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Impact of climatic and other environmental changes on food production and population health in the coming decades

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World population will reach an estimated nine billion by 2050. Given this factor and continued economic development in today's low-income countries, the total global demand for food will increase approximately threefold over the coming half-century. Meanwhile, against this background, newly-occurring global environmental changes such as climate change are anticipated to affect food production. Other incipient large-scale environmental changes likely to affect food production include stratospheric O_3 depletion, the accelerating loss of biodiversity (with knock-on effects on crop and livestock pest species) and the perturbation of several of the great elemental cycles of N and S. The ways in which these various environmental influences affect the production of food (crops and livestock on land, and wild and cultivated fisheries) are complex and interactive. Uncertainties therefore persist about how global climate change is likely to affect world and regional food production. On balance, recent modelling-based estimates indicate that, in the medium to longer term, if not over the next several decades, climate change is likely to affect crop yields adversely, especially in food-insecure regions. The prospect of increased climatic variability further increases the risks to future food production. Given these possible though uncertain adverse impacts of climatic and other environmental changes on world food production, there is a need to apply the Precautionary Principle. There are finite, and increasingly evident, limits to agro-ecosystems and to wild fisheries. Our capacity to maintain food supplies for an increasingly large and increasingly expectant world population will depend on maximising the efficiency and sustainability of production methods, incorporating socially-beneficial genetic biotechnologies, and taking pre-emptive action to minimise detrimental ecologically-damaging global environmental changes.

Environment: Climate: Food production: Twenty-first century

Historically, food availability has been the most fundamental constraint on human population size. Over time, man has found ways to expand food supplies, and hence the environmental carrying capacity. As human numbers have duly increased, and as agriculture has replaced foraging and hunting and, in turn, has become both more extensive and intensive, so the expansion of local environmental carrying capacity has tended to become less sustainable. Hence, there are many historical examples of local ecological declines that caused societal collapse, such as in Mesopotamia, the Harrapan civilisation of the Indus Valley, the Mayans, the Anasazi of southwest America, the West Vikings and the Easter Islanders (Diamond, 1997). The fratricide in Rwanda in 1994 is deemed by some commentators to have reflected the land pressures, and food shortages, in a rapidly-growing population of eight million living in a tiny country with an environmental carrying capacity estimated at only six to seven million.

Looming large in this ongoing debate about food, population and survival is the thesis of the Reverend

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Thomas Malthus. An English cleric and pioneer in political economy, Malthus made the famously grim prediction in his essay on population, first published in 1798, that gains in food production could not keep up with natural population increase (see Malthus, 1985). He referred to 'the constant tendency in all animated life to increase beyond the nourishment prepared for it', and therefore to the inevitability of 'positive checks' (starvation and deaths) occurring when mouths outnumbered food. He thus argued the inevitability of local subsistence crises whenever population size outstripped food supply.

Malthus' views have subsequently been contested or elaborated by many other economists. Two prominent economists, whose writings in the 1980s bore on this issue, were Ester Boserup (1981) and Julian Simon (1981). They took the counter-position that man is a 'resource' (the greater the population you have, the more likely it is that invention and innovation will flow). Other economists (as yet, a minority) argue that the recent advent of global environmental changes obliges us to recognise the fundamental limits to the capacity of the biosphere, that it is essentially a closed system, and that continuing sustainable gains in food production cannot be assumed.

The contemporary situation

Subsistence crises, with famine and starvation, have long been part of the human story. Today, the picture is rather different. Modernisation, trading networks, other forms of interconnectedness and an emerging ethos of international aid have acted to reduce the impact of local famines. Meanwhile, however, we face the unprecedented prospect of population size exceeding food supplies at a global level. The twenty-first century will therefore provide, at this larger scale, a critical test of the classical Malthusian formulation about the dynamic tension between food production and population size.

World population size appears set to undergo a sixfold increase, from 1·5 billion in 1900 to about nine billion in 2050, after which it may plateau at a level not much higher than that, or, if either disaster (e.g. an amplified HIV and AIDS pandemic) or unprecedented collective enlightenment supervenes, it may actually decrease. Meanwhile, the modern agricultural revolution, with its beginnings in the late eighteenth century, has intensified; the green revolution has boosted grain yields during the latter half of the twentieth century, and we stand now on the brink of applying genetic biotechnologies and precision-farming techniques to the future expansion of world food production.

Today's world food profile, as baseline for future projections, underscores the need for gains in both the production of food and access to it; i.e. in Amartya Sen's 'food entitlement' (Sen, 1981). Malnutrition remains a serious international public health, social and economic problem. Although the proportion of the population who are malnourished has declined gradually over recent decades, the absolute numbers are not yet obviously declining (Food and Agriculture Organization, 1999). The estimated total number in the year 2000 is 830 million, of which 790 million are within the less-developed countries. In the 'global burden of disease' assessment made by the World Health Organization (Murray & Lopez, 1996), malnutrition accounts for 16 % of the world's total burden of disabling illness and premature death, measured in disability-adjusted life-years. Relatedly, 17 % of the world's annual total of approximately 140 million births entail birth weights < 2500 g. Again, about 90 % of these births occur in the less-developed countries.

An understanding of the emerging world food situation requires more than simple arithmetic and linear extrapolations. There are qualitative shifts occurring to the ecological infrastructure that underpins the world's food-producing systems. Land degradation has occurred widely, with now approximately one-third of fertile soil moderately or severely damaged via erosion, salination, water-logging, chemicalisation, loss of organic material and physical compaction (Greenland *et al.* 1998). The increasing reliance on irrigation has not only caused salination and water-logging in many locations, but groundwater supplies have been widely depleted as aquifers have been over-pumped. This problem could become critical in various parts of the world, including northern China, the American midwest and northwest India. The chemicalisation of soil and waterways will increase as the use of nitrogenous fertiliser increases, particularly in Latin America and (if it can afford it) Africa. Already the past half-century's combination of huge increases in nitrogenous fertiliser use, in livestock production and in the combustion of fossil fuels has added greatly to the level of biologically-active ('fixed') N within the biosphere. Man now produces more fixed N annually than do the world's natural processes (vulcanism, lightning, naturally-occurring rhizomes, etc.). This factor has contributed to the acidification of soils and has resulted in increasingly high nitrate levels in ground water. In China, for example, nitrate levels are already well above the WHO standard, set in relation to public health risks, and these levels may well double over the coming half-century.

Against this background, questions arise about how, in future, other great changes in global environmental systems and processes might affect food production. Global climate change is an acknowledged major source of likely future stress on both terrestrial and marine food production, and is attracting much of the scientific and policy debate. However, the world, as ever, is multivariate; there are other incipient large-scale environmental changes that will affect food production, including stratