, climate change, pollution, unsustainable harvesting of natural resources, and introduction of exotic species (Pimm et al. 1995; Sala et al. 2000).

Inputs: The intensive use of *chemical inputs,* for example, fertilizers and pesticides, impacts ecosystems by changing the resource base and variety and level of services.

A number of trends and responses are evident in the case of *human inputs,* which include labor, management skills, and institutional arrangements. Production systems in many developing countries rely more on human labor than on mechanization. Hence, rural-to-urban migration of young adult males results in the burden of hard labor falling on women and the elderly (FAO 2001c). Investing in human capital in agriculture not only improves production efficiency, but also facilitates the adoption of new techniques, regulations, and practices that conserve and protect environmental resources. The recent trends of reducing agricultural extension services may not only slow agricultural productivity increases and provision of agricultural services, but may also negatively affect environmental protection and conservation of resources.

In the context of institutions and governance, a number of developing countries have undertaken reforms in support of agriculture including structural adjustment programs, poverty reduction strategies, fair commodity prices for products, increased levels of schooling, promoting gender equality, and reducing the scourge of HIV/AIDS. These institutional responses are important for increasing production, alleviating hunger and poverty, and achieving food security.

Detailed information and figures on status and trends is provided in MA *Current State and Trends,* Chapters 8 (Food), 26 (Cultivated Systems), and 18 (Marine Fisheries Systems).

6.2.2.1 Crops

Existing production systems include rain-fed, irrigated, wetland, and peri-urban farming systems. *Intensification* of existing production systems is a more realistic alternative for enhancing food production than undertaking further extensions (FAO 2003b, p.126). Intensification aims at increasing yields as a result of greater use of external inputs. Improved varieties and breeds, utilization of unused resources, improved labor productivity, irrigation, and better control of pests and diseases may also aid intensification. *Extensification* possibilities should be carefully considered, as much of the potentially available additional arable land is presently under tropical forests (in Africa and South America). The use of these lands for cultivation would be detrimental to biodiversity conservation, and increase greenhouse gas emissions causing regional climate and hydrological changes

The findings of MA *Current State and Trends,* Chapter 8, state that over the forty-year period, 1961–2001, the total output of crops expanded by some 235% globally. This indicates an average increase of just over 2% per year, always keeping ahead of global population growth rates. Output growth varied by region and over the period as a whole. Many middle-income and richer countries have seen a gradual slowing down in the growth of crop output in line with the deceleration of population growth and the attainment of generally satisfactory levels of food intake. Decelerating growth patterns in crop output have been most evident in developed countries and in Asia. Since food crop production has not grown as markedly, and population growth rates remain high, sub-Saharan Africa remains the only region in which per capita food production has not seen any sustained increase over the last three decades.

The cereal sector remains singularly important in several ways; in 2001, production of the principal cereal crops were: rice (381 million tons), maize (278 million), wheat (264 million), sorghum (44 million), millet (28 million), and barley (23 million). Cereals provide almost half of the calories consumed directly by humans globally (48% in 2001). Cereal production comprises about 58% of the world's harvested crop area, and an often disproportionately larger share of the usage of fertilizer, water, energy, and other agrochemical inputs. With regard to current trends, following a peak in foodstuff prices in 1996, a strong growth in crop output in 1999 was registered by both industrial and developing countries, but since then the general pattern of growth deceleration has resumed. In industrial countries, output actually declined in 2001 and 2002. In the case of cereals, global output levels have stagnated since 1996, while grain stocks have been on the decline.

During the last four decades, the best prospects of increasing food production were from raising yields on already cultivated lands, safeguarding against land degradation, and minimizing conversion of high-productive cultivated lands in the process of urbanization and economic transformation. Systematic research on productivity enhancement led to the Green Revolution, whose main components were increased use of high-yielding varieties of grain (primarily wheat and rice) and increased use of inputs such as fertilizers, energy, irrigation water, and pesticides. (See MA *Scenarios,* Chapter 7, for a more extensive discussion of the Green Revolution.)

Subsistence production is practiced by smallholders producing mainly for self-consumption with limited surplus production, and often constrained by lack of access to markets. Poverty is often severe among smallholder families. Their vulnerability is high since many cultivate poor soils and in areas prone to drought. Generally, low inputs (such as in finance, labor, seeds, and fertilizers) have led to low production, hunger, and thus poverty and low economic growth. Low productivity also negatively affects health and education, which in turn lowers productivity. Some traditional farming systems have improved yields and have been safeguarding the resource base by upgrading and diversifying cropping and adopting integrated pest management. For example, Indonesian rice farmers who adopted IPM, which reduces the need for pesticides, achieved higher yields than those who relied solely on pesticides (FAO 1996).

6.2.2.2 Livestock

Livestock and livestock products are estimated to make up over half of the total value of agricultural gross output in the industrialized countries, and about a third of the total in developing countries, but this latter share is rising rapidly (FAO 2003b). While growth rates in industrial countries have hovered at just over 1% for the past 30 years, growth rates in developing countries as a whole have been high and generally accelerating. As with many other global and developing-country trends, the situation in East Asia (and within that region, China) exerts a strong influence, where livestock product growth rates of over 7% per year have persisted for some 30 years, admittedly from a low base. As with crops, two regions draw attention: the transition economies and sub-Saharan Africa. The transition economies exhibit the same pattern of slow long-term shrinkage of output, followed by collapse in the early 1990s. Sub-Saharan Africa, faced with the world's highest stresses of poverty, malnutrition, and population growth, and continuing insecurity, particularly in pastoral areas within the sub-continent, has made slow progress and per capita output has hardly increased at all (Ehui et al. 2002). (See also MA *Current State and Trends,* Chapter 8.)

Technologies for sustainable animal agriculture are available for most of the world's livestock production systems. If applied, they will restore the balance between land and livestock and close nutrient cycles, thus reducing land degradation and nutrient loading of water resources. By restoring the balance between land and livestock, they will also address the social and health effects of the Livestock Revolution. However, these technologies will only be adopted if an appropriate policy framework is established.

Three broad types of production systems can be distinguished:

Industrial production systems: Industrial production of pork, poultry, and (feedlot) beef and mutton is the fastest growing form of animal production. In 1996, it provided more than half the global pork and poultry meat (broiler) production and 10% of the beef and mutton production. This represented 43% of total global meat production, up from 37% in 1991–93. Moreover, it provided more than two thirds of the global egg supply. Geographically, the industrial countries dominate intensive industrial pig and poultry production, accounting for 52% of global industrial pork production and 58% of poultry production.

Mixed farming systems: Mixed farming systems, the largest category of livestock systems in the world, cover about 2.5 billion hectares of land, of which 1.1 billion hectares is arable rain-fed cropland, 0.2 billion hectares is irrigated cropland, and 1.2 billion hectares are grassland. Mixed farming systems produce 92% of the world's milk supply, all buffalo meat and approximately 70% of the sheep and goat meat. About half of the meat and milk produced in this system is produced in the OECD countries, Eastern Europe, and the Commonwealth of Independent States, and half comes from the developing world. Over the last decade, meat production from mixed farming systems grew at a rate of about 2% per year and thus remained below global growth in demand.

Grazing systems: Grazing systems supply about 9% of the world's production of beef and about 30% of the world's production of sheep and goat meat. For an estimated 100 million people in arid areas, and probably a similar number in other zones, grazing livestock is the only possible source of livelihood. For the world's tropical rangelands, most attention has been on the arid lands, because of their perceived heavy degradation. However, recent findings stress the high prevailing level of productivity of meat and milk per unit area of land, the strong resilience of these arid rangelands, and the importance of traditional mobile grazing practices in maintaining the resource base. For the subhumid tropical savannas, human and livestock population pressure is lower. Finally, livestock-induced deforestation in the humid tropics has received much attention. Past driving forces behind the slashing and burning of tropical rain forest concerned export subsidies, subsidized interest rates for ranch establishment, and land tenure laws, which induced land speculation. More recently, the main driving force for deforestation has shifted toward smaller farmers, and food production for local consumption in forest margins as part of mixed farming systems.

6.2.2.3 Fisheries

Global fisheries landings peaked in the late 1980s and are now declining despite increasing effort and fishing power, with little evidence of this trend reversing under current practices. At the beginning of the twenty-first century, the biological capability of commercially exploited fish stocks was probably at an historical low. FAO (2003b) has reported that about half of the wild marine fish stocks, for which information is available, are fully exploited and offer no scope for increased catches. Of the rest, 25% are underexploited or moderately exploited. The remaining quarter is either overexploited or significantly depleted. Today, about 90% of wild fish come from the sea, the remainder from lakes and rivers. Of the fish caught at sea, probably about 10% (by volume) are caught in the high seas (that is, the areas outside the 200 nautical mile exclusive economic zone claimed by most countries bordering the sea). The vast majority of catches are obtained from waters on the continental shelf.

Although information on inland fisheries is less reliable than for marine capture fisheries, it appears that freshwater fish stocks are recovering somewhat from depletion in the Northern Hemisphere, while the large freshwater lakes in Africa are fully exploited, and in parts are overexploited. Some fish species exhibit more dramatic threshold effects, appearing less able to recover, than others.

Nine out of ten full-time fishers conduct low-intensive fishing (a few tons per fisher per year), often in species-rich tropical waters. Their counterparts in industrial countries probably number less than 1.5 million (FAO 1997) and generally produce several times that quantity per year, but they are not many and their numbers are falling as fishing is seen as a dangerous and uncomfortable way to earn an income. As a result, in some industrial countries, fishers from economies in transition or from developing countries are replacing local fishers.

During the past fifty years, aquaculture has become a globally significant source of food. By the end of the last century, it contributed roughly one third (by volume) of all fish consumed as food. The variety of supply from aquaculture is much below that of capture fisheries: only five different species of Asian carp comprise about 35% of world aquaculture production.

6.2.3 Impacts on Ecosystems

Crop production using the methods and inputs described above has major impacts on ecosystems, increasing their vulnerability. These impacts affect directly and indirectly, via ecological feedbacks, the resource base (land, water, biodiversity) through: direct use of resources as inputs, degradation due to agricultural pollution, effects on ecosystems' resilience (including processes and functions such as regeneration and self-cleaning capacities), or productivity. Crop production also has effects on human health and the health of other species.

For marine systems, the key factors that impact the ecosystem are salinity, ocean currents, and temperature changes. For inland waters, hydrological changes (for example, caused by dams, water abstraction), and water quality changes (including eutrophication, anoxia, water acidity, pollution, and toxic events) are the key factors.

Human impacts on the world's oceans, mainly through fisheries, have been substantial, leading to concerns about the extinction of marine taxa. For commercially exploited species, it is often argued that economic extinction of exploited populations will occur before biological extinction. However, this is not the case for non-target species caught in multispecies fisheries or for species with a high commercial value, especially, if this value increases as the species becomes rare. The perceived high potential for recovery, high variability, and low extinction vulnerability of fish populations have been invoked to avoid listing commercial species of fishes under international threat criteria. There is a need to learn more about recovery, which may be hampered by negative population growth at small population sizes or ecosystem shifts, as well as spatial dynamics and connectivity of subpopulations before the nature of responses to depletions is understood (Dulvy et al. 2003).

Livestock can have both positive and negative impacts on ecosystems around the globe. The positive impacts are mainly confined to smallholder farming systems where livestock provide a way to improve nutrient cycling and plant available nutrients. In pastoral systems, livestock may also provide unexpected benefits to wildlife where grazing pressure is light to moderate. Livestock production is also a main driver for massive transport of nutrients from developing to industrial countries, in the form of livestock feed. On balance, however, livestock impacts on ecosystem goods and services are largely negative, through impacts such as deforestation nutrient overloading, greenhouse gas emissions, nutrient depletion of grazing areas, dryland degradation from overgrazing, dust formation, and bush encroachment.

6.3 Responses: Selection and Analysis

The major responses associated with food provisioning services of ecosystems and their ecological feedbacks comprise a large variety of policy interventions and responses at the local, national, and international level. These address the complex and intertwined social, environmental, and economic issues. The responses are in a sense interventions induced by changes in drivers such as population and demography, economy and environment and natural resources, as well as science and technology.

In analyzing and assessing responses we seek to identify impacts on ecosystems, since all responses examined have impacts not only on food provisioning services, but also on supporting services through the ecological feedbacks. Impacts on ecosystems can result from unintended ecological feedbacks, from an intervention that was aimed at increasing food production (for example, the Green Revolution led to increased use of fertilizers, pesticides, and irrigation water); or they can be direct impacts aimed at correcting or preventing negative effects of existing responses (for example, the environmental component of the EU's Common Agricultural Policy).

In the context of food provisioning, we examine responses which can be associated with: (1) impacts on human well being; (2) the evolution of the economy and its institutions, including issues such as globalization, trade agreements, food related policies, and the design of agricultural policies; (3) knowledge and education related to food production and consumption; (4) technological change; and (5) impacts on the resource base (for example, water, fisheries).

The responses represent interrelated economic/financial, institutional, technological, social, and legal interventions covering the whole spectrum of the MA typology. By affecting food provision and food security, these responses have a direct impact on human well-being as well as the functionality and viability of ecosystems and ecosystem services. Actors initiating the response are mainly the state or international bodies, while the scale of operation ranges from local to global. Examples of the wide variety of responses impacting upon food supply and consumption are listed in Table 6.1.

6.3.1 Recognition of Gender Issues

Women play an essential role in achieving food and water security. (See Box 6.1.) While women play a critical role and have multiple responsibilities within the household and communities in securing healthy nutrition, their realties are often ignored at all levels of decision-making. Women farmers account for some 60–80% of food production in many developing countries. Women often spend more then nine hours a day fetching water and fuelwood and preparing food. They produce more than half the world's food and own 1% of the land. Response polices need to be gender sensitive and designed to empower the women by providing knowledge and ensuring access and control of resources toward achieving food security. This needs to be based on a systematic analysis of gender dynamics and explicit consideration of relationships between gender and food and water security.

6.3.2 Globalization, Trade, Domestic and International Policies on Food

Changes in world food production and international trade, as well as the conditions of access to world markets offer both obstacles and opportunities to developing countries. Different approaches to trade and production have opened huge gaps within the developing world in terms of productive capacity and international marketing (Stallings 1995). Some developing-country businesses have become foreign investors (for example, from the East Asian newly industrialized countries) while others cannot even sell in domestic markets without protection (Asia, South Africa, much of Latin America). As protection declines in the process of globalization, the situation of the latter countries becomes more precarious.

Regarding food and nutrition, in many cases, advocates of globalization favor export-oriented agriculture, often from large-scale operations, and modern food marketing methods including the use of packaged foods. On the other hand, excessive reliance on global markets entails dangers for poor countries (which are price takers and concentrate on a few exportable food commodities) when world markets become weak.

Another related issue is that increased global food production does not guarantee adequate access to food at either the household or the national level. The World Food Summit (in 1996) identified access to food—rather than the globally produced amount of food—as the key issue for food security.

Over the years, a complicated web of government policies has been developed around food production. Among the main goals of these policies are the support of domestic farmers' income, the support of domestic production, provision of research and development, security of food quality, and—more recently—protection of the environment. While some of these policies could have positive welfare effects, the traditional policies that subsidize agricultural production do have adverse effects. This section aims at tracing some of the effects of commonly used economic policies on food provisioning, human well-being, and the ecosystems. The most commonly used instruments of agricultural policy are listed in Table 6.2.

Figure 6.1 shows total support policies by type in the OECD countries for the period 2000–2002. The policies could have adverse economic, social, and environmental effects, that is, negative effects on sustainable development. On the economic side, they impose an extremely high cost. In 2002, this cost totaled $235 billion in OECD countries, of which $100 billion was accounted for by the European Union and $40 billion by the United States (OECD 2003b). They also distort market forces by diverting resources from their most productive utilization and lead to overproduction. Furthermore, they distort the terms of trade, reducing the profitability of agricultural production in developing countries. Finally, they promote overuse of certain inputs such as fertilizers and pesticides.

On the social side, they make farmers overly dependent on taxpayers for their livelihood, and they change wealth distribution and social composition by benefiting large corporate farms to the

Table 6.1. Examples of Policy Interventions and Responses Affecting Food Production, Distribution, Access, and Consumption. In *target* column, E = ecosystems; W = well-being. *Purpose:* A = access; D = distribution; P = production; R = resource base. *Type:* Ec = economic; F = financial; K = knowledge; L = legal; T = technological. *Level:* G = global; N = national; L = local.

Target	Objective	Purpose	Type	Intervention	Main Actor	Level	Impact on Well-being	Impact on Ecosystem
W	child nutrition	D	Ec	school feeding program		N	++	none
W	acute hunger	A	Ec	emergency food aid	WFP, bilateral	N	++	none
W	poverty, chronic hunger	A		"food stamps"	government	N, L	++	none
W	poverty	D	Ec	"food for work", etc.	government, NGOs	N	++	+/−
W	poverty	D	Ec	consumer price subsidy	government	N	+	none
W	health	P	Ec	food quality standards	WHO, government	G, N	+	none
W	health	P	Ec	labeling	government	N	+	+
E	resource management	D	Ec	integrated land use planning	government	N, L	+	+
E	biodiversity, ecosystem protection	P, R	Ec	protected areas	IUCN, government	G, N, L	+	++
E&W	poverty reduction and biodiversity conservation	D, P, A	Ec	direct payments for services provision by rich to poor	government, NGOs, private sector	G, N, L	+	+
E	land resources	D, R	T	land reclamation	government	N, L	+	−
E	land use	R	Ec, T	"grain for green"	government	N, L	+	+
W	land tenure	D	L	land ownership, access rights	government	N	+/−	+/−
W	land tenure	D	Ec	land, property tax	government	N, L	+/−	+/−
E	water supply	D	T	reservoir construction	government	N	+/−	−
W	water use	D	L	water rights	government	N, L	+/−	+/−
W	water use	A	Ec	water pricing	government, private sector	N, L	+/−	+
W	farm income	D	Ec	producer subsidy	government	N	+	+/−
W	revenue creation	P	F	producer tax	government	N, L	−	+/−

E	resource management	P	L	production quota	government	G, N	+	+
E	fishery management	P	L	total allowable catches	government	G, N	−/+	+
E	fishery management	P	Ec	tradable quota	government	G, N	−/+	+
E	fishery management	P	L	decommissioning schemes	government	G, N	−/+	+
W	agricultural production	P, D	F	credit	government, private sector, NGO	N, L	+	+/−
E	sustainable production	P, R	K	R&D, extension services	government, private sector, NGO	N	+	+/−
E	crop production	R	T	irrigation development	government, private sector	N	+	−
W	transport	A, D	T	infrastructure development	government, private sector	N	+	−
E	air, water, soil quality; health	P	Ec	agri-environmental regulation	government	N	+	+
E, W	water quality; health	P	Ec	input ceilings	government	N	+	+
E, W	water quality; health	P	Ec	environmental taxes, charges	government	N	+	+
W, E	farm income, supply, environment	A, P	Ec	set-aside programs	government	N	+	+
E	protection	P	L, Ec	trade quota	government	N	+/−	+
E	protection	P	Ec	tariffs	government	N	+/−	+
W	economic efficiency	D	Ec	trade agreements	government	G, N	+/−	+/−
E, W	watershed management	R	L	transboundary agreements	government	N	+	+

BOX 6.1

Case Study on Gender and Agriculture (www.fao.org/gender)

Often the most fundamental problem in policy and planning for the food and agriculture sector is to get those in decision-making positions to agree that there is a gender issue. Decision-makers either consider that "gender" is not a useful category for the purpose of economic policy and planning or refer to the lack of gender-disaggregated information and data as preventing the incorporation of gender in analytical work.

In developing countries, rural women are the main producers of staple crops like rice, wheat, and maize. These crops often provide up to 90% of the food intake of the rural poor. The contribution of the women in secondary crop production, such as legumes and vegetables, is even greater. Grown mainly in home gardens, these crops provide essential nutrients and are more often than not the only food available during the lean seasons or if the main harvest fails. Also, once the harvest is in, rural women provide most of the labor for post-harvest activities, taking responsibility for storage, handling, stocking, processing, and marketing.

In the livestock sector, women feed and milk the larger animals, while raising poultry and small animals such as sheep, goats, rabbits, and guinea pigs. In many countries, it is mostly the women who are engaged in inland fishing and aquaculture. They perform most of the work of feeding and harvesting fish, as well as processing and marketing the catch.

FAO studies demonstrate that while women in most developing countries are the mainstay of the agricultural sectors—the labor force for the farm and food systems—they have been the last to benefit from, or in some cases have even been negatively affected by, the prevailing economic growth and development processes and policies. Gender bias and gender blindness persist: farmers are still generally perceived as male by policy-makers, development planners, and agricultural service deliverers. As a result, women find it more difficult than men to gain access to valuable resources such as land, credit, agricultural inputs, technology, extension, training, and services. These are the very resources that could enhance their productive capacity.

Technology does not always benefit women. All too often, technology developed in response to the needs of commercial farmers—who are mostly men—actually works to the disadvantage of those who are already disadvantaged, especially women from poor or landless families. In Bangladesh, milling rice with a foot-operated mortar and pestle had traditionally provided the only source of income to many poor, landless women, particularly widows and divorcees. The introduction of mechanical hullers reduced the labor input from 270 hours per ton of rice to 5 hours per ton, thus freeing some 100,000 to 140,000 women (in relation to some 700 mills) for other lucrative work.

Agricultural extension programs ensure that information on new technologies, plant varieties, and cultural practices reach the farmers. However, in the developing world, extension and training services are primarily directed toward the men. Female farmers receive only 5% of all agricultural extension services worldwide, and only 15% of the world's extension agents are women. In Egypt, for example, women account for 53% of agricultural labor but only 1% of Egyptian extension officers are women. The resulting lack of information undermines women's productivity as well as their ability to safeguard the environment by using natural resources in a sustainable way.

Communication is a force for change. Information targeted at rural farmers can help them increase the quantity and improve the quality of the food they produce. Just as important is the information collected from them. Many development efforts fail women in particular, because planners have a poor understanding of the role women play in farming and household food security. They do not take the time to learn more about the activities and needs of the women from the women themselves.

Actions that can enfranchise and empower women in agriculture include:

- reform of inheritance and land tenure laws that limit ownership and use of land by women;
- mobilizing banks and credit institutions to lend to women even if they are constrained by lack of collateral of property and land;
- training of women agricultural extension agents and targeting extension services to women farmers;
- expanding and strengthening education programs directed toward girls and women;
- incorporating the needs and priorities of women in agricultural research and technology programs; and
- facilitating membership of women in agricultural cooperatives and farmer's organizations.

detriment of smaller family farms. While a primary aim of support polices is to support the income of farmers, in fact, only some 23% of the total expenses in price supports translates into additional income for farm households, as Figure 6.2 illustrates (OECD 2003c).

Table 6.2. Commonly Used Instruments of Agricultural Policy

Market price supports (minimum prices on selected products)	application of tariffs on imports
	purchasing predetermined quantities at minimum price
Payments to support agricultural income	based on farmers' output
	based on area planted/animal numbers
	based on historical entitlements
	based on input used
	based on input constraints
	based on overall farming income

In the context of policies affecting food provisioning and sustainable agriculture, research and development is of critical importance. Although in the past, public sector investment in agricultural research and development was significant, in recent years private sector investment is gradually increasing.

The problems of biodiversity loss and biosafety are related to the intensification of agriculture (including fishery, forestry, and animal husbandry), the increased role of the private sector in defining the research agenda, and the lack of regulatory mechanisms. Loss of biodiversity results in two ways. Directly, since industrial agriculture promotes the use of a selected small number of species on which all research is concentrated, and indirectly through the destruction of habitat and land conversion (FAO 2002b). It is well observed that, especially for the most commercial crops (such as rice, wheat, and peas), a small number of varieties account for a relatively large share of the total production, leading to a rapid decline in genetic diversity. The problem is intensified by the fact that the majority of subsidies and support systems are directed toward particular crops and livestock. Thus subsidization needs to be reduced and diversified, while investment in R&D need to be directed to support not only industrial agriculture, but also

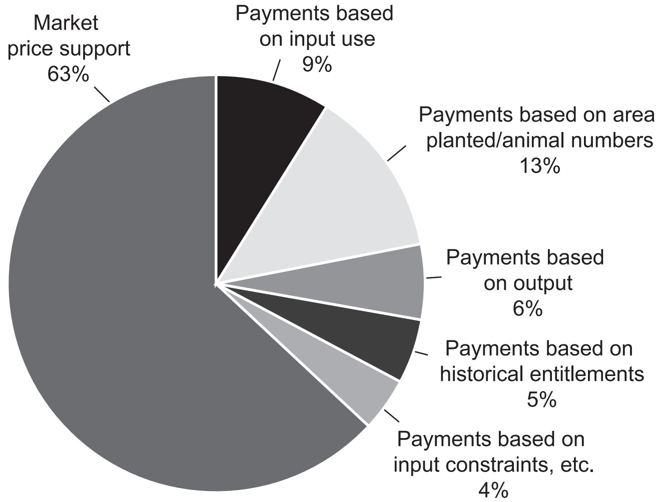


Figure 6.1. Composition of Agricultural Support Policies (OECD 2003)

alternative sustainable means of production that promote biodiversity.

The issue of biosafety in agriculture has become a very important one since it could affect human health and have long-term effects on sustainability of agriculture and food safety. Thus there is an urgent call for public investment in assessing and monitoring the possible effects of using genetically modified organisms in agriculture.

The WTO Agreement on Agriculture, which is under development, emphasizes the reduction of subsidy policies. Although trade liberalization could have positive effects, its overall impact on environment is ambiguous. Increased trade flows will affect the scale of agricultural activities and the structure of production in different countries, the mix of inputs and outputs, the production technology, and finally the regulatory framework. These adjustments, in turn, will impact on the international and domestic environment. International environmental effects include transboundary spillovers (such as greenhouse gas emissions), changes in international transport flows, and the potential introduction of nonnative species, pests, and diseases alongside agricultural products. Domestic environmental effects include ground and surface

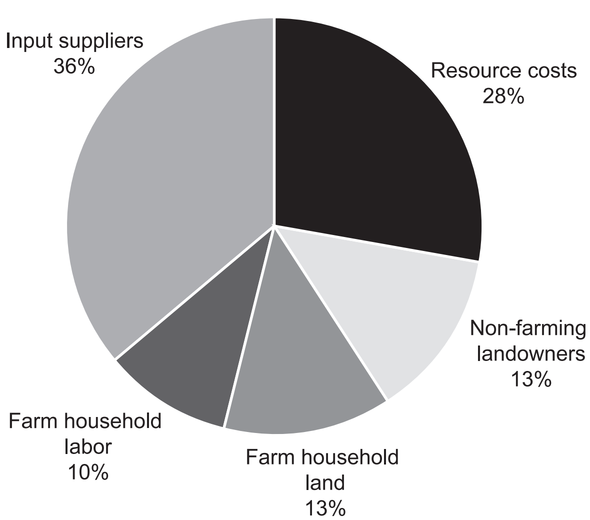


Figure 6.2. Allocation of Price Support (OECD 2003a)

water pollution from fertilizer and pesticide runoffs, and changes in land use that affect landscape appearance, flood protection, soil quality, and biodiversity (Walkenhorst 2000).

In general, there are traditional conflicts between free trade and environmental goals, and arguments are made supporting the view that the contribution of agriculture to environmental degradation could increase with trade liberalization. However, many studies find that the majority of benefits from trade liberalization in agricultural products will go to consumers in the industrial countries (FAO 2002b). Thus economic policies and institutions need to be developed in order to limit the adverse effects while enabling collection of the benefits from trade liberalization. Box 6.2 provides a detailed case study of distortions in the sugar market.

The Common Agricultural Policy is the most important and the most comprehensive sectoral policy ever developed in the European Union, and a forceful instrument of European integration. The CAP was developed with the aims of allowing free competition between farmers in member countries, eliminating as far as possible unequal treatment in different areas, and providing help in the modernization and development of European agriculture (European Commission 1997), although promotion of free competition among EU farmers, and especially between EU farmers and the rest of the world, has hardly been achieved. Box 6.3 discusses the CAP's evolution, including its incorporation of environmental goals.

6.3.3 Knowledge and Education

The food system of the world is going through a rapid and substantive transition. Knowledge and education are essential to achieve a sustainable food system, ensuring that farmers can efficiently produce food that is socially, economically, and environmentally sustainable and that consumers can make informed choices of food that is nutritious, safe, and affordable.

6.3.3.1 Sustainable Food Production Knowledge System

Historically, farmers produced food for their own needs and sold any surplus in the domestic market. This is still the norm among millions of poor farmers in the developing world. Local knowledge of resource conserving farming practices aimed at producing and harvesting different crop varieties, livestock, and fish to meet the needs of the farmers and the local markets have been at the core of traditional agricultural systems. These practices were in equilibrium with the environment.

The unprecedented increase in population and income growth during the last half-century led to increasing food demand, with changing consumption patterns. National and international agricultural research efforts responded by developing high-yielding crop varieties, intensifying livestock production systems and freshwater and marine fishing. The high-yielding varieties from the Green Revolution of the 1960s contributed to a doubling of world food production. However, over time environmental and social problems associated with high levels of inputs, monoculture systems, inefficient and polluting use of water, and the inability to reach many small farmers have come to the fore. Intensive livestock feeding systems have given rise to serious food safety and health concerns. Some marine fish stocks are already under threat of extinction due to overfishing.

The ongoing trade liberalization and globalization of food systems and lack of progress in WTO agricultural negotiations is contributing to widening disparities. Many producers in developing countries cannot compete against the large subsidy induced production and exports of many developed countries. At the na-

BOX 6.2

International Markets and Trade: The Case of Sugar Markets

The sugar market is one of the most heavily distorted agricultural markets. EU and U.S. support policies are primarily responsible for this distortion. The support policies not only fail to achieve their original intent of providing support to local small farmers, but also impose high costs on local consumers and taxpayers, and even higher costs on developing countries. The case of the sugar markets is a clear demonstration of the problems created by the agricultural support policies and illustrates in the most profound way the unfairness of the international trade system in its current state.

Description of the world market

Sugar is produced in more than 100 countries; global production in the year 2001 exceeded 130 million tons. More than 70% is produced from sugar cane, and the rest from sugar beet. The cost of producing sugar from beet is double that of producing it from cane. Brazil and India, both producing sugar from cane, are currently the leading producers followed, by the European Union of 15 countries. Figure A shows the main sugar producers in 2001; in that year, the top ten producing countries accounted for almost 70% of the total production. Production shares have little to do with differences in cost of production among countries, since they are strongly influenced by support policies.

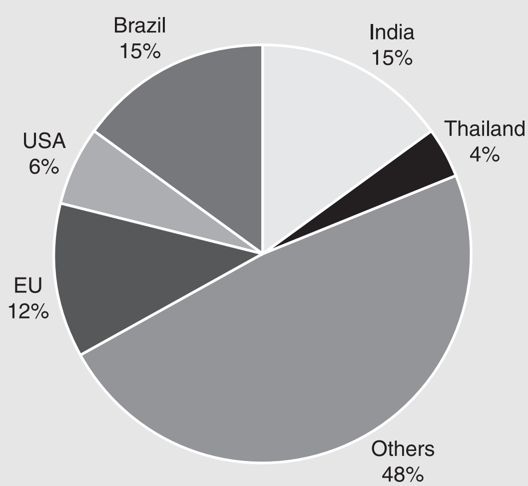


Figure A. World Production of Raw Sugar, 2001 (Statistical and Economic Information 2002, available at http://europa.eu.int/comm./agriculture/agrista/2002/table_en4321.pdf)

World market and support policies

Approximately 28% of the world's sugar is traded in world markets. The export market is very concentrated. The world's top five exporters (Brazil, the European Union, Australia, Thailand, and Cuba) supply approximately 72% of all world free market exports. The main exporter of raw sugar is Brazil, with 2% of world exports; followed by the EU-15 countries, with 15%, and Australia (10%), Thailand (9%), and Cuba (8%) (EU 2003c). While trade in raw sugar has been declining from the mid-1970s to the mid-1990s, the trade in refined sugar has steadily increased. The European Union is the main exporter of white sugar as Figure B illustrates.

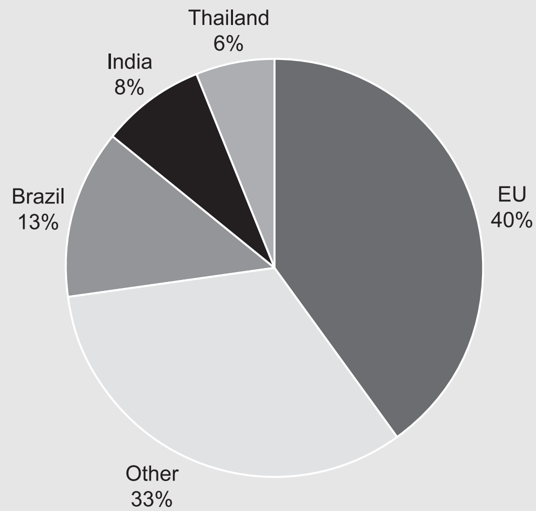


Figure B. World Exports of Refined Sugar, Share of Markets 2000–2001 (Oxfam Briefing Paper 27, available at http://www.oxfam.org.uk/what_we_do/issues/trade/bp27_sugar.htm)

Through the price support system (intervention prices, import duties, and export refunds) and its quota system, the European Union has managed to insulate its production from the world market, so that the prices received by EU producers for the quota production are two to three times higher than the world prices. Furthermore, through a system of production levies and export refunds, even production above the quota receives at least twice the world market price, adding to the pressure on the world market price. Tariffs for sugar imports are the highest in the European Union, reaching up to 140%, or 419 per ton (EU 2003a), effectively blocking all free market imports. EU imports raw sugar for processing at the high EU price on a preferential basis from a small number of developing countries. This web of policies has allowed the European Union to be a main player on the world sugar market, with a share of 12% of the production, 12% of the consumption, 15% of the exports, and 5% of the imports of the world (EU 2003a).

Although the United States remains a net importer of sugar, it has managed through a set of support policies to increase its production and as a result to restrict imports. The high support prices for internal production and the tariffs on sugar imports that reach up to 150% have restricted imports to just above 10% of the total demand in the United States. Currently, with world prices below 10 cents per pound on a raw basis, the EU support price is in excess of 30 cents per pound for raw sugar, while in the United States the minimum support price is 18 cents per pound for raw cane sugar and 22 cents per pound for refined beet sugar (Schmitz 2003). The support prices are expected to increase under the sugar program in the 2002 U.S. Farm Bill. This program contains price supports, payments in-kind, tariff rate quotas, and storage facility loan programs. The low U.S. imports add to the decrease in the world demand for sugar and thus to the decrease in the world price.

tional level, governments need to invest in facilitating participatory and transparent utility-oriented knowledge systems that empower farmers to adopt sustainable food production systems. Agricultural knowledge systems should give particular attention to integrating modern and traditional knowledge. The development in geographical information systems, including remote sensing, offers opportunities to build natural resources databases, critical for spatially relevant agricultural assessments. In many developing countries where agriculture is an important sector of the economy, there is an urgent need for investments in education to

Internal effects of support policies

The support policies in the United States, but most importantly in the European Union, receive strong criticism both domestically and internationally. Domestically, the main points of criticism concern distributional issues, as well as the extremely high cost to consumers and taxpayers. For example, the annual report of the European Court of Auditors mentions the ". . . high cost to consumers and overproduction in the EU . . . that continue to exist despite the . . . successive renewals of the common market for sugar" (European Court of Auditors, 2002, p. 71). While consumers and taxpayers bear the cost of the support policies, the benefits are reaped mainly by the highly concentrated sugar processing industry. In eight out of the fourteen sugar-producing countries, there is just one company controlling the quota. Despite the fact that sugar beet is one of the most profitable arable crops in the European Union, the quota system is such that it favors the larger sugar beet businesses. Small farmers receive a relatively small portion of the total benefits.

Environmental impact

Because of the support policies, sugar beet production is relatively intensive in Europe with negative effects on the environment. Sugar beet is commonly grown in rotation with other crops such as wheat, and it is generally found in the most productive arable regions of the European Union. Production is highly mechanized. It involves a particularly high level of herbicide use compared to other major temperate crop types, which reduces the presence of weeds, and probably other wild species (Baldock et al. 2002; DEFRA 2002). The high levels of nitrates potentially released from the leaves of the plant pose a risk for the pollution of groundwater and surface water (Baldock et al. 2002). Finally, the mechanized harvesting of the sugar beet has led to high levels of soil loss from the land and some areas where beet is grown are also vulnerable to erosion by wind (DEFRA 2002).

Impact on developing countries

The EU support policies have a positive effect on only the seventeen countries that enjoy preferential access to the EU market. Of those countries, four—Madagascar, Malawi, Tanzania, and Zambia—are least developed countries and their quota is only 4% of the total EU imports. In contrast, 80% of the benefits go to just five non-LDC countries—Mauritius, Fiji, Guyana, Swaziland and Jamaica. Other sugar producing LDC countries, such as Mozambique and Senegal, have no access to the EU market for raw sugar. At the same time, developing a sugar processing industry in these countries is not viable given the amount of EU exports. EU support policies also create problems for a number of low-income sugar producing countries such as Cuba and South Africa. The restricted access to the EU and U.S. markets and the reduction in the world price of sugar have had devastating effect on both the processing industries, as well as the farming business of these countries.

The support policies not only harm the economies of these countries as a whole, but they have a devastating effect at the community level since the farmers in most of these countries are small producers with no alternative source of income. Despite the fact that some of these countries, such as Mozambique and South Africa, have the lowest cost of production, sugar farming cannot guarantee a viable income to small farmers. These farmers cannot afford to harvest and transport sugar cane to the mills because of the extremely low world price and, as a result, are forced to give up farming and live in poverty. Sugar farming plays a less important role in the economies of developed countries than in those of developing countries. In the EU, employment through agriculture was just over 4% in 2000 (OECD 2001), while in the developing world an average of 50% of the people make their living from farming and agriculture (FAOSTAT database, August 2001). Allowing for a more open world market for sugar will be very important for the successful development of, and subsequently reducing poverty in, some LDC countries.

Potential changes

Apart from the cost to the sugar producing LDC countries, the support polices have negative effects on the economies of some of the low cost producing countries. A number of these countries, namely Australia, Brazil, and Thailand, have recently filed a request with the World Trade Organization to determine whether EU sugar production and export subsidies are legal under existing trade treaties. This move puts pressure on the European Union to change its support policies. Although, technically the European Union is within the bounds of the Uruguay round of agreements on agricultural products, it is quite obvious that its policies distort the international sugar market. This is unquestionable in the case of quota production, since the European Union exports the excess production at a price that is between one third and one half of the domestic guaranteed price. For example, in mid 2002, EU processors of white sugar were guaranteed a price of at least $620 while the world market price was just $180 (Oxfam 2002).

Similar arguments hold for the exports of white sugar, produced from the import of cane sugar from developing countries, as well as for the non-quota exports. Without the support policies, EU exports would most likely be eliminated because of the high costs relative to its main competitors. Not only would EU exports be eliminated, but the European Union would also cover most of its demand from imports. In such a case, although production would shift to more efficient producers, the world price would increase because the demand would be higher and the subsidized production would not exist. However, because the market would be thicker, the world price would be more stable (van der Linde et al. 2000).

Although a major relaxation in U.S. and EU support policies is needed, there is little evidence that it will be realized any time soon. The sugar sector is the only one that was not affected by the 1992 reform process of the EU Common Agricultural Policy. The CAP promoted competitiveness by compensating institutional price cuts with direct income payments (EU 2003b). The failure of the "Everything but Arms" initiative of the European Union and the new Farm Bill in the United States provide an indication that no major changes should be expected in the near future. Equally disappointing is the very slow movement in the current negotiations under the Doha Round for an Agreement on Agriculture. However, changes under the CAP reform proposals could have some positive effects, if price supports are replaced by direct income payments.

produce a cadre of agricultural researchers, as well as provide training of farmers and extension services personnel. Without this capacity, agricultural development to provide livelihoods for a substantial proportion of the populations in developing countries cannot succeed. And in turn, without a strong agricultural foundation, many developing countries cannot develop other sectors of the economy and services.

At the international level, the agricultural knowledge system must facilitate the exchange and sharing of national-level information and experiences. The international agricultural research sys-

BOX 6.3

The Common Agricultural Policy

The basic principles of the Common Agricultural Policy were set out in the Rome Treaty in 1957. The replacement of national agricultural policies with a common one was looked upon as a way of combining efforts to secure the supply of agricultural products to the consumer and provide a better standard of living to the agricultural community. In this sense, and following the historical evolution of the CAP in association with the enlargement and the integration processes in Europe, the CAP can be regarded as a response with a major impact on human well-being and poverty reduction in the EU countries.

Impacts on ecosystems

The CAP has contributed to a large degree to the modernization of agriculture in the European Union, but this modernization has been accompanied by damaging effects on the environment. In particular, the politically stimulated intensification of agricultural production has led to surpluses in certain products and to environmental degradation.

An example of the impact of agriculture on the environment is the change in the "Kempen" landscapes. These are high diversity enclosed areas found in Flanders (Belgium), southern and eastern Netherlands, North-Rhine-Westfalia (Germany) and Les Landes (France). They have a patchwork layout of woods, heath, swamps, mixed crops, scattered farmsteads and roads. Intensification of agriculture, use of fertilizers, manure disposal, and fragmentation of wild life habitats pressurized and increased the vulnerability of the ecosystems, by increasing the risks of soils dying out and also of groundwater pollution.

The increased attention regarding environmental conditions in the last decades resulted in attempts to introduce environmentally friendly policies in the CAP. These attempts marked the beginning of an ongoing process of integrating environmental concerns into agriculture and developing a unified agri-environmental policy framework.

Environment and the Common Agricultural Policy

The first attempts for environmental protection at the EU level started in 1972, since there was no mention of environmental policy in the Treaty of Rome. During the 1970s and the 1980s, the member states adopted more than 200 measures aimed mainly at reducing vehicle emissions, industrial and agricultural emissions, and effluents and noise. The environmental dimension was incorporated into the Single European Act, which came into effect in 1987, and provided the legal basis for environmental policy. It introduced three environmental policy objectives: (1) preserving, protecting and improving the quality of the environment, (2) protecting human health, and (3) prudent and rational utilization of natural resources. It also introduced four principles: precaution, prevention, rectification at the source, and polluter-pays.

It is important to contrast these objectives and principles with the corresponding objectives and principles of the CAP. The objectives of the CAP are: (1) increased agricultural productivity, (2) fair standard of living for the agricultural community, (3) stabilization of markets, (4) availability of supplies, and (5) reasonable consumer prices. The CAP principles are: market unity, financial solidarity, and community preference.

Since then, important statements issued by the Commission introduced the idea of controlling agriculture and protecting the environment. The Maastricht Treaty (1993) recognized environmental policy as a common policy, endorsed the sustainability principle, and set as an obligation the integration of environmental requirements in all EU policies. In the Fifth Environmental Action Program (1992–2000), agriculture is one of the five target sectors, and a fundamental objective is the achievement of sustainable agriculture, through the conservation of natural resources such as water, soil, and genetic resources. CAP reform in 1992, by encouraging farmers to use less intensive production methods, provided a way of reducing environmental pressures and unwanted surpluses. Furthermore, it included direct agri-environmental and afforestation methods. As for the structural aspects of CAP, environmental policy was recognized as a major component of the EU's rural development policy. In 1993, the assessment of environmental effects of activities was made compulsory.

The specific environmental measures associated with the CAP can be found in all three aspects of the CAP: the Common Market Organization, the accompanying measures, and the structural measures. Regarding the CMO, the set-aside program for cereals, oilseeds, and protein crops has direct environmental impacts. The set-aside program involves compensatory payments to farmers. It is beneficial to the environment since it reduces pressures from farm activities. On the other hand, to prevent negative environmental consequences, if land is left fallow, member states need to apply appropriate environmental measures. Under the set-aside and non-food production scheme, farmers are allowed to grow non-food

tem has a particular responsibility toward training and capacity building in developing countries. This is particularly important for new agricultural research and technology that not only requires a long time horizon, but is also highly capital and knowledge intensive.

6.3.3.2 Sustainable Food Consumption Knowledge System

The world's food consumption system is also going through a radical transformation. Consumers are increasingly separated from the food production systems. They need the knowledge and education to make informed food choices. This includes ethical, moral, and welfare, as well as economic and environmental, considerations.

Consumer concerns go well beyond basic human health. The quality of food and how it is produced; animal welfare; modern technology, and environmental, ethical, and cultural differences—all feature in the growing public debates about food quality and safety. Chemical and hygiene, as well as food security issues also cause concern.. We are faced with the problems of under- and overconsumption and a growing trend toward consumption of unhealthy processed foods. The emerging problems of overconsumption of the wrong kinds of foods is more and more driven by corporate food processing and marketing companies that use the media to change peoples' eating habits and taste. An example of this is the rapidly increasing incidence of obesity and diabetes due to consumption of high-sugar-content processed food combined with lifestyle changes with little exercise and physical activity. Government budgets increasingly have to deal with such health ailments and they have a responsibility to implement regulatory systems that ensure the availability of healthy and safe foods. The future food crisis may well be one of poor nutrition and related serious health issues.

The food consumption knowledge system needs to ensure that:

- scientific research findings on the implications of food technologies for human health and for the environment are presented clearly and underpin knowledge-based policy considerations, while recognizing that scientific evidence is often incomplete and equivocal;

products on set-aside land while still receiving the set-aside premium. These non-food products could have a positive impact on the environment, since they can be used as biomass or biofuel raw materials like fiber or ingredients for pharmaceutical products, thus reducing pressure on nonrenewable resources. Under the cropland set-aside and the long-term environmental set-aside, introduced by the accompanying agri-environmental measures, farmers could set aside land for twenty years in order to create biotopes or small natural parks.

The objectives of the agri-environmental measures, introduced with the accompanying measures, are to combine beneficial effects on the environment with a reduction in agricultural production, and to contribute to agricultural income diversification and rural development. In the context of these objectives, member states could provide aid for farmers who: (1) reduce the use of fertilizers, or introduce organic farming, (2) change to more extensive forms of crops, including forage production, (3) reduce the number of sheep and cattle per forage area, (4) follow environmentally friendly farming practices, (5) ensure the upkeep of abandoned farmlands, (6) set aside farmland for at least twenty years to establish biotope reserves and natural parks, or to protect hydrological systems, and (7) manage land for public access and leisure activities. Examples of such measures in action are the management of salt marshes in coastal lands in the United Kingdom, the program for the protection of flower species in Germany, the reduction in use of nitrogen fertilizers in Denmark, and the maintenance of grassland areas for extensive livestock farming in France.

Agricultural structural measures stress the environment as an essential part of sustainable rural development. These measures include horizontal measures, such as promotion of organic farming and better use of by-products and waste recycling. Specific regional measures promote objectives such as water management, soil conservation, combating erosion, biodiversity conservation, and landscape protection (see Leader initiative, European Commission 2003).

The new fundamental CAP reform adopted by the EU farm ministers on June 26, 2003, addresses these issues. Its key elements include:

- a single farm payment for EU farmers, independent of production; limited coupled elements may be maintained to avoid abandonment of production;
- the linkage of this payment to respect for the environment, food safety, animal and plant health and animal welfare standards, as well as the requirement to keep all farmland in good agricultural and environmental condition (“cross-compliance”);
- a strengthened rural development policy with more EU money, new measures to promote environmental quality and animal welfare, and assistance to farmers in meeting EU production standards;
- a reduction in direct payments (“modulation”) for bigger farms to finance the new rural development policy;
- a mechanism for financial discipline to ensure that the farm budget fixed until 2013 is not overshot; and
- revisions to the market policy of the CAP including asymmetric price cuts in the milk sector; reduction of the monthly increments in the cereals sector by half, with the current intervention price being maintained; and reforms in the rice, durum wheat, nuts, starch potatoes, and dried fodder sectors.

Conclusion

The CAP constitutes a major response by the European Union aimed at securing food supply on the one hand, and enhancing the well-being of the rural communities on the other. The intensification of agriculture that followed the introduction of the CAP undoubtedly created environmental pressures and degradation of European ecosystems. In response, the EU introduced policies that affect the environment both indirectly, through the land set-aside programs, and directly through agri-environmental measures, structural measures, environmental policy related to agriculture, and nature and resource conservation measures. It is expected that citizens could thus enjoy a higher provision of environmental services and a greater variety of products obtained through environmentally friendly practices.

Overall, the introduction of the environmental dimension into the CAP can be regarded as a direct recognition of the fact that the provision of food by ecosystems within a policy framework that attempts to protect both consumers and producers might create undesirable environmental pressures. This policy framework design needs, therefore, to include appropriate environmental policy objectives and measures for achieving them.

- food regulations including labeling are consistent with scientifically defined risks to health and the environment. The similarities and differences in regulation across countries need to be analyzed in relation to rigorously defined and agreed standards; and
- governments, the scientific community, the private sector, and civil society are transparent in presenting information on food risks and in putting in place measures to address these risks.

The information and communication revolution has a significant role to play in evolving national and international agricultural knowledge systems. While a third to a half of the population in the developed world has access to the Internet, in Asia and Africa this proportion is 0.5% of the population. The Internet provides a worldwide network for sharing of agricultural knowledge systems and it is essential that the wide digital divide be given priority attention.

It is not just a question of knowledge generation and transfer, but also an interaction of knowledge networks involving multiple stakeholders, namely the farmers, buyers, transporters, processors, distributors, retailers, and consumers. They all need to be involved in the development of agricultural knowledge systems.

In the knowledge economy, agricultural research and technology are as much social and economic activities as they are technical. Openly communicating with the broad public on an ongoing basis about the flows of new knowledge, its utility and potential socioeconomic implications, is essential. Given that future outcomes of new knowledge cannot be fully anticipated in advance, the agricultural knowledge system must be transparent and responsive and must foster trust.

6.3.3.3 Integrating Ecological and Socioeconomic Responses

The scientific and development policy community at the national and international level must work expeditiously toward the goal of achieving health-enhancing food systems that are socially, economically, and environmentally viable and sustainable. This will require multidisciplinary analytical capacity building, focusing on a systemic combination of relevant sciences, including biological and biochemical, agroecological and environmental, social and economic, as well as informatics. (See Box 6.4.)

BOX 6.4

Integrated Assessment: Agroecology, Economy, and Climate Change

The Food and Agricultural Organization of the United Nations and the International Institute for Applied Systems Analysis have over the last two decades developed integrated ecological and economic analytical tools and global databases. The focus has been on multidisciplinary scientific research, analyzing the current and future availability and use of regional and global land and water resources, in the face of local, national, and super-national demographic, socioeconomic, international trade and globalization, technological, and environmental changes, including climate change and climate variability.

AEZ/BLS (Agroecological Zones/Basic Linked System) combines a spatially explicit biophysical model of potential productivity of global land resources with a 34-region, 10-sector general equilibrium model. The spatial component allows a more detailed and realistic accounting for available land, its potential productivity, and the effect of future climate change on productivity.

The AEZ methodology for land productivity assessments follows an environmental approach; it provides a framework for establishing a spatial inventory and database of land resources and crop production potentials. This land-resources inventory is used to assess, for specified management conditions and levels of inputs, the suitability of crops/and utilization types in relation to both rain-fed and irrigated conditions. It also quantifies expected production of cropping activities relevant in the specific agroecological context. The characterization of land resources includes components of climate, soils, landform, and present land cover. Crop modeling and environmental matching procedures are used to identify crop-specific environmental limitations, under various levels of inputs and management.

Results of the AEZ/BLS integrated ecological–economic analysis of climate change on the world food system includes quantification of scale and location of hunger, international agricultural trade, prices, production, land use, etc. The analysis assesses trends in food production, trade, and consumption, and the impact on poverty and hunger of alternative development pathways and varying levels of climate change.

Following accession to the World Trade Organization, China is facing the challenge of defining transition strategies that maintain a socially sustainable level of rural incomes and employment, meet the needs of rapidly growing urban populations, are environmentally sustainable, and meet international commitments. A detailed case study of China (the CHINAGRO project) takes into account two prominent trends: China's increasing international trade relations as a result of its accession to the WTO and the change in dietary patterns due to rapid per capita income increases and fast urbanization. The project analyses the impacts of these trends on the agricultural sector and on the livelihoods of the rural population depending on agriculture.

Specifically, one of the issues under study is whether, in light of the fast-rising demand for animal proteins by Chinese consumers, and the sustained rural to urban migration, the country needs to aim at (1) self-sufficiency in cereals, protein feeds, and meat, including animal feed; or (2) importing feed; or (3) importing meat. A second issue under investigation is, not surprisingly, how the WTO accession, the Doha Round, and more generally China's opening to world trade will affect the agricultural economy of the country, and what feedbacks to the world market and hence consumers and producers in other regions can be expected. A third issue is to assess the implications of major ongoing infrastructural projects, in particular those aiming at redirecting water flows.

Agroecology has emerged as the integrated discipline that provides a holistic approach to manage agroecosystems and the sustainable use of natural resources. It provides guidelines to develop diversified agroecosystems—systems that take advantage of the effects of the integration of plant and animal biodiversity enhancing complex interactions and synergisms and optimizes ecosystem functions and processes, such as biotic regulation of harmful organisms, nutrient recycling, and biomass production and accumulation. Agroecology is of particular relevance to small farmers, emphasizing a development methodology that encourages participation, use of traditional knowledge, and adaptation of farm enterprises that fit local needs and socioeconomic and biophysical conditions (Altieri 1996).

6.3.4 Technological Responses

The agricultural science and research challenge is to combine the best of conventional breeding with safe and ethical molecular and cellular genetics research and biochemistry, to develop nutritionally enhanced and productive germplasm. (See Box 6.5.) The specific food crops of the poor, including coarse grains, roots and tubers, and plantains and bananas should be given the highest priority. Considerable scope exists for environmentally sound fish farming and intensive livestock production, with due consideration to health hazards and animal welfare consideration.

Technological responses in agriculture have had a massive, often regional, impact on the environment, human health, and development in the past. Recent technological responses will globally affect human health, food security, food safety, environment and environmental health, and socioeconomic and ethical issues. Food production systems have rapidly developed into globalized trading systems. Technological responses are considered inevitable for future food security and adaptation to local agroecological, socioeconomic, or ethical needs. Risk assessment, risk management, and risk communications are central elements in developments of the food production system. While risk assessment is based on science, scientific evidence and analysis cannot always provide immediate answers to questions posed.

6.3.4.1 Crop Breeding Strategies

Crop breeding strategies are highly dependent upon preservation of diversity of crops and wild relatives. There is growing scientific and public concern about a rapid decline of diversity, for example, of land races. There are two major alternatives for the conservation of genetic resources: in situ and ex situ.

In situ conservation refers to the conservation of important genetic resources in wild populations and land races, and it is often associated with traditional subsistence agriculture. It is concerned with maintaining the population of various species in the natural habitats where they occur, whether as uncultivated plant communities or in the fields of the farmers as part of existing agroecosystems. In situ conservation of crop plants involves the conservation on-farm of local crop cultivars (or landraces) with the active participation of farmers.

If the focus is only on agricultural varieties, the approach is only partially effective because traditional crop varieties, though much more diverse than elite varieties, are themselves much less diverse than wild populations and wild relatives. An attractive approach is to combine nature reserves focused on protection of

BOX 6.5

International Agricultural Research

The fundamental considerations include identification of the priority crops of relevance to the poor, what combination of public and private sector science can be most efficient and effective, and also where research effort can best be located.

Developed countries traditionally provided generous support to national agricultural research in that they created a wide and strong scientific capacity and produced products and innovations that were freely available. The intensified development of private sector research, accompanied by intellectual property protection and the trends in reduced public funding, calls for new research partnerships.

Developing countries such as China, India, Brazil, etc., have the scientific capacity and resources to research at the forefront of agricultural science. However, for most developing countries the scientific research capacity is severely limited and establishing national agricultural research systems (NARS) is generally a non-viable proposition. The poorest developing countries have less then one scientist and engineer per 10,000 people, in comparison to about 70 in the United States and Japan.

A decentralized global agricultural research partnership would be an effective and efficient way forward to produce the necessary research innovations of relevance to food-insecure countries. This could comprise a network of regional agricultural research centers linked to advanced NARS institutions in developing and developed countries, as well as, the international agricultural research system, namely the Consultative Group on International Agricultural Research. The multilateral institutional cosponsors of the CGIAR—the World Bank, the Food and Agriculture Organization of the United Nations, the United Nations Development Programme, and the International Fund for Agricultural Development—and bilateral donors must give serious consideration to creating regional agricultural research centers of excellence. This would also be of benefit to these aid partners in terms of complementing their own individual development efforts to reduce hunger and poverty.

The CGIAR has a particularly important role to play in this. It started out some 30 years ago with a strategic core research focus on productivity enhancement. However, over time there has been a shift toward programs of natural resource management, strengthening NARS, and policy research. At present, productivity-increasing research accounts for only about a third of CGIAR's annual expenditure of some $370 million. This level of funding is disparately miniscule in comparison, for example, to some $350 billion spent annually on agricultural subsidies by the developed countries.

In the developed countries, agricultural research funding amounts to some $14 billion, comprising half in the public sector and half in the private sector. For the developing countries, the total expenditure is about $8 billion. CGIAR funding is a minute share of these levels of expenditure and yet this international public good research system has demonstrated its major impact during the last 30 years and its beneficiaries have been farmers not only in developing countries, but also in the developed countries.

wild races and wild relatives with traditional agricultural practices. However, we should not expect traditional farmers to forgo the substantial economic benefits that may attend the switch to elite varieties. Hence, this may require direct economic subsidy or conservation of traditional varieties in some other way.

Ex situ conservation refers to the conservation of genetic resources off-site in gene banks, often in long-term storage as seed. A key international agreement, which comes up for renewal every four years, governing many of the world's most important crop diversity collections was recently renewed for an additional four years by 165 countries, ensuring that this diversity, which is critical for crop improvement, will remain in the public domain for the foreseeable future. Today, the Future Harvest Centers of the CGIAR conserve more than 500,000 samples of seeds and other plant parts in storage facilities called gene banks. The Centers do not own the material in the collections, but serve as trustees or custodians for them on behalf of the world community.

However, seeds of many important tropical species are recalcitrant, that is, difficult or impossible to store for long periods. Many crop plants are clonally propagated. Storing seed does no good, and tissue culture techniques for long-term storage are poorly developed. New technologies require to be explored to improve the possibilities for ex situ protection of diversity and in situ conservation policy and methods are more critical for such species.

6.3.4.2 Precision Agriculture

Precision agriculture or site-specific management refers to the differential application of inputs to cropping systems or tillage operations across a management unit (field). Input applications may vary either spatially or temporally within management units. The methods involved include application via predefined maps based on soil or crop condition or sensors that control application as machinery traverses the field. As monitoring systems, such as global positioning systems, allow monitoring by square meters instead of square kilometers, traditionally spatial changes across the field allows precocious control of chemical, fertilizer application, irrigation, or pest management.

Positive impacts on environmental quality will start to emerge as tools become available to apply chemicals, fertilizers, tillage, and seed differentially to a field, as well as tools to collect the yield or plant biomass by position across the field. Remote sensing technology will allow observation of the variation within a field throughout the growing season relative to the imposed management changes. Monitoring equipment to capture the surface water and groundwater samples needed to quantify the environmental impact through surface runoff or leaching is available. Technology to capture the volatilization of nitrogen or pesticides from the field into the atmosphere from modified practices exists (Hatfield, 1991).

Until a few years ago, precision agriculture was thought to have potential only in areas where technical facilities, as well as, field structure were compatible. Farmers in sub-Saharan Africa, however, have been practicing precision farming for centuries (Brouwer and Bouma 1997). A better knowledge of field level ecological variability, gained in part by making use of modern statistical techniques, can help farmers and researchers increase nutrient user efficiency through improved precision agriculture, also in low-input, low technology situations (Brouwer and Powell 1998; Voortman and Brouwer 2003; Voortman et al. 2004). It would also allow farmers to maintain, at least partially, the spatial variability that can contribute to risk-reduction in their production systems (Brouwer et al. 1993). Furthermore, adding science to traditional knowledge and practices is relevant and important to optimizing systems for production and to sustain them.

6.3.4.3 Genetically Modified Organisms in Agriculture

Modern methods of biotechnology include genetic modification to enable the development of crops, animals, or bacteria that exhibit traits which could not be introduced with classical breeding methods.

Only products derived from a limited number of genetically modified organisms (such as cotton, maize, oil seed rape, papaya, potato, rice, soybean, squash, sugar beet, tomato, wheat, and carnations) have been approved as yet in some countries. From these products, only a few products such as herbicide- and insect-resistant maize (BT maize), soybeans and oil seed rape—are on the international markets at present. During the six-year period 1996–2001, the major trait incorporated into genetically modified organisms was herbicide tolerance, with insect resistance being second. Major new developments include:

- in the near future, most market introductions of new transgenic crops will concern agronomic traits, especially herbicide resistance and insect resistance;
- altered nutrition and composition (for example, Vitamin A or iron deficiency);
- genetic modification of plants used to produce vaccines for human and animal illnesses;
- salt tolerant and drought resistant crops;
- transgenic crops in which the introduced trait is active in only one generation, so-called ''Genetic Use Restriction Technologies'';
- the first transgenic animal for food purposes that is likely to be licensed is fast- growing Atlantic salmon. Other fish in which genes for growth hormones have been introduced experimentally include carp, trout, tilapia, and wolf-fish. It should be emphasized that licensing of such transgenic species will require assessment of impacts and risks to the aquatic environment, because of their connectivity and the relative competitiveness of strains;
- most efforts in creating transgenic arthropods, such as insects for food-related uses, are in the area of pest control (for example, transgenic, sterile male plague insects have been produced experimentally); and
- soil bacteria-promoting crop development.

6.3.4.3.1 The scientific gene modification debate and concerns about biodiversity

While genetically modified organisms, generated following the purposeful introduction of exogenous DNA into plants or animals, should in theory present no more risks than plants or animals improved through selective breeding approaches, genetically modified organisms have a better predictability of gene expression than conventional breeding methods. Moreover, the transgenes are not conceptually different than the use of native genes or organisms modified by conventional technologies. Today, extensive areas have been planted with genetically modified crops in the United States and China, without untoward effects.

Biotechnology may help achieve the productivity gains needed to feed a growing global population; impart resistance to insect pests, diseases, and abiotic stress factors; and improve the nutritional value and enhance the durability of products during harvesting or shipping. New crop varieties and biocontrol agents may reduce reliance on pesticides, thereby reducing the crop protection costs of farmers and benefiting both the environment and public health. Research on genetic modification to achieve appropriate weed control can increase farm incomes and reduce the time women farmers spend on weeding and thus allow more time for childcare.

Biotechnology would also offer cost-effective solutions to micronutrient malnutrition, such as vitamin A and iron. Research in biotechnology on increasing the efficiency of utilizing farm input could lead to the development of crops that use water more efficiently and extract phosphate from the soil more effectively. The development of cereal plants capable of capturing nitrogen from the air could contribute greatly to plant nutrition, helping poor farmers, who often cannot afford fertilizers. By increasing crop productivity, agricultural biotechnology could help reduce the need to cultivate new lands and conserve biodiversity. If the appropriate policies are put into place, productivity gains could have the same poverty-reducing impact as the Green Revolution,.

The debate over genetic modification has highlighted the potential impacts on human health, environment, agrobiodiversity, and economic aspects, stemming mainly from impacts from random DNA integration into the genome of recipient organisms.

Human health: Impact on human health occurs through the formation of new products with allergenic or other effects. Although no direct risks for human health have been observed with genetically modified foods, the concerns have resulted in the establishment of risk assessment measures, recently established in CODEX guidelines on genetically modified foods (Haslberger 2003).

Environment: Impacts on the environment occur in several ways—by direct competitive effects through faster growing plants, animals or fish compared with wild species; by indirect effects (such as insect- resistant genes incorporated into plants reducing the activity or health of natural insect pollinators); by effects on wild relatives through the transfer of transgenes to wild species causing some change in function (such as inducing herbicide resistance in weedy species). There is however still controversy among scientists, as different outcomes have been reported on issues such as insecticide/pesticide use, yield increases, and environmental benefits (for example, Obrycki et al. 2001; Hilbeck 2001; Dewar et al. 2003). Different local agroecological conditions may contribute to different outcomes in the use of such crops; thus, their deployment may require careful case-by-case consideration. Risks to the environment of the transboundary movement of genetically modified organisms are being dealt with under the Cartagena Protocol of Biosafety.

Agrobiodiversity: For crops, the process of seed trading and transport can contribute to a potential spread of transgenes. Outcrossing of recombinant DNA could result in a significant transfer of recombinant DNA to wild or weedy plants, especially, in centers of origin of crops or in areas of high species diversity of plants related to the crop plant. Genetically engineered insects, shellfish, fish, and other animals that can easily escape, are highly mobile and form feral populations easily. They are of concern, especially, if they are more successful at reproduction than their natural counterparts. For example, it is possible that transgenic salmon with genes engineered to accelerate growth released into the natural environment could compete more successfully for food and mates than wild salmon, thus endangering wild populations. Thus particular guidelines, sterile release strategies, and other controls will be necessary to fully exploit the potential production advantages.

Economics: The mixing of genetically modified and unaltered crop products make the produce impossible to sell in markets unwilling to buy such products. This is currently the case as customers in some regions differentiate GM foods as unethical or unsafe, compared with agricultural products derived from plants and animals improved through conventional breeding programs.

The biggest risk of modern biotechnology for developing countries is that technological development may bypass poor farmers because of a lack of enlightened adaptation. It is not that biotechnology is irrelevant, but research needs to focus on the problems of small farmers in developing countries. Private sector research is unlikely to take on such a focus, given the lack of future profits. Without a stronger public sector role, a form of scientific apartheid may develop, in which cutting edge science becomes oriented exclusively toward industrial countries and large-scale farming.

The focus of biosafety regulations needs to be on safety, quality, and efficacy. The need and extent of safety evaluation may be based on the comparison of the new food and the analogous food, if any. In relation to environment, one has to look at the interaction of the transgenes with the environment. The potential of recombinant technologies allows a greater modification than is possible with conventional technologies. In most of the developing countries, there is no system in place to regulate the production and use of genetically modified organisms. The management, interpretation, and utilization of information will be an important component of risk assessment, and determine the effectiveness and reliability of this technology.

While modern biotechnology offers promise to increase productivity and protect natural resources and ecosystems, the risks of such events occurring need to be evaluated in a scientific manner. Strategies (such as the production of self-limiting populations of genetically modified organisms) need to be developed in the first instance, to limit the spread/escape of new materials. Among the measures needed:

- evaluations of risks need to be pre-planned and evidence-based;
- communication strategies for the results of such trials need to be developed for policy makers and for the general public and implemented; and
- future policy needs to be formulated on the basis of evidence and cost-benefit analyses, which include levels of estimated risk.

6.3.4.3.2 Analysis and assessment

Precision agriculture and integrated agricultural systems are generally believed to have the potential for supportive effects on sustainability, according to their use in specific agroeconomic conditions (for example, farm scales). Modern biotechnology is purported, from a technical perspective, to have a number of products for addressing certain food security problems of developing countries (Conway 1999; Skerrit 2000). The availability of such products could have not only an important role in reducing hunger and increasing food security, but also the potential to address developing world health problems. However, some governments believe the risks (safety, environmental, and/or economic) associated with modern biotechnology far outweigh the benefits.

Modern methods of biotechnology, as well as molecular methods for the preservation of germplasm diversity are generally accepted as important tools for improved sustainability in agriculture (Shah and Strong 2000).

The use of GM organisms in food production has developed into a significant part of agriculture in some countries. Scientific proof of advantages such as pest reduction can be shown for some crops in some areas, but many scientific uncertainties about advantages or risks (for example, out-crossing) are still evident. Present experiences suggest that it may not be possible to assess advantages or risks of genetically modified organisms in food production in general, but rather that they must be addressed case by case for specific agroecological or even socioeconomic conditions. Improved regulations, which allow a regional differentiated use of certain products in addition to a globalized trading system, may be desirable.

6.3.4.4 Sustainable Food Production Systems and Organic Farming

Improving the sustainability of complex food production systems requires a thorough understanding of the relationships between food consumption behaviors, processing and distribution activities, and agricultural production practices, as well as, a good understanding of the links between societal needs, the natural and economic processes involved in meeting these needs, and the associated environmental consequences. The ultimate goal is to guide the development of system-based solutions. Indicators covering the life cycle stages include origin of (genetic) resource; agricultural growing and production; food processing, packaging and distribution; preparation and consumption; and end of life.

Current trends in a number of indicators threaten the long-term economic, social, and environmental sustainability of the food system. Key trends include: (1) rates of agricultural land conversion, (2) income and profitability from farming, (3) degree of food industry consolidation, (4) fraction of edible food wasted, (5) diet-related health costs, (6) legal status of farm workers, (7) age distribution of farmers, (8) genetic diversity, (9) rate of soil loss and groundwater withdrawal, and (10) fossil fuel use intensity. Effective opportunities to enhance the sustainability of the food system exist in changing consumption behavior, which will have compounding benefits across agricultural production, distribution, and food disposition stages (Heller and Keoleian 2003), as well as alternative agricultural practices. One way of doing this is by enhanced breeding methods enabling improved traits for specific socioecological situations. Another is integrated organic farming.

6.3.4.4.1 Principles of organic farming and standardization

Organic farming management relies on developing biological diversity in the field to disrupt the habitat for pest organisms, and the purposeful maintenance and replenishment of soil fertility. Organic farmers are not allowed to use synthetic pesticides or fertilizers. Organic farming represents an alternative and more holistic view of agriculture and food production, and directly addresses the problems faced in many areas of conventional agricultural practice. Concerns about the environment and nature, livestock welfare, and food quality are thus essential elements of the philosophy behind organic farming.

The special values and principles of organic farming stem from the recognition that human society is an integrated part of nature, and that—due to the complexity of the socioecological systems—we have incomplete knowledge of the far reaching and future consequences of our actions. Based on these fundamental assumptions, three general principles—the cyclical principle, the precautionary principle, and the nearness principle of action and development—can be set out.

There is a special conception of sustainability in organic farming, which has been termed "functional integrity." Functional integrity corresponds to a systemic view, seeing agriculture as a complex system of production practices, social values, and ecological relations. The functional integrity of the system depends on the use of cyclical processes and the reproduction of crucial elements, such as soil fertility, crops, livestock, nature, and human institutions. As a principle of action, this is sometimes expressed in terms of the development of system's harmony with nature.

There is also a special conception of risk decisions and prevention in organic farming, which can be characterized in the form of the precautionary principle, which involves a self-reflective awareness of the limits of knowledge and control, and strategies for handling ignorance and uncertainty. The principle is implemented by acting before conclusive scientific understanding is available, and involves early detection of dangers through comprehensive research, and promotion of cleaner technologies.

6.3.4.4.2 Evidence for enhanced sustainability in organic farming

In a 21-year study of agronomic and ecological performance of biodynamic, bioorganic, and conventional farming systems in Central Europe, crop yields were found to be 20% lower in the organic systems, although input of fertilizer and energy was reduced by 34–53% and pesticide input by 97 %. However, at the global level, the scope for and adoption of organic agriculture is likely to be very limited since, for example, a 20% decline in crop yields would have serious consequences on food supplies. Enhanced soil fertility and higher biodiversity found in organic plots may render these systems less dependent on external inputs (Maeder et al. 2002). A long-term project (1992–1997) in the United Kingdom comparing conventional and integrated arable farming systems found that, in terms of total energy used, the integrated system appears to be the most efficient. However, in terms of energy efficiency, energy use per kilogram of output, the results were less conclusive (Bailey et al. 2003).

Results comparing data from organic or conventional farming are mostly a matter of intensive debate because of various specific or local aspects; while organic farming certainly shares many risks with conventional methods (for example, mycotoxin residues), the increase of organic farming has undoubtedly resulted in enhanced sustainability indicators as well as in an improved focus of the public perception in these problems. According to an FAO report (1999a), the unique aspect of organic farming is that almost all synthetic inputs are prohibited. Crop rotations are mandated and proper use and management of manure is essential. Organic farming helps conserve water and soil on the farm. Reduction in the use of toxic pesticides, which the World Health Organization estimates poison 3 million people each year, is important with regard to health risks of farm families.

In several developed countries, organic agriculture already represents a significant portion of the food system. According to a study the International Federation of Organic Agriculture Movements (IFOAM 2004), currently more than 24 million hectares of farmland are under organic management worldwide. FAO (1999a) reported that in developing countries, under the right circumstances, the market returns from organic agriculture can potentially contribute to local food security by increasing family incomes and some of the developing countries have begun to seize the lucrative export opportunities presented by organic agriculture.

The dramatic increase in the use of agrochemicals in developing countries in recent decades and concentration on cash crops has often resulted in environmental contamination, severe health problems, and unprofitable crop production. The need for changes has resulted in a need for alternatives: crop production systems which do not rely heavily on chemical inputs, but which nevertheless produce economically viable yields while minimizing environmental impacts. Integrated pest management is one such system that has been successfully implemented on a wide range of crops and agroclimatic zones. Many aid and development agencies have adopted IPM as the model for the agricultural development they support, and the OECD Development Assistance Committee encourages its member states to support IPM. (See Box 6.6.)

6.3.5 Water Management

Governments and water managers are faced with the need to increase water supply to meet a still expanding population's increasing demand for food and water, while at the same time insuring that the water supply is sustainable and that ecosystems contributing to that sustainability are protected. Although the total available fresh water of the world is considered, in the aggregate, sufficient to satisfy today's demand, the uneven distribution of the world's freshwater resources and the current mounting pollution of many waterways and aquifers result in a situation where at least 30 countries are considered water stressed (with freshwater resources less than 1,700 cubic meters per capita); 20 countries are water scarce (with less than 1,000 cubic meters per capita) (Rosegrant 1995). In regions where water is already stressed or scarce, meeting increasing demand for all water uses including ecosystem protection becomes increasingly difficult and expensive, particularly under the traditional approach of constructing new water supply projects. However, there are many options for providing the necessary water, many of which may be better and cheaper than constructing new projects. Some response options are listed below.

In terms of *supply-side management,* options include: constructing additional water storage and distribution systems; making better use of natural systems, such as wetlands and ground cover, to reduce erosion, store and filter water, and recharge aquifers; improving the efficiency of existing storage and distribution systems; improving water management techniques and institutions; importing bottled water; and desalinating seawater.

Demand side management options include: increasing water productivity; improving water pricing; importing more food rather than growing it; applying water quotas; using economic incentives to reduce withdrawals and pollution; improving water quality regulations; and initiating a pollution permits market.

6.3.5.1 Water Pricing in Irrigated Agriculture

Water pricing is one of the most important elements of recent water management frameworks, because it is the basis for achieving efficient allocation of water resources. Conversely, inappropriate water prices could encourage inefficient use of water and contribute to water shortages or depletion of water resources in the long run and degradation of the environment and the ecosystems (for example, Koundouri et al. 2003; Pashardes et al. 2002; Chakravorty and Swanson 2002).

Efficient pricing is also very important in the management of groundwater where, in addition to standard pumping and distribution costs, there are costs associated with externalities. These costs can be classified as (Howe 2002): (1) *contemporary pumping externalities* associated with the fact that individual pumping affects other groundwater users in the vicinity by lowering their water table and increasing their pumping costs; (2) *intertemporal externalities* stemming from the fact that pumping groundwater now affects its future availability; and (3) *groundwater quality externality* resulting when water has different quality characteristics in different parts of the aquifer and when pumping causes salt water intrusion.

Typically water prices in agriculture, when they exist, cover more or less the variable cost of water supply, while public authorities cover fixed costs. Sometimes prices are set according to some notion of farmers' "ability to pay." The structure of water pricing systems usually takes one of the following forms (Tsur and Dinar 1997): standard volumetric and fixed tariffs, area-pricing, tiered or block-rate pricing, land betterment levy pricing or passive trading, volumetric pricing with bonus, or water markets.

BOX 6.6

Integrated Pest Management

Definitions of IPM cover a range of approaches: from safe use of pesticides to elimination of virtually all pesticide use. The presence of pests does not automatically require control measures, as damage may be insignificant. A system of non-chemical pest methodologies needs to be considered before a decision is taken to use pesticides. Suitable pest control methods should be used in an integrated manner and pesticides need to be used on an as-needed basis only, and as a last-resort component of an IPM strategy. In such a strategy, the effects of pesticides on human health, the environment, and sustainability of the agricultural system and the economy need to be carefully considered. IPM programs are designed to generate independence and increased profits for farmers, and savings on foreign imports for governments.

IPM enables farmers to make informed decisions to manage their crops. Successful IPM programs replace reliance on most spraying, including calendar spraying of pesticides. It builds on the knowledge of women and men farmers of crop, pest, and predator ecology, to increase the use of pest-resistant varieties, beneficial insects, crop rotations, and improved soil management. Supportive agricultural research, training of extension workers and farmers, and farmer participation in pest management solutions, are key elements. IPM programs encourage access to information on non-chemical alternatives. Government adoption of IPM, as part of its agricultural policy, will move IPM from the level of individual projects to a more common approach, and will bring national benefits.

IPM programs involve farmers and field staff from national and local government units and nongovernmental institutions, enhancing ecological awareness, decision-making and other business skills, and farmer confidence. IPM thus has long-lasting socioeconomic benefits far beyond the field of plant protection.

Pesticide Problems Avoided with IPM

Hazards to Health	Hazards to Environment	Crop Production Problems
Acute poisoning: 3 million poisonings including 20,000 unintentional deaths occur annually (WHO) Symptoms of acute poisoning include severe headaches, nausea, depression, vomiting, diarrhea, eye irritation, severe fatigue, and skin rashes Chronic ill-health problems can affect women and men, girls and boys exposed to pesticides whether because of their occupation or because they live near areas of use. Such problems can include neurological disorders, cancers, infertility, birth defects, and other reproductive disorders	Contamination of drinking water and ground water Water contamination kills fish Soil contamination Wildlife and domestic animals can be killed by spray drift or by drinking contaminated water Exposure may also cause infertility and behavioral disruption Persistence in the environment and accumulation in the food chain leads to diverse environmental impacts Loss of biodiversity in natural and agricultural environments	Pesticide resistance: 520 species of insects and mites, 150 plant diseases, and 113 weeds are resistant to pesticides (FAO) Resistance can create a treadmill syndrome, as farmers use increasing inputs to little effect, while elimination of beneficial insects causes secondary pest outbreaks High costs of pesticides can lead to falling incomes for farmers: newer products are often safer, but more expensive Farming communities lose knowledge of good horticultural practices and become dependent on expensive external inputs

Water markets have become an increasingly important mechanism for efficient and flexible water allocation. (See Box 6.7 for selected examples.) Water markets and tradable water rights give water a value separate from land and provide incentives to use water more efficiently, since water saving can be sold for extra revenues or can be used to further increase production. Water markets are promoted by international organizations such as the World Bank and have been pursued within many developing countries (Thobani 1997).

In developing countries, the practicality and true ecological and livelihood impact of water pricing and markets is under scrutiny. Given this, a broader term of economic incentives will certainly be important. These could include positive incentives for farmers to save water, rather than penalizing the rural poor when it is often the urban wealthy who benefit from low food prices and could better afford the cost of dealing with negative externalities. (Box 6.8 shows how one system works.)

In addition to the issue of efficient water use, attention must be paid to the possible negative effects of irrigation (FAO 2002b). Irrigation of farmlands in areas with water scarcity could cause degradation of water-based ecosystems, such as wetlands and forests. Regional transfers of irrigation water could cause problems both in the withdrawal and the receiving regions. Intensive irrigation farming in arid and semiarid areas leads to water pollution through chemical runoff into surface water or percolation into groundwater. Overirrigation also often results in soil salinity problems, for example, the Indus Basin in Pakistan.

6.3.5.2 Responses to Water Pollution

6.3.5.2.1 The nature of agricultural non-point source pollution

Agriculture is the single largest user of water resources. Except for water lost through evapotranspiration, agricultural water is recycled back to surface water and/or groundwater. However, agriculture is both a cause and a victim of water pollution. It is a cause through its discharge of pollutants and sediment into surface and/or groundwater; through net loss of soil from poor agricultural practices; through salinization and water logging of irrigated land; and through salt water intrusion in coastal aquifers due to over pumping. It is a victim through use of wastewater and polluted surface and groundwater, which contaminate crops and transmit disease to consumers and farm workers. This section examines responses related to the regulation of agricultural water pollution, which is probably the most representative of the so-called non-point source pollution problems.

BOX 6.7
Experience with Water Markets (Bjornlund and McKay 2002)

Water markets have emerged in both developed and developing countries. Some examples are:

- In Mexico, permanent and temporary water trading took effect in 1994 with a new Water Act. Water transfers can be freely made and at low cost within water users' organizations, and on a communal basis. Inter-district transfers require government approval.
- Informal water markets have operated within irrigation districts in India and Pakistan, often illegally. Payment for water takes place through arrangements involving two-way share farming, where one party supplies water and the other supplies the land, and all other costs and profits are shared. Another possibility is the three-way share farming, where one party supplies land, one water, and one labor, and all other costs are shared. These informal markets have increased water availability and supply reliability, and promoted more socially equitable outcomes from irrigated farming within the community.
- In the United States, most water trade involves transfers from agriculture to urban users, or to industrial users, such as mining and power generation. Many water sources are organized within mutual companies providing water through networks of canals. Irrigators own shares in the company, giving them rights to a certain volume of water. Shares and the associated water are freely transferable within the area. Water banks, which prioritize buyers and facilitate sale of large volumes of water, have also developed in some western states. The U.S.US experience shows that the more well defined property rights are, the more water markets develop; and the larger the trading area and the more diverse the users groups, the more efficient they are.
- In Chile, the water code established in 1981 separated water rights from the land, made these rights freely transferable, and distinguished between consumptive and non-consumptive rights, the latter mainly for power generators.

The significance of non-point-source-type pollution is indicated by the fact that part of the degradation of many of the world's lakes and reservoirs can be traced to this type of pollution. (See Box 6.9 for a case study examining the Aral Sea.) Degradation is caused by a number of factors including nutrient loading due to intensive farming practices; toxic substances entering the water bodies as agricultural runoff along with forestry drainage, which includes a range of toxic pesticides and herbicides; accelerated sedimentation caused by farming on fragile soils and steep slopes, forestry activities, construction activities and urban drainage; acidification of aquatic systems from emissions of sulfur dioxide and nitrous oxides due to acid rain or through leaching from affected land. In a non-point source pollution problem, an environmental regulator can measure the ambient pollution at specific ''receptor points,'' but cannot attribute any specific portion of the pollutant concentration to a specific discharger. Therefore, the problems that characterize a non-point-source pollution problem are mainly informational; Braden and Segerson (1993) have identified two broad classes of problems: those related to monitoring and measurement, and those related to natural variability.

6.3.5.2.2 Regulation

The inadequacy of the standard instruments of environmental policy to deal with NPS pollution has led, in recent years, to the development of policy schemes appropriate for NPS pollution problems (Xepapadeas 1997, 1999). These schemes can be divided into two broad categories: (1) ambient taxes where the scheme is based on the observed ambient pollution, and (2) input based schemes, where the policy scheme consists of taxes applied to observable polluting inputs.

Actual policies against water pollution that are common in many countries (OECD 1994) include user charges for sewerage and sewage treatment, water effluent charges, and charges in agriculture, along with a number of more specific policies. These are general policies that do not readily conform to the stylized characteristics of the NPS pollution instruments discussed above; nevertheless there are features that attempt to address the non-observability of individual emissions.

Charges in agriculture are a more profound case of input-based schemes. Charges on fertilizers as applied in many countries are based on the nitrogen and phosphorus content of fertilizers, which are the main contributors to NPS pollution in surface water. A number of off-farm management methods also exist for reducing phosphorus runoff such as vegetation buffer stripes, riparian zones, and dredging of the lake sediment.

More specific policies aimed at addressing NPS pollution problems, especially in relation to agriculture also exist. For example, in Austria there are groundwater protection zones in which, if the water quality is reduced, farmers have to comply with certain management practices or change land use. Spain has zonal programs for reducing fertilizers, the Netherlands has a manure and ammonia policy, England and Wales have codes, which give farmers guidance on maintaining good agricultural practices. Ireland has a voluntary scheme for farmers to follow a specific nutrient management plan.

6.3.6 Fisheries Management

As described in this chapter and MA *Current State and Trends,* Chapter 18, capture or wild fisheries have been overexploited (and habitats damaged) to the extent that current global catch levels are stable or are actually reducing. A conundrum that has helped mask effective global action so far is that apparent global stability in the catches does not highlight severe regional instances of overfishing, or the reduction of sizes and trophic levels of the fish being caught. Shortfalls in capture fisheries and price increases have led to ill-advised exploitation of ''new'' fisheries (sometimes of long-lived fish like orange roughy which reproduce slowly). These have gone through rapid boom and bust cycles and exacerbated the global decline.

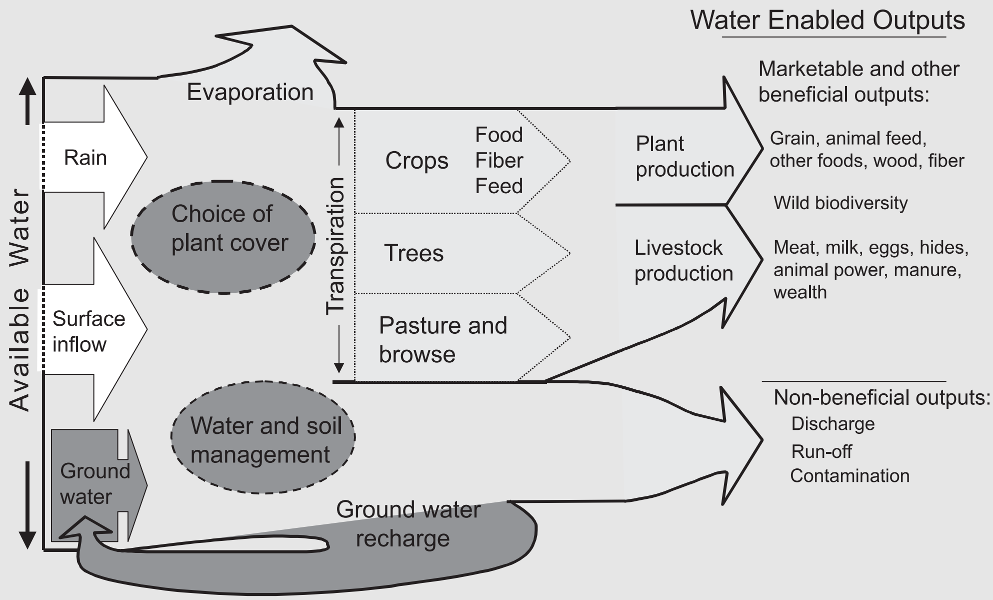
In addition to effects on the structure of fisheries, further environmental effects are being noted, for example, on sea beds as a result of trawling, and damage to habitats such as tropical coral reefs through overfishing and destructive fishing practices. Capture fisheries are associated with large government revenues through taxes and exports, and employment (often for poorer communities and coastal areas). Individual national responses to overfishing have been frequently insufficient, or actively protectionist of the industry through subsidies and poor enforcement of existing regulations. (See Box 6.10.) As a result, global fishing capacity is far in excess of what is economically viable. Probably the most important causes of fishery collapse have been poor decision-making and lack of political will. Of late, there is a growing awareness that the traditional approach to managing fisheries, which considers the target species as independent, self-sustaining populations, is in need of revision. The need to implement ecosystem-based fisheries management is now being emphasized (FAO 2002a).

BOX 6.8

Water and Mixed Crop–Livestock Systems

Mixed crop–livestock production characterizes most irrigation and rain-fed agriculture in developing countries. Pure crop production is largely restricted to developed countries. Discussed here are rain-fed mixed crop–livestock systems, but livestock are a fundamental and overlooked component of most irrigations systems in developing countries.

Water accounting tools enable understanding of water use in mixed crop–livestock production systems (see Figure below). Although the geographic scale of analysis is largely arbitrary, water enters into and exits from farming systems, agroecosystems, and river basins. Within these systems, available water supports agricultural production, non-agricultural human needs and ecosystem services. Water used for food production competes with other uses. Water that does not leave farming systems is stored and available for future use. Water that has been used but does not leave these systems remains available for re-use provided that its quality has not been reduced to unacceptable levels. Losses of water also include evaporation, discharge, and contamination. Transpiration is the most essential form of agricultural water use that drives both agricultural production and maintenance of wild biodiversity.



Water Accounting Framework Showing Relationships among Water Supply, Water Loss, Water Storage, and Livestock and Crop Production in Mixed Crop–Livestock Production Systems (modified from Molden et al. 2003)

Water discharged from upstream food producing systems affects downstream users. Excessive run-off causes downstream flooding while upstream food production can make water less available to downstream users. Yet upstream increases in infiltration can provide improved quality and a seasonally available downstream supply. Thus changing water use and productivity in one place may have both adverse and beneficial impacts elsewhere.

Farmers, planners, and policy-makers have many options for promoting a more efficient use of water. On the supply side, investments are possible in infrastructure to import water, and in development of water storage facilities such as ponds, dams and tanks. In addition, any land management activities or agricultural practices that encourage groundwater and soil-moisture recharge contribute toward storing or maintaining available water. On the demand side, water management is an important strategy to improve water use in mixed farming systems. This requires coherent policies, practices, and technologies that promote an optimal mix of plant species that are collectively responsible for enabling beneficial outputs, including animal and plant production and ecosystems services.

Choice of plant species serves to re-allocate water through benefit-producing transpiration pathways. Demand management also requires improving land management practices that promote groundwater and soil-moisture recharge through practices such as controlled grazing, maintaining vegetation cover, terracing, and conservation agriculture. This approach helps in retaining water for use in dry periods and reduces undesirable flooding downstream.

In developing countries, in contrast to industrial countries, livestock are not just productive commodities. They play a much larger role through provision of farm power and in many communities they represent wealth assets.

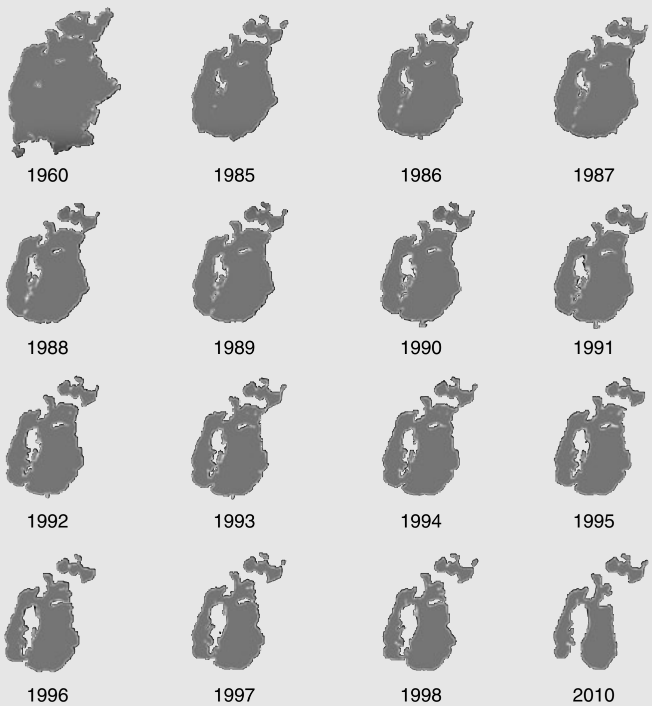
Overgrazing is often blamed for high rates of soil erosion, run-off, and flooding particularly in steep lands. Evidence from Ethiopia suggests strongly that the primary cause has been the replacement of grazing land with annual cropland requiring better integration of water management with crop and livestock production. Options for improvement include terracing, conservation agriculture, and de-stocking of livestock populations accompanied by action to increase the productivity of each animal. The framework provided in figure shows a framework that can help increase understanding of the interactions among people, water, crops, and livestock, and identify options to improve agricultural water productivity.

BOX 6.9

Agricultural Water Pollution Case Study: The Aral Sea Disaster

The Aral Sea lies in Central Asia; its basin includes Southern Russia, Uzbekistan, Tajikistan, Kazakhstan, Kyrgyzstan, Turkmenistan, Afghanistan, and Iran. The Aral Sea has no outlet, but equilibrium had been reached between the inflow and evaporation. In 1960, the Aral Sea was the fourth largest lake in the world, fed by the Amu Darya and Syr Darya rivers. The population of the area was 23.5 million in 1976 and has risen since then.

In the 1920s, the former Soviet Union started transforming the area into a major cotton producing area and used the river waters to irrigate the dry lands upstream from the Aral Sea. During the 1960s, the effects of the water diversion to massive irrigation schemes started to appear. The Aral Sea began to shrink, the shoreline retreated, and the salt concentration increased dramatically. The desiccation of the Aral Sea, derived from satellite remote sensing data, is shown here for the period 1960 to 2010 (projected).



The Aral Sea has lost more than 60% of its area and approximately 80% of its volume (until 1998). The sea level has dropped about 18 meters in the same time period. Historical data indicate that the inflow to Aral Sea was 56 cubed kilometers per year prior to the intervention. During the period 1966–70, the inflow fell to 47 cubed kilometers per year; during 1981–85, it was 2. There was a huge increase in the salinity. In Uzbekistan, for example, the salinized area in 1982 was 36.3% of the total irrigated area; by 1985 it had risen to 42.8% of the total irrigated area.

The major ecological and water quality impacts include: salt content of major rivers exceeds standard by factors of two to three; contamination of agricultural products with agrochemicals; high levels of turbidity in major water sources; high levels of pesticides and phenols in surface waters; excessive pesticide concentrations in air, food products, and breast milk; loss of soil fertility; induced climatic changes; major decline and extinctions of animal, fish, and vegetation species; and destruction of commercial fisheries.

These developments have had a devastating impact on public health, as seen in this table showing public health impacts in the Aral Sea area since the 1980s (Ongley 1996).

Typhoid	29-fold increase
Viral hepatitis	7-fold increase
Paratyphoid	4-fold increase
Hypertonia, heart disease, gastric and duodenal ulcers	up 100%
Increase in premature births	up 31%
Morbidity and mortality (Karakalpakia, 1981–87)	
Liver cancers	up 200%
Gullet cancers	up 25%
Oesophageal cancers	up 100%
Cancer in young persons	up 100%
Infant mortality (1980–89)	up 20%

Agriculture is considered to be the root cause of the Aral Sea disaster (UNEP 1993). In particular, the agricultural practices resulted in effects such as: increase in irrigation area and water; withdrawals; use of unlined irrigation canals; rising groundwater; extensive monoculture and excessive use of persistent pesticides; increased salinization and salt runoff leading to salinization of major rivers; increased frequency of dust storms and salt deposition; discharge of highly mineralized, pesticide-rich return flows to main rivers; and excessive use of fertilizers.

UNEP responded to Russia's request to address the problem (World Bank 1997). Initial studies indicated that it was not possible to restore the Aral Sea. It is important to notice here that agricultural practices led to an *irreversible* change in the ecosystem. The Aral Sea Basin Program launched 19 projects in eight thematic areas for the purpose of attaining partial remedies. The main issues tackled include water and salt management, wetland restoration, and immediate project impact.

Water and salt management: Water management includes mainly water sharing as a transboundary issue, since there are five independent states involved, with the upstream states requiring water for electricity generation, and the downstream states requiring water for irrigation. Salt management is the most pressing problem, the land is losing productivity due to salinization and might be out of production, and salinity jeopardizes drinking water resources.

Wetland restoration: The purpose is to restore part of the Sea or to rehabilitate some ecosystems on the Sea's perimeter.

Immediate impact: The aim is to alleviate suffering in the disaster zone, by helping to provide clean water and fishing opportunities in the deltas, health care for people living near the Sea, and repair of the infrastructure (for example, schools, hospitals). Due to the size of the problem, additional joint action was taken by the World Bank, UNDP, UNEP and the European Union, all of which call for a synergy of the current efforts in the region and offer a wide opening for further initiatives.

Developments in the Aral Sea since the 1960s represent one of the greatest environmental disasters ever recorded with major social, economic, and ecological impacts. The Aral Sea provides a catastrophic example of how responses aimed at increasing production of the agricultural sector can generate feedbacks that devastate a once-productive region.

The *combined quantity-quality* water degradation proved to be devastating for the whole ecosystem. It is important to note here that agricultural pollution led to an *irreversible* change in the ecosystem; furthermore the change was *fast,* indicating the existence of *threshold* effects. Quantity-quality interactions, irreversibilities, and fast change after threshold points are issues discussed in theoretical models of pollution accumulation, and in this sense the Aral Sea disaster can be regarded as constituting a real life example of theoretical modeling.

In summary, the response of adopting massive agricultural development plans, without any precaution for detrimental side effects, created a major negative impact on human well-being and poverty in Central Asia. This in turn, seriously impeded the attainment of goals such as security, basic material for a good life, health, and good social relations.

BOX 6.10

The Collapse of the Newfoundland Cod Fishery

Combined stock and regulatory fluctuations, leading to eventual collapse, have been observed in fisheries. The Canadian cod fishery off the east coast of Newfoundland experienced its boom-bust phase in the mid-1950s. With the appearance of a new breed of factory-fishing, countries such as Germany (East and West), Great Britain, Spain, Portugal, Poland, the Soviet Union, Cuba, and countries in East Asia had legally fished to within 12 miles of the eastern Canadian and New England (U.S.) seaboards. Canada (and the United States), concerned that stocks were being reduced to almost nothing, passed legislation in 1976 to extend their national jurisdictions over marine living resources out to 200 nautical miles. Catches naturally declined in the late 1970s and stocks started recovering after the departure of the foreign fleets. However, national regulation did not set catch quotas at the late 1970s levels, and furthermore, new technology in the form of factory-trawlers, or draggers as they became known, became the mainstay of Canada's Atlantic offshore fishing fleet. As a result, the northern cod catch began a steady rise again, with a corresponding decline in stocks (MA *Current State and Trends,* Chapter 18).

By 1986, the stock decline was realized, and by 1988, there were scientific opinions recommending that the total allowable catch be cut in half. Possibly because of delayed regulatory response, by 1992, the biomass estimate for northern cod was the lowest ever measured. The Canadian Minister of Fisheries and Oceans had no choice but to declare a ban on fishing northern cod. For the first time in 400 years, the fishing of northern cod ceased in Newfoundland. The fisheries department issued a warning in 1995 that the entire northern cod population had declined to just 1,700 tons by the end of 1994, down from a 1990 biomass survey showing 400,000 tons (Greenpeace 2003).

This collapse illustrates the vulnerability of fish stock. It is a story that has been repeated in many other fisheries, including the California and Japanese sardine fisheries, and the Southwest African pilchard and North Sea herring fisheries.

Aquaculture has developed rapidly, particularly in Asia, but also in key countries in Europe, the United States, and Latin America to increase supplies. Over the past three decades, aquaculture has become the fastest growing food production sector in the world; it has increased at an average rate of 9.2% per year since 1970—an outstanding rate compared to the 1.4% rate for capture fisheries or the 2.8% rate of land-based farmed meat products (FAO 2002a; Kura et al. 2004).

In 2001, aquaculture produced 37.9 million tons of fishery products, nearly 40% of the world's total food fish supply and valued at $55.7 billion (FAO 2002a; Vannuccini 2003). Aquaculture production is expected to continue to grow in the future to meet the increasing demand for fish and fishery products. Aquaculture has become such a rapidly increasing sector by expanding, diversifying, and intensifying production, as well as by technological improvements in its operations.

However, the initially unregulated expansion of the fish farming industry has led to inappropriate land and water use in some cases, and breaks on potential levels of productivity through pollution, contamination, and disease losses. Although a more mature industry is developing, several issues must be addressed for aquaculture to start to balance losses in capture fisheries in a way that does not simultaneously damage the environment. Food safety and trade issues in aquaculture products mirror those for livestock products and have severe implications for developing countries that exploit fisheries for trade and also for food security purposes.

This section examines two types of responses, one related to the management of capture fisheries and the other related to aquaculture.

6.3.6.1 Capture Fisheries

6.3.6.1.1 The international framework for improving fisheries management

Much of the current depletion of marine fish stocks derives from the fact that oceans for hundreds of years have been managed as open access resources. These resources are highly vulnerable to overexploitation because there is no incentive for individual fishers to restrain their harvest (MA *Current State and Trends,* Chapter 18).

The United Nations Convention on the Law of the Sea provides coastal countries sovereignty over marine resources within 200 nautical miles of their coast so that the responsibility to manage coastal fisheries in a sustainable manner is squarely in the hands of coastal nations. Not all nations have adequate fisheries management plans and laws in place. Even when they do, implementation and enforcement often fall short, and fisheries are still subject to overfishing. Also, distant water fleets from industrial countries have been able, through payment of various fees, to access the exclusive economic zones of developing countries in many cases and rapidly deplete their resources

The FAO Code of Conduct for Responsible Fisheries provides voluntary guidelines according to the following principles:

- manage stocks using the best available science;
- apply the "precautionary principle," using conservative management approaches when the effects of fishing practices are uncertain;
- avoid overfishing; prevent or eliminate excess fishing capacity;
- minimize waste (discards) and bycatch;
- prohibit destructive fishing methods;
- restore depleted fish stocks;
- implement appropriate national laws, management plans, and means of enforcement;
- monitor the effects of fishing on all species in the ecosystem, not just the target fish stock;
- work cooperatively with other states to coordinate management policies and enforcement actions; and
- recognize the importance of artisanal and small-scale fisheries, and the value of traditional management practices.

More than 150 countries have formally embraced the Code since it was introduced in 1995 (FAO 1995b). To augment the general provisions of the Code, the FAO has issued a number of "technical guidelines for responsible fisheries" that look at certain important subjects in depth and interpret the Code with greater specificity. For example, the FAO has issued technical guidelines on applying the precautionary principle, integrating fishery management into coastal area management, developing aquaculture responsibly, and applying an "ecosystem approach" to fisheries, among other topics (FAO 2001a). In addition, it has overseen the development of four International Plans of Action, which consist of a set of recommendations on how nations should cooperate to track a given problem, assess its magnitude, and develop individual national plans of action to address the problem. So far, IPOAs on reducing seabird bycatch, conserving shark fisheries, reducing fishing capacity, and reducing illegal, unreported, and unregulated fishing have been approved by FAO member nations (FAO 2002a).

The elaboration of the principles in the Code and their general acceptance as norms by nations provides the important framework for more sustainable fishing. However, the Code of Conduct and the IPOAs are all voluntary agreements, free of legal mandates or enforcement mechanisms. Global action is undermined by nations that fail to fully implement or enforce them (Kura et al. 2004). Clearly, elaborating and implementing national plans in accordance with the Code of Conduct for Responsible Fisheries, including provision for traditional and small-scale fisheries in different countries, is a continuing requirement.

6.3.6.1.2 Tools currently exploited to manage fisheries

Fishery management generally aims at preventing stock depletion and securing the standards of living in the fishing sector. In the future, achieving the necessary reduction in fishing capacity will require fishers and vessels to leave fishing, and thus establishment of alternative livelihoods. As a consequence, economic support programs will become an integral part of future management strategies.

A number of fishery management methods and practices have been developed to reduce or restrict the capacity of fleets. Those, such as the imposition of total allowable catch for the fishery, vessel catch limits, mesh and size restrictions on gear, license limitation, individual effort quotas, and buy backs of vessels or licenses to reduce fleet numbers can all be considered as limitations of fishing capacity. They contrast with methods that seek to adjust the incentives for fishing. These seek to provide individual or group incentives and market mechanisms for meeting output targets, with greater flexibility of operation. Various responses are sketched in Table 6.3. In practice, a mixture of input and output controls appropriate to the individual fishery is the best way of managing it (World Bank 2004).

While designed to manage fishing, the above responses sometimes have inadvertent effects or incite perverse behaviors in relation to resource exploitation and sustainability. For example, the allocation of licenses to fishers or fishing vessels, entitling them to harvest from one or more stocks, is the most widely used system for controlling the fleet capacity (Cunningham and Gréboval 2001). However, licensing programs are insufficient on their own to control a fleet's overcapacity. A major limitation is that they do not prevent licensed fishers from expanding the capacity of their vessels or adding new technology to increase their catch.

The most common application of catch controls is the total allowable catch. If set at the right level (no higher than the fishery's maximum sustainable yield), TACs can effectively reduce the direct pressure on a fish stock. However, TAC systems give fishers the incentive to fish as quickly and intensively as possible to maximize their share of the allowable catch. This competition often leads to overfishing and high bycatch rates (for species not specified in the TAC). To combat this, individual fishing quotas have been introduced, where a specific proportion of the TAC may be allocated to individual fishers to harvest at their own pace. In many instances, fishers are allowed to treat these individual transferable quotas as personal assets, with the legal right to buy or sell them. The theory behind ITQs is that fishers are more

Table 6.3. Main Policies for the Management of Open-access Fisheries

Policy	Description
Fishing effort regulation	In this policy, one of the inputs in the index for fishing effort is restricted (for example, number of days at sea).
Decommissioning schemes	The purpose of this policy is to bring the capacity in line with catch potentials. This is done by reducing the fleet capacity through subsidized buy backs.
Marine protected areas	The aim of this response is to protect some fragile parts of a marine area by banning fishing within these areas. Some examples of use of this regulatory instrument are the Shetland box and the Norway pout box (Holden 1996).
Total quotas or total allowable catches	In this policy, a total quota is imposed on the fishery and when this quota has been filled, the fishery is closed (Clark 1990). The total quota is often recommended to be set at a level where maximum sustained yield is reached. Total quotas have in some cases been used in conjunction with individual quotas (for example, in the case of Iceland and New Zealand).
Rations	Under a rations policy, the total quota is distributed in short time intervals on vessels reflecting seasonal variations in catch possibilities. Rations are used for some species in Denmark. However, the system of rations creates huge information requirements.
License systems	A license system normally specifies how much can be caught and the weight of this catch. The purpose is to control the catch of each individual vessel.
Individual quotas	This policy sets a non-transferable individual annual quota that cannot be changed during the year and may, therefore, be thought of as a property right. Indeed, property rights regulation is very popular within fisheries; more than 55 fisheries in the world are regulated by property rights.
Individual transferable quotas	Under this policy, individual quotas are made transferable between fishermen; ITQs are used in, for example, Iceland, the Netherlands, and New Zealand.
Taxes or landing fees	In this policy, either fishing effort or catch is used to compile the tax. In practice taxes are not popular among fishermen and there are severe implementation problems.

likely to use sustainable practices if they hold a long-term interest in the fishery in the form of a guaranteed percentage of the harvest. The introduction of ITQs has indeed brought benefits in some fisheries. Iceland and New Zealand both have comprehensive ITQ programs that are generally considered successful in reducing overall fishing effort and improving the efficiency of the industry as a whole (Hannesson 2002).

But individual transferable quotes still rely on setting a total allowable catch,, and suffer from the same scientific difficulties in determining a reliable estimate of sustainable yield. ITQs give fishers an incentive to ''high-grade,'' or substitute larger (and more valuable) fish caught later in the day for smaller fish caught earlier. The smaller fish are usually discarded overboard—dead or dying. If these management rules are imperfectly implemented it is difficult for fisheries managers to follow the precautionary approach to protect fish stocks. The stability of the quota system is built on setting the TAC in advance of the fishing season, and not altering it as the season progresses (Copes 2000), therefore, managers have little flexibility to change if they realize mid-season that the TAC is too high and overfishing can result. ITQs may be appropriate to cold water, single species fisheries but they are unlikely to be useful in multi-species tropical fisheries where multiple TACs and ITQs would make the system impractical. Management by areas and output monitoring may be more sensible in this case.

6.3.6.1.3 Time and area closures

Time and area closures can be effective management tools for fisheries, but are usually combined with other regulations because, on their own, neither will reduce the overall pressure. *Closed seasons* are used to protect stocks at critical times in their lifecycle—such as when they are spawning—or as a way of lowering the total catch. A major disadvantage of establishing a closed season is that fishers will have an incentive to race for fish during the open season. *Closed areas* are used to help depleted stocks recover, or to protect biologically critical areas such as spawning grounds or juvenile nurseries. However, if taken in isolation, this approach does not necessarily decrease the overall fishing pressure, as fishers simply move to an adjacent open space, increasing fishing pressure there. Establishing marine reserves—one type of ''marine protected area,'' where fishing and other human activities are restricted—is one approach that limits fishing effort in certain areas. Given the proven ability of marine reserves to nurture stocks within their boundaries, there is a growing expectation that they will also enhance commercial stocks in surrounding waters and beyond.

The biological benefits of marine reserves for organisms and ecosystems within the reserves are well documented. But their benefits to commercial fisheries outside the reserves are still the subject of debate (Ward et al. 2001). Part of the problem is that few marine reserves have been strictly protected and monitored for long enough to determine the effect of potential benefits in surrounding waters. In addition, monitoring and demonstrating the spillover effect is no easy matter, and documenting benefits to distant waters is even more difficult. Nonetheless, there is some evidence to support the idea that reserves can benefit fish stocks outside their borders. Case studies and research in localized reef systems show that the recovery that comes from the establishment of a reserve can affect areas immediately adjacent to the reserves (Ward et al. 2001; Polunin 2003). Similarly, after a five-year closure of about 25% of the George's Bank, stocks of several species have increased, including scallop, haddock, and flounder (Murawski et al. 2000). These improvements are now beginning to spill over into waters outside the closed areas (Paul Howard, New England Fishery Management Council, personal communication, cited in Gell and Roberts 2003).

There is still much we do not know about marine reserves or how to maximize their benefit. The rate and nature of recovery of different fish species within reserves is likely to vary considerably. On the other hand, an understated strength of marine reserves is that they provide a clear example of one type of ecosystem-based approach to fisheries management, since they protect both fish and the ecosystem where they live. This may be especially useful in the tropics, where many species may be commercially exploited in one fishery. Recognizing the wide-ranging benefits of an ecosystem approach to managing fisheries, some countries have started testing the concept of a marine reserve with a commercial fisheries goal in mind.

6.3.6.1.4 Future requirements for better governance

An institutional framework for improved governance of the fisheries sector requires international collaboration in the following (see World Bank 2004):

- the fisheries management system;
- the monitoring, control and surveillance system;
- the fisheries judicial system;
- an institutional framework linking different types of stakeholders, including small-scale fisheries;
- a system of allocation of user rights (to counteract the unregulated nature of open access fisheries);
- control and development instruments (to ensure equitable development, as many aspects of fishing rights, etc., tend to be appropriated by large scale entrepreneurs);
- establishment of protected areas where appropriate and following multiyear research;
- managing exploitation patterns (through regulation of fishing operations by the means discussed above);
- fishing vessel and effort reduction programs;
- restocking (as and when feasible and appropriate);
- promoting aquaculture (discussed below);
- food safety and ecolabeling; and
- promotion of alternative livelihoods to fishing.

At the World Summit on Sustainable Development in 2002, many countries made a commitment to replenish overfished marine stocks by 2015 to sustainable levels, reflecting the increasing belief that fishery resources must be managed and used in sustainable ways taking the ecosystem that nurtures them into account. There is growing recognition that principles, policies, and mechanisms for prioritizing and allocating uses of aquatic areas must be put in place so that the impacts of fisheries on other sectors and vice versa are taken into account. Traditional approaches to managing fisheries, which tend to consider the target species as independent and self-sustaining populations, have proven to be insufficient. The need to implement ecosystem based fisheries management is currently being emphasized (FAO 2002a), although how to achieve this remains a continuing challenge to research and applied management.

6.3.6.2 Aquaculture

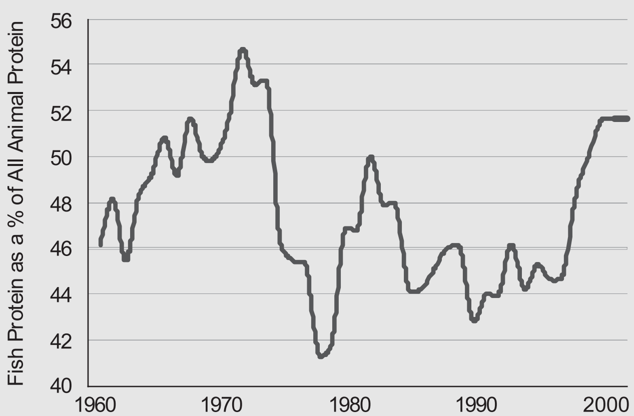
There are many different kinds of aquaculture and each system has its own strengths and weaknesses, which may positively or negatively affect overall productivity and the environment (Kura et al. 2004). Aquaculture as an integrated farming practice has the possibility of augmenting nutritional and income security for small farmers. However, many forms of aquaculture involve transforming land, coastal, and freshwater ecosystems, with serious ecological consequences for ecosystem integrity, and thus the delivery of other ecosystem services. For example, the replacement of mangroves to establish shrimp aquaculture facilities has been responsible in a major way for the loss of the mangrove habitat, particularly in Southeast Asia and Latin America (Boyd and Clay 1998). The destruction of hundreds of thousands of hectares of mangrove forests reduces crucial coastal protection and filtering functions. Box 6.11 discusses fish farming in Bangladesh.

Intensification of aquaculture leads to the emergence of issues that parallel the intensification of terrestrial livestock production. High stocking densities, poor water quality, and poor seed quality can lead to outbreaks of disease, which then spread to other ponds through water exchange. Increased movements of live aquatic animals and products as the industry grows have made the accidental spread of disease more likely. Effluent from aquaculture and pens is often released directly into surrounding waterways, causing pollution problems stemming from fertilizer, undigested feed, and biological waste in the water. This effluent can contribute to eutrophication of downstream waters, harm benthic communities, and cause damage to water and soil quality (Funge-Smith and Briggs 1998). Disease can then lead to pond abandonment and land degradation. Antibiotic drugs and other pro-biotics can significantly degrade the surrounding, local environment, and even have health effects on humans.

BOX 6.11

Shrimp Farming in Bangladesh

Bangladesh is one of the least developed countries in the world, with a per capita income of $350 (World Bank 2002a). Agriculture including fisheries contributes about 30% to the gross domestic product of the country (BBS 2000). The contribution of the fishery sector to GDP was slightly over 5% in the year 1998–99. The fish industry, and particularly shrimp, plays a major role in nutrition, employment, and foreign exchange earnings of the country. In Bangladesh, about 51% of animal protein is supplied by fish (see Figure below).



Contribution of Fish to Total Supply of Animal Protein in Bangladesh (Kura et al. 2004)

In recent years, there has been a marked increase in the contribution of fish to the total animal protein supply. About 1.2 million people are directly and indirectly employed in the fisheries sector, while another 11 million are indirectly employed (Vannucinni 1999). Bangladesh is a net exporter of fish and fishery products, which account for about 12% of the total of Bangladesh exports. Contribution of shrimp to total fish and fishery products is about 86%.

Loss of biodiversity is another important concern. According to Barkat and Roy (2001), the largest source of shrimp fry in commercial farming is wild fry. Using this process, thick nets are used to collect wild fry, following which the shrimp fry are sorted out and all the rest abandoned. In this crude process, millions of wild fry of other aquatic flora and fauna are lost, leading to reduced fish populations and ecological imbalances in the coastal region.

In addition, farmed fish that escape into the wild can threaten native species by acting as predators, competing for food and habitat or interbreeding and changing the genetic pools of wild organisms. Traits bred into farmed fish are often different from those that confer reproductive fitness in the wild, and interbreeding between escaped farmed fish between escaped farmed fish and wild fish may result in the loss of important local adaptations (such as home river returning capacity in wild salmon). The risk is greatest for small populations that are already threatened. The majority of these effects, including disease (ectoparasite) transmission, have been documented in large-scale salmon rearing operations. Escaped fish are intrinsically harder to monitor and control than vegetable crops or terrestrial animals.

Nearly one third of the world's fish caught in the wild, such as small pelagic fish like anchovies and menhaden are not consumed directly by humans but rather ''reduced'' to fish meal and fish oil and consumed by farm-raised animals, such as chickens, pigs, and carnivorous fish in some aquaculture systems. Aquaculture consumes more fishmeal so far than terrestrial livestock and poultry, as these have increasingly switched to vegetable-based meals. Wild-caught fish are also used as seed fish in some developing-country aquaculture operations, posing risks to wild fish stocks by removing juveniles from the population, although this is expected to diminish with research on closing life-cycles in culture.

6.3.6.2.1 Future regulation of aquaculture

The major challenge regarding aquaculture will be to maintain the balance between support for further development of the sector and regulation to prevent potential adverse environmental and social impacts. Because the aquaculture industry has expanded so rapidly, the legal and political frameworks for maintaining it as a sustainable business have lagged behind. Article 9—Aquaculture Development—of the FAO Code of Conduct for Responsible Fisheries adopted in 1995, sets principles and guidelines for the sustainable development and management of aquaculture (Kura et al. 2004). Following these principles, many countries have started to implement national regulatory guidelines that address the environmental and social impacts from aquaculture in order to ensure its sustainability (FAO 2003d). Canada, for example, has developed a comprehensive Aquaculture Action Plan, which provides clear guidelines for applying regulatory responsibilities to aquaculture under the existing legislation (DFO 2001). The World Bank, Network of Aquaculture Centers, WWF, and FAO have initiated a process to provide guidelines for shrimp aquaculture and the environment (World Bank 2002b). These trends should be encouraged and unified.

Despite such progress, aquaculture-producing countries still face enormous challenges to support responsible practices. (See Box 6.12.) While there are examples of environmentally sound practices, one of the limiting factors is the lack of financial resources for some countries to take advantage of the advanced technology that lessens the impact of aquaculture on the surrounding environment (Emerson 1999). Thus national governments and development donors could assist through supporting formulation of comprehensive strategic development and zoning frameworks for aquaculture in coastal and inland settings. Integra-

BOX 6.12

Aquaculture in Africa

Aquaculture was introduced in much of the African continent around the 1950s as an innovation that would improve the economic and nutritional well-being of producers. In the former Belgian Congo, fishponds were built in mining areas to produce high protein food to feed miners (Moehl 1999). Fishponds were seen as an ideal component of integrated farming systems, as a fish crop was grown using by-products from the home and farm. Indeed, from Kenya to Sierra Leone, thousands of ponds were built, many to be abandoned after a few years of meager production.

In 1986, UNDP, FAO and the Norwegian Ministry of Development and Co-operation undertook a thematic evaluation of aquaculture. The evaluation recommended that future efforts should focus on a specific combination of species and aquaculture systems; identify geographical regions which correspond to specific species/systems combinations that should receive priority attention; pay close attention to recipient governments' effective commitment to aquaculture; and ensure systematic monitoring and evaluation of impact generated assistance provided.

In 1993, FAO, assisted by other collaborators, assembled a series of twelve national aquaculture reviews from countries responsible for 90% of the region's aquaculture production (Coche 1994). The major constraints identified by these reviews on the continental level were that (1) there were no reliable production statistics; (2) limited credit was available for small-scale farmers; (3) the technical level of the fish farmers was very low; (4) local feed ingredients were unavailable; (5) there was a lack of well-trained senior personnel; (6) transport costs were prohibitive; and (7) there was a lack of juvenile fish for pond restocking.

Today, Africa's fish and shellfish aquaculture production is slightly over 110,000 tons. It is only about 0.4% of the world's total production (Moehl 1999). In spite of the region's rich endowments, including untapped land, water, and human resources, African aquaculture remains undeveloped. The problems with regard to aquaculture in Africa are mainly institutional and technical. Institutional problems stem from frequently changing institutional homes for aquaculture and over-reliance on donor funds. Technical problems exist on two levels. Technologies were presented to farmers with little appreciation for what the farmers' needs are—a top down technology transfer. Secondly, when results were lower than anticipated, completely new technologies and/or culture species were sought, when in fact the initial technology had the capacity to produce more. In most cases, poor harvests were a result of poor management.

In spite of aquaculture's modest growth in Africa, the past three decades have not been without some tangible results. Aquaculture is now known throughout Africa, having evolved into a well-known, if not well-understood, production system. Fishponds are now an accepted component of farming systems on most of the continent (Moehl 1999).

Based on past experiences, the following lessons should be noted and incorporated into national development policies (Entsua-Mensah et al. 1999):

- Major government fish culture stations should be given financial autonomy and put under good management.
- Public infrastructure should be ultimately self-supporting.
- Farming inputs should not be distributed free to farmers, but should have at least a subsidized price.
- Technology should not be based on imported commodities (for example, hormones, feed, etc.)
- Selected culture species should be reproducible by the farmers themselves. On-station research to support small-scale aquaculture development should be based on inputs available to farmers and should be farmer-driven through joint activities.
- Sociocultural surveys should be conducted before introducing a new technology to a region.

There is, at present, a need for aquaculture policies (national development plans); national aquaculture information systems; demand-driven research that includes the socioeconomic aspects of research and development; reinforced linkages between research and development; adapted research on brood stock development; regional and sub-regional research and/or training centers involving NGOs in training and development; and training at all levels including practical training of farmers, technicians and extensionists (Entsua-Mensah et al. 1999).

tion of aquaculture and water management for complementary uses will help regulate environmental quality and resource sharing. Agencies can control and implement other environmental standards, guide species selection and effective hatchery operation, and help manage inputs and technical standards of safety in operation (for example, governing escapees) and the health of products (World Bank 2004).

Market incentives, such as certification for sustainably farmed products are leading to the development of guidelines. These guidelines are being promoted by producer organizations in industrial countries. This needs to be expanded, especially to developing countries, in order to promote the use of best practices to reduce the impacts of aquaculture.

6.3.6.2.2 Technological progress

Selective breeding approaches (as with crops and livestock) have been successful at creating improved breeds of fish for aquaculture (for example, salmon, tilapia, and carp), which will increase the yield and overall efficiency of aquaculture production (both for intensive as well as more extensive forms of aquaculture). Genetic transformation technologies may also be useful in the future for breed improvement. However, particular care must be taken in the use and release of genetically modified fish because of competition effects and ease of mixing with wild stocks in aquatic environments. Successful deployment of such strains may depend upon the successful extrapolation of sterile animal techniques that do not allow reproduction breed if they escape (Bartley 2000; Bartley et al. 2001). There is active research on protein feeds and biotechnologies that may increase the opportunities for developing non-fish-based aquaculture feed alternatives.

Advances in hatchery technology have raised the possibility of replenishing wild fisheries (restocking) from such sources (Munro and Bell 1997). Unfortunately, much of the research into stocking marine species is still at the experimental stage (Bartley and Casal 1999), and positive effects on augmenting fish populations are limited to a few specific examples. Restocking with *alien* species for the purposes of augmenting fisheries production can have disastrous effects on local biodiversity and need to be avoided from an environmental standpoint. The case of perch in Lake Victoria illustrates how the introduction of a non-native species for the purpose of increasing food production can lead to an ecological disaster. (See Box 6.13.) However, restocking of artificial reservoirs (with low indigenous biodiversity) can provide means for enhancing the production of fish for food.

BOX 6.13

Introduction of Non-native Species: The Case of Lake Victoria

Lake Victoria, with a surface area of 68,000 square kilometers and an adjoining catchment of 184,000 square kilometers, is the world's second largest body of fresh water (after Lake Superior), and the largest in the developing world. It is relatively shallow, with an average depth of 40 meters and a maximum depth of 80 meters. About 85% of the water entering the lake does so from precipitation directly on the lake surface, with the remainder coming from rivers draining the surrounding catchments. The most important of these rivers is the Kagera River, which contributes 7% of the total inflow. Tanzania, Uganda, and Kenya control 49%, 45%, and 6%, respectively, of the lake's surface.

Fishing pressure on Lake Victoria began to intensify in 1905 when the British introduced flax gill nets, which soon replaced papyrus nets and fish traps used by the local villagers. The most important fish species were the haplochromines (a type of cichlid) and the two endemic tilapias *Oreochromis esculentus* and *Oreochromis variabilis.*

By the 1960s, officials were actively stocking the Lake Victoria with Nile perch. Up until 1978, the Nile perch *Lates niloticus* accounted for less than 2% of the lake's fish biomass and the haplochromines accounted for 80% of the biomass. Between 1974 and 1978, there was hardly any stock assessment done in the Lake. In the 1980s, an abrupt change was noticed in Kenyan waters, and later on in Ugandan and Tanzanian waters also. The Nile perch suddenly jumped up to 80% of the lake's fish biomass, while the haplochromines dropped to 1%.

Ecological disaster

Before the 1970s, Lake Victoria had more than 350 species of fish from the cichlid family, of which 90% were endemic. However, the introduction of the Nile perch and tilapia caused a collapse in the lake's biodiversity. It also resulted in deforestation since wood was needed to dry the oily perch, while the haplochromines and other native cichlids could be sun dried. Forest clearing in turn increased siltation and eutrophication in the lake, putting in jeopardy the Nile and tilapia fishery (WRI 2001). A fishery that once drew on hundreds of species, mostly endemic, now relies on just three: a native pelagic cyprinid, *Rastrineobola argentea,* the introduced Nile perch *Lates niloticus,* and tilapia *Oreochromis niloticus (*Rabi 1996).

Socioeconomic impact

At first, official concern was for the problems the Nile perch posed on shore. The fish was big and could grow to nearly 2 meters, thus fishers needed bigger gear to deal with it. Also the villagers did not know how to cook the oily fish and could not sun-dry it. There were no markets for the fish, prices were low, and most of the fish was left on the beach to rot (Rabi 1996). Using U.N. funds, a Kenya Marine Fisheries Research Institute (team toured lakeside villages and Nairobi hotels, demonstrating how to fillet, freeze, smoke, and cook the fish. Foreign aid groups and investors moved in with processing plants and refrigerated trucks. The price for Nile perch soared and the local people could not afford the high prices. Shoes, belts, and purses were made from tanned perch hide and the dried swim bladder was sent to England for filtering beer and to Asia for making soup stock.

Before the introduction of the Nile perch, the native fish of Lake Victoria were harvested by small-scale fishers and processed and traded by women for local consumption. With the introduction of the Nile perch, large boats began to haul out the perch in tons on the open lake, where local fishers could not take their canoes. Many rich investors see the perch as being economically useful because it brings in dollars. The fish is sold to processing plants built along the Kenyan and Ugandan shore by investors from Asia, Europe and Australia. The fish is filleted, frozen, boxed, and loaded on trucks headed for the port of Mombassa, Kenya, where it is shipped to Europe and the Far East.

The traditional ways of the local people have been severely disrupted. They have moved to squatter camps near the fish-processing factories and are left with the scraps of *Lates* from the food-processing factories. The fleshy heads and tails are fried and sold to the local people as they are the only fish most local people can afford (Rabi 1996). Lake Victoria's Nile Perch Fishery generates as much as $400 million in export income, but few villagers around the lake benefit from it. While tons of perch find their way to restaurants in Europe, scientists have documented protein malnutrition around the lake (WRI 2001).

The revenues generated by the Nile perch fishery are much greater than those realized from the lake's native species. The distribution of wealth resulting from the Nile perch fishery is also different from the original artisanal fishery. Most of the local fishers are actually worse off, while large-scale operations that exploit the introduced species for foreign currency are doing well.

Conclusions

An estimated 30 million people depend on Lake Victoria, a lake whose natural resources are under increasing stress (Fuggle 2001). The population on the shore has grown fast over the past century, with corresponding increases in the demand for fish and agricultural products. Following the introduction of gill nets by European settlers at the beginning of the twentieth century, populations of indigenous fish species declined. Many were specially adapted to eat algae, decaying plant material, and snails that host the larvae of Schistosomes, which cause bilharzias in humans. As the lake started to eutrophicate, people became more vulnerable to disease.

As fish catches declined, non-native species were introduced, causing further stress to indigenous fish. The greatest impact resulted from the introduction of the Nile perch (*Lates niloticus*) in the 1960s as the basis of commercial freshwater fisheries. This had repercussions on the local fishing economy and distribution of wealth. Local people who had previously met most of their protein requirements from the lake began to suffer from malnutrition and protein deficiency. Although 20,000 tons of fish are exported annually to European and Asian markets, local people can only afford fish heads and bones from which the flesh has been removed.

Wetlands around the lake have been converted to grow rice, cotton, sugarcane, and their original function as natural filters for silt and nutrients has been lost. Run-off now carries soil and excess nutrients from the cultivated areas straight into the lake. The resulting algae growth clouds the surface water and reduces oxygen availability, seriously affecting the habitat of endemic fish species, which prefer clear waters, while their predator, the Nile perch, thrives in such murky waters. This further aggravates food insecurity in lakeside communities.

Increased nutrients, much of which are in the form of sewage, have stimulated the growth of the water hyacinth (*Eichornia crassipes*), one of the world's most invasive plants. This has seriously affected water transport and paralyzed many local fisheries. By the end of 1997, the 70% decline in economic activity reported at Kisumu port was attributable to water hyacinths choking the port and fish landings. The dense cover of water hyacinth also stimulated secondary weed growth and provided habitats for snails and mosquitoes.

Stock enhancement (to increase yields over normal levels) has been carried out in marine systems (notably for species of scallop), but is limited as a general approach by the economics of production, ability to harvest stocked individuals as adults, and returns on yields.

6.3.6.2.3 Marine reserves

Marine reserves have been proposed as a remedy for overfishing and declining marine biodiversity, but concern that such reserves would inherently reduce yields has hampered their implementation. However, some research has demonstrated that marine reserves deliver fishery benefits beyond their own boundaries because species inside the reserve rapidly increase in numbers, grow larger, and have more reproductive potential. Part of the population (as larvae or as adults) migrates outside the reserve, increasing yields for fishermen in the surroundings (Gell and Roberts 2003). The positive effects have been shown for resident and more mobile populations, but a wider application of the ecosystem and precautionary approaches is essential.

According to current research, the effectiveness of marine reserves in recovering fish stocks is influenced by a number of conditions, including the size, design, and location of the reserve, the life history and behavioral pattern of target fish species, how depleted the fish stock is when restoration begins, how much fishing has contributed to the decline of the fish stock, and how long the reserve remains closed to fishing (Ward et al. 2001).

Unfortunately, much remains unknown about marine reserves or how to maximize their benefit. We do not yet know if it is feasible to establish a network of reserves sufficient to recharge stocks and sustain the modern fishing industry at the same time, given that modeling studies indicate that as much as 20–50% of the range of a target fish population might have to be protected from all exploitation in order to sustain the fish stock over the long term (Ward et al. 2001). With this level of uncertainty, it will undoubtedly be very difficult for many politicians and fishers to support the kind of large and long-lasting closures in heavily fished waters, which fish recovery via a marine reserve system would call for. On the other hand, conventional fishery management approaches, such as quota systems and seasonal closures, also do not guarantee fish recovery and require concessions from fishers too. Moreover, the commitment nations made at the Johannesburg Summit to restore stocks is too ambitious to rely on these traditional approaches only, adding pressure to explore the marine reserve option further.

6.3.7 Livestock Management

The demand for livestock and livestock products has led to an intensification of livestock production systems, first in industrial countries and more recently in developing countries. Intensive (factory-farming) systems for dairy production and beef are most common in North America, while intensive poultry and swine production is common worldwide. The intensification of systems in developed countries has led to several concerns. These include nutrient pollution, rapid transmission of infectious disease agents, food safety, and animal welfare concerns. This section examines responses related to livestock production and their impacts on regional and global ecosystems.

6.3.7.1 Industrial or Intensive Livestock Production Systems

Environmental impacts of industrial or intensive livestock production are varied and important, mostly related to the disposal of manure. In the developing world, these systems are found mostly near urban areas in Asia and Latin America. Impacts include (de Haan 1997):

- Excretion of nitrogen and phosphate. Pigs and poultry excrete 65–70 % of their nitrogen and phosphate intake. Nitrogen can evaporate in the form of ammonia with toxic effects. Much of it is lost to the atmosphere as nitrous oxide, a greenhouse gas. Nitrates are leached into the groundwater posing human health hazards. Phosphorus saturation can also lead to eutrophication.
- Excretion and digestion of protein. Pigs excrete 70% of the protein in their feed, and chickens 55%. Ammonia from the digestion of protein acidifies the soil, causes acid rain, etc.
- The application of manure can cause N and P loss, N leaching into the water as nitrates, and contamination of surface waters leading to eutrophication.
- Anaerobic decomposition of manure releases large amounts of methane when stored in liquid form.
- Biodiversity may be reduced because of: (1) high demand for concentrate feed may create a need to clear more land for feed production, (2) the effect of waste on terrestrial and aquatic systems, and (3) requirement for uniform animals in large operations.
- In addition to these environmental problems, human health can be affected by zoonoses common in intensive production systems.

6.3.7.2 Mixed Crop–Livestock Systems: Increased Efficiency or Nutrient Mining?

The transfer of nutrients between soils, crops, and animals is an important environmental issue of modern agriculture. Animals harvest nutrients from the environment through the intake of feed, forages and crop residues. In time, some of those nutrients, whether metabolized or in their natural form, are recycled back to the ecosystem. The type of production system heavily influences the degree of interaction between crops and livestock, and the nature of nutrient cycling. Sere and Steinfeld (1996) classify livestock production as industrial, mixed farming or grazing systems. As systems transform from grazing to industrial, the extent of nutrient transfer between soil, crops/pastures and animals moves beyond the farm level to a national, regional and even global scale. In addition, the environmental impact of nutrient cycling by crop–livestock interactions is also determined by the state of nutrient balances in agricultural land. At a global scale, nutrient-deficient and nutrient-surplus regions are identified. Agricultural areas with serious nutrient depletion are widespread in Africa, Latin America, and marginal lands of Asia (Stoorvogel et al. 1993; Craswell et al. 2004). In contrast, nutrient-surplus regions are found in Western Europe, some areas of Eastern Europe, in the eastern and mid-western United States, in Southeast Asia and the large plains of China (Steinfeld et al. 1997; Craswell et al. 2004).

Thus in general terms, it is in industrial countries that nutrient-surplus areas are more common, and where more intensive industrial livestock production takes place, and in the developing world where drastic nutrient depletion of soil occurs and grazing and mixed farming systems are widely spread. It should be noted, however, that many of the environmental impacts of industrial-type livestock systems could also be found in large cities of developing countries with large concentrations of animals in peri-urban farms.

6.3.7.2.1 Industrial systems and use of manure in nutrient-surplus regions

A common feature of industrial systems is that the locations of feed production, livestock feeding, and manure and urine disposal are not geographically contained within the same farming system. Thus nutrients are exported from feed-producing regions and imported to the soils where manure is applied. Inappropriate manure application in nutrient-surplus areas can produce excess nitrogen and phosphorus, which leaches or runs off, polluting groundwater, aquatic, and wetland ecosystems, or leaves high levels of nitrates, phosphates. and potassium in the soil (Steinfeld et al. 1997; Zaccheo et al. 1997; Chamber et al. 2000; Craswell et al. 2004). Furthermore, deficient management of excessive amounts of manure/slurry can increase the production of volatile ammonia (Chamber et al. 2000) and methane (Yamaji et al. 2003).

6.3.7.2.2 Mixed farming/grazing systems and use of manure in nutrient-deficient regions

Due to the nature of mixed farming and grazing systems, nutrients voided in urine and manure have the potential to be recycled within the farming system. Several authors agree that manure application can be a valuable means of improving the characteristics of nutrient-poor soils; it has been reported that manure increases soil fertility, organic matter, pH, and water-holding capacity (Olsen et al. 1970; McIntosh and Varney 1973; Mugwira 1984; Fernández-Rivera et al. 1995; de Haan et al. 1997; Ehui et al. 1998). Urine can account for 40–60% of total N excretion, and although urinary-N is rapidly available for plant use, it is also easily lost through volatilization and leaching. Fecal-N on the contrary, is released in the soil at a slower rate, providing a sustained N supply that is better synchronized with crop demands. The amount of phosphorus voided in feces is relatively high and its excreted form is easily available for plant growth. Where soils are P-deficient, as is the case for most soils of sub-Saharan Africa, manure application on agricultural land improves P-availability for crops.

In grazing systems, most of the nutrients are recycled in situ, as urine and manure are spread in the areas where animals graze, although some of the nutrients are brought into the farm when animals are penned at night. While some volatilized N has the potential to return to the landscape after combining with rainfall, most P is not redistributed to grazing areas, but builds up where livestock is kept (Augustine 2003). Manure collection and management is easier in mixed farming than in grazing systems and enables farmers to make decisions on the use of manure—usually concentrating manure in the fields with valuable crops. With this practice, nutrients are exported from one field to the other and fertility gradients across fields within the same farm are generated (Prudencio 1993; Ramisch 2004).

Most of the plant material available for feeding cattle in mixed farming systems of the developing world is crop residue with poor nutrient content. In this case, feeding low-quality forage to livestock and subsequently using the manure as fertilizer helps to maintain the viability and sustainability of the system. In general, the lower the quality of the feed, the more beneficial the application of manure over the raw plant material (Delve et al. 2001). It is important to consider that, in the context of the sustainability of crop–livestock systems, the long-term benefits of manure application for soil characteristics are far more important than its short-term role as a nutrient provider (Murwira et al. 1995).

6.3.7.2.3 Nutrient cycling by crop–livestock interactions: policy and research for the future

The current state of agriculture and its global effects have focused increased attention on the way human-induced activities are altering the recycling of nutrients between soils, crops, and livestock. Crop–livestock interactions, which transfer nutrients through the collection, storage, and application of manure are causing an impact beyond the limits of the farming system, and their nature largely depends on regional economic characteristics.

Agriculture in developed countries, where nutrient-surplus regions prevail, is producing and adopting better guidelines for the storage and application of manure (Chambers et al. 2000; Salazar et al. in press). Some countries are enforcing the adoption of nutrient accounting schemes at the farm level (Breembroek et al. 1996; Craswell et. al. 2004), environmental costs are moving to the center of the debate of nutrient cycling, and legislation on water pollution and waste disposal is put in place. The international trade of feed and livestock products and their influence on national nutrient balances has also entered the global economic and environmental debate (for example, Lindland 1997; McCalla and de Haan 1998).

The panorama is quite different for the developing world where it has been forecast that the demand for livestock products will double by the year 2020 (Delgado et al. 1999), and that the intensification of crop–livestock systems in these countries is the path to meet this demand (McIntire et al. 1992; Steinfeld et al. 1997). As the intensification of mixed farming systems increases, the role of manure as the means to recycle nutrients will become essential. In some nutrient-deficient regions, however, manure itself cannot restore the fertility of soils that have been nutrient-mined continuously for many years. In these cases, calculations show that the amount of manure necessary to compensate for soil nutrient losses is, in practice, unattainable (Murwira et al. 1995). Research in crop–livestock systems in developing countries is focusing on better understanding of the use of manure and its interaction with other organic and inorganic fertilizers to enhance the viability of current production systems (for example, Thorne and Tanner 2002; Sanginga et al. 2003; Chikowo et al. 2004).

6.3.7.3 Pastoral Ecosystems of the Developing World: Causes, Change Processes, and Impacts

A suite of strong pressures within and outside pastoral systems are currently driving change in these systems in the developing world. Pastoral land use and the extent of rangelands around the world are contracting, principally through conversion to other land uses (croplands principally, but also into protected areas and urban land-use), but also because of a hypothesized loss in function of the remaining rangelands (Niamir-Fuller 1999). However, in Central Asia, the removal of the policy of collectivization has resuscitated traditional pastoralism in the last decade as pastoralists are no longer supplied with inputs like fencing and veterinary care, and thus the advantages of settled life are gone (Blench 2000). Globally, the tenure in pastoral systems is increasingly becoming privatized and customary political and management systems are becoming weaker (Galaty 1994; Niamir-Fuller 1999), limiting pastoral access to crucial key resources (swamps, deltas, riverine areas) in much of Africa and in Central Asia (de Haan 1999).

Some national governments invoke policies to settle pastoralists in villages (Galaty 1994). In Africa, several decades of drought (Nicholson et al. 1998) have coincided with high human population growth, adding further pressure on pastoral lands, especially those with higher potential for cultivation in the semiarid zone (Galaty 1994). In North Africa and West Asia, the expansion of irrigation has pushed pastoralists into very arid ecosystems, but this is not irreversible: the very opportunism inherent in pastoralism means that if the skills are not lost, pastoral systems can be revived (Blench 2000). Livestock development projects are also driving change in pastoral lands by opening up remote pastures with the spread of bore hole technology, and fragmentation of rangelands by veterinary cordon fences, particularly in southern Africa.

The impacts of the changes are numerous and include changes in land use, overgrazing, competition and synergies between livestock and grazing, carbon sequestration, and dust formation.

Changes in land use (expansion of cultivation and settlement): Expansion of cultivation fragments rangeland landscapes when farmers convert rangeland into cropland (Hiernaux 2000), leading to strong wildlife and vegetation losses (Serneels and Lambin 2001). Fragmentation can also occur when fence lines are built to prevent the spread of disease or to prevent wildlife from foraging in enclosed pastures. Often, fences exclude all domestic and wild grazers from key resources like swamps, riverine areas, and other productive areas.

Overgrazing: Overgrazing is the loss of ecosystem goods or services through heavy livestock grazing (over-trampling is implicitly included). Heavy livestock grazing occurs where livestock concentrate: around pastoral settlements, around water points, along animal tracks (Hiernaux 1996), and in open access pasture. If driven by cultivation, this overgrazing occurs in the wet season, when rangelands are most sensitive to grazing (Hiernaux 2000). In the Sudan, this concentration of livestock leads to loss of vegetative cover and accelerates erosion (Ayoub 1998). By contrast, heavy livestock grazing around pastoral settlements in arid areas (169 millimeters rainfall) of Namibia had minor impacts on woody vegetation and biodiversity, with impacts confined within the settlements themselves (Sullivan 1999). In the Kalahari, overgrazing around settlements often converts grassland into bush land within about two kilometers of the settlement (Dougill and Cox 1995). Across southern Africa, woody vegetation has replaced palatable grass species in heavily grazed areas (bush encroachment), caused by grazing pressure rather than climate (Perkins 1991; Skarpe 1990).

Competition and synergies between livestock and wildlife: By contrast, the impacts of heavy grazing on wildlife may be exactly the opposite of that on vegetation: greater impacts in drier than wetter ecosystems. Wildlife appears to avoid heavily grazed areas completely in arid northern Kenya (De Leeuw et al. 2001) but livestock mix more closely with wildlife in semiarid rangelands in southern Kenya. Around Samburu pastoral settlements in these arid lands, Grevy's zebra graze away from the settlements during the day, but move close to them during the night (Williams 1998). Disease transmission is a potential issue where livestock keeping and wildlife overlap)

Carbon sequestration: It is not clear whether current changes in rangelands (land-use change, overgrazing, fragmentation) are causing a net release or net accumulation of carbon, both above and below ground. Expansion of cultivation into rangelands probably strongly reduces carbon below ground, but may increase carbon above ground if farmers plant significant numbers of trees. If overgrazing converts grassland to bush land, then above-ground carbon will increase, but below ground carbon may decrease. In addition, rangelands are a significant carbon sink (IPCC 2000), but the potential of these areas for further sequestration may be difficult to realize (Reid et al. 2003).

Dust formation: Livestock grazing may be partly responsible for the dust plume that forms in the Sahel and moves west over the Atlantic Ocean each year (Nicholson et al. 1998), but this is unknown. The generation of dust in different land use types and in different geomorphologic positions needs to be measured to assess how livestock affects this source.

6.3.7.4 The Role of Livestock Production in Deforestation around the Globe

Pasture creation and cattle ranches have been blamed as major driving forces behind deforestation in Latin America, particularly in Brazil (Hecht 1985; Downing 1992; Kaimowitz 1996; Walker et al. 2000). The amount of land that has been converted from tropical rain forest to pasture, as well as the rate of conversion, is under reconsideration as the higher quality and resolution of new satellite imagery is aerially revealing more details of the extent of deforestation and clearance of secondary forests. Nevertheless, estimates are that approximately half of the deforestation in the Amazon is due to pasture generation.

Above and beyond the global environmental consequences, the conversion of land from humid tropical forest to pasture would appear to be inherently unsustainable given the low soil fertility and abundance of invasive weeds and woody species. The presence of the invasive, sometimes toxic species necessitates frequent burning. These factors behind pasture degradation reduce stocking densities and restrict the long-term use of the land for ranching (Walker et al. 2000). Heavily degraded land is difficult and uneconomic to recuperate, so the clearing for pasture often condemns the land to waste; it is estimated that half the area cleared in the Amazon for pasture has been abandoned (Hecht 1989; Faminow 1998). Despite the environmental implications and limitations, ranching continues to be profitable and conversion of forest to pasture continues (Arima 1997).

Intensifying production on the agricultural frontier may reduce the pressure to clear further forest. However, the assumption that intensifying productivity on the frontier will reduce deforestation might not hold (Hecht 1989; Angelson and Kaimowitz 1999). Increasing productivity on the forest edge may well prove to be an attractant, pulling new migrants to the area. Labor saving or income generating technologies may simply reduce production constraints allowing households to put more land under production, leading to additional land clearance. Perhaps most importantly, improved technologies do not address the underlying forces behind deforestation, such as migration push and pull factors, government programs, and the desire to clear land in order to claim ownership.

6.3.7.5 Livestock and Greenhouse Gas Emissions

The primary greenhouse gases emissions from agriculture are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Livestock contribute to emissions of these gases in several ways. At the animal level, rumen fermentation creates methane gas, which is 24.5 times more powerful as a greenhouse gas than CO_2 (IPCC 1995). Livestock emit 16% of all methane globally (IPCC 1995). Most of these emissions come from ruminants: cattle, sheep, and goats. Methane contributes 30% of the global warming potential of all agricultural emissions (Kulshreshtha et al. 2000). Besides livestock, the other main source of methane in agricultural systems is rice paddies (IPCC 1995). Livestock are responsible for about 110 million tons CH_4 per year, while rice paddies contribute about 60 million tons.

Methane production from livestock is controlled both by the level of productivity per animal and the quality of the feed. More productive animals emit less methane per unit product because a lower proportion of methane produced is used for maintenance (de Haan 1997). Methane production in livestock is also sensitive to diet quality and to the timing and amounts of forage fed (feed management strategies). Higher quality feed allows more efficient operation of the rumen and thus more efficient digestion; this results in more output per unit input (meat, milk) and reduced methane emissions per unit intake (Kurihara et al. 1999).

At the field level, improved forage for livestock has a role in reducing methane emissions, but may also function as a carbon sink. Fodder trees and shrubs sequester significant carbon above ground and store more carbon below ground than cereal-based cropping systems (IPCC 2000).

Another greenhouse gas, N_2O, with 320 times the warming strength of CO_2, is emitted during storage of liquid manure, produced either by ruminants or non-ruminants (IPCC 1995). Liquid manure is usually stored in highly intensified livestock systems for later use or sale. On the other hand, livestock can also reduce N_2O emissions by the substitution of manure for inorganic fertilizers. These fertilizers are a major source of N_2O emissions, and thus more substitution with organic manure is an important avenue for emission reduction.

At the landscape-level, the largest impact of livestock on greenhouse gas emission is through deforestation. Tropical forest systems are of great concern because they hold more than half of the world's above ground carbon (IPCC 2000). In the forests of Brazil, Peru, Cameroon, and Indonesia, pastures and grasslands hold 1% of the above ground carbon stocks of primary forest, less than short-term fallow cropping systems (Palm et al. 1999). These same pastures contain only 20% less carbon below ground compared with forests. Improved pastures do not improve carbon sequestration substantially over short fallow and degraded pasture systems (Palm et al. 1999).

Livestock also contribute to greenhouse gas emissions in rangelands, although conversion of rangeland to cropland is a large source. As rangelands contract and are converted to cropland, 95% of the above ground carbon can be lost and more than 50% of the below ground carbon (calculations based on IPCC 2000 figures). Within rangelands, overgrazing is the principle cause of loss of soil carbon (Ojima et al. 1993). Thus improved grazing management can have direct and substantial effects on soil carbon pools (IPCC 2000). In addition, heavy grazing and changes in fire regimes can convert grassland systems to bush land systems. This conversion may increase carbon above ground (Boutton et al. 1998), but it is not clear how carbon below ground is affected.

Lastly, the projected doubling of demand for livestock products over the next 20 years (Delgado et al. 1999) is likely to strongly increase the emissions of greenhouse gases into the atmosphere. Even though improvements in nutrition will likely lead to reduced emissions from livestock, the sheer increase in numbers necessary to meet demand will probably overwhelm any reductions in gas production through nutrition. The predicted rapid expansion of industrial livestock systems will create the potential for strongly increased production of nitrous oxide from excessive manure. Further, demand for livestock products is also likely to fuel more clearing of natural vegetation for ranching in the rain forest and to produce concentrate feed for burgeoning livestock populations.

6.4 Conclusion

The challenge of food and ecosystems in the twenty-first century will require comprehensive assessments and knowledge at the local, national, and international level of agroecological and socioeconomic conditions, in order to ensure that farmers can produce food in a manner that is environmentally, economically, and socially sustainable and that consumers have the opportunities to make choices regarding food that is nutritious and healthy, safe and affordable.

The scientific challenges of producing the food needs of the world will require targeted and prioritized agricultural research with the participation of farmers.

Specific research focusing on the differential vulnerability of farmers, as well as, ecosystems will be required. Additionally, the threats of global environmental change, for example, agricultural impacts of climate change, will need to be explicitly considered in mobilizing agricultural research efforts. This is especially true, since a long time horizon is required from initiation of research to local farm level implementation. The scientific challenge ahead is a formidable one and can only be met through national and international commitments to use the opportunities that science must provide in the coming decades.

In the second half of the twentieth century, the Green Revolution substantially reduced the risks of mass starvation and famines in the developing world. The international agricultural research efforts over two decades from the 1940s on focused on breeding high-yield dwarf wheat that increased yields two to threefold. In the following three decades (1960s to 1990s), this Green Revolution enabled world cereal production to increase threefold on about the same land acreage. Without this success, world farmers would have had to increase cereal harvested land area from 650 million hectares to over 1,500 million hectares, with all the environmental consequences of forest clearance and loss of biodiversity.

Beyond the main cereal crops, high yielding varieties of millet, sorghum, cassava, and beans among others were also developed in partnerships between national agricultural research systems in developing and developed countries together with CGIAR.

The scientific and technological experiences of the last half century, including the remarkable progress in science-based conventional breeding, will need to be combined with safe and ethical biological sciences—genomics and molecular genetics, physiology, and informatics research, as well as improved crop and land management systems, caring and environmentally sound livestock production, and fish farming. The developments in geographical information systems, including remote sensing and the increasing quality and coverage of sub-national, national, and global resource databases of soils, climate, land cover, etc., together with methodologies for crop, livestock, and fish productivity assessment and mathematical modeling tools need to be systemically integrated to ensure spatial sustainability. The consideration of a number of other issues, such as the increasing privatization of agricultural research and patenting, will also be critical to ensure that the millions of poor farmers are not bypassed by the new breakthroughs in agricultural science and technology.

The national and international agriculture research system faces a formidable challenge to harness the power of science, including:

- *Using science responsibly.* The emerging scientific tools of cellular and molecular biology can shorten the time and cut the costs required to develop innovative food varieties. Biotechnology tools can introduce genes that counter soil toxicity, resist insect pests, and increase nutrient content. Still, the questions of determining appropriate levels of risk and the ethics and societal acceptance of manipulating genetic material need to be resolved before the potential of biotechnology and genetic engineering can be fully realized.
- *Ensuring ecological sustainability.* New scientific tools will need to be combined with knowledge about natural resources in order to ensure sustainable and productive use and avoid inefficient water use, loss of arable lands and productivity declines,

deforestation, pollution and destruction of ecologically critical watersheds, loss of biodiversity, and health and environmental risks of intensive livestock production and fish farming.

- *Harnessing the Information Revolution.* The phenomenal potential of the information and communication revolution including the Internet, remote sensing, GIS, etc., can enable interactive global agricultural research systems combining the best of science with traditional knowledge.
- *Integrating ecology and socioeconomy.* The progress in understanding the functioning of ecological systems; the compilation of agricultural resources databases at sub-national, national, and global levels; and the development of analytical and mathematical modeling tools will be critical to enable spatially relevant application of the results of agricultural research to ensure that the best choice are made at the sub-national level in the context of national needs within a world food economy.

The poor need the deliverance of the promise of science, and without a global partnership and responsible commitment to productive and sustainable agriculture, there can be little progress toward reducing hunger, poverty, and human insecurity.

Governments, civil society, and the private sector around the world must provide the means for mobilizing science and research for food and agriculture. A participatory worldwide effort, building on the lessons and experiences of the last Green Revolution combined with the best of new agricultural sciences can enable the next agricultural revolution to meet world-wide food needs in the twenty-first century, with environmental, economic, and social sustainability.

One of the main lessons learned from the analysis of the responses is that the impacts on ecosystems from attempts to increase food production have been realized mostly as secondary effects, and as such they often represent negative externalities of agricultural production. These externalities have been ignored by small-scale agents, like individual farmers, in their decision-making processes, but also by governments in their effort to attain primary targets regarding food production. Externalities have also been ignored in non-cooperative situations emerging in international competition or in the presence of transboundary or global problems. Since these impacts have had a profound effect on the current state of well-being, but hold the potential for even more dramatic negative impacts on the capacity of the ecosystem to provide future services, it is essential that proper measures be undertaken in the present time.

Because the quantification of some of these impacts is uncertain, the design of policies could consider the precautionary principle, by taking into account "worst-case" scenarios and potential irreversibility in ecosystems, such as those experienced for example, in the Aral Sea disaster and the collapse of the Newfoundland Cod Fishery. New analytical approaches of decision-making under deep uncertainty, such as robust control methods, might prove helpful in designing policies following the precautionary principle.

The need to mitigate impacts on ecosystems and sustain their capacity for future generations makes necessary the introduction of appropriate regulatory frameworks at all levels from local to global, that will control for the externalities affecting the capacity of ecosystems to sustain their food provisioning services. Regulation is not without cost, but this cost basically represents the cost of using the services of the ecosystems for producing food. This service is currently largely unpaid, due to well-known reasons associated with missing markets and lack of well-defined property rights. Water pricing is an example of how governments are coming to grips with the valuation of scarce resources and essential environmental services. Other environmental services must be similarly valued and paid for to ensure their appropriate exploitation and the sustainability of production systems. If this cost is ignored, as has thus far generally been the case, then the capacity of ecosystems to maintain or even enhance their food provisioning services is at risk.

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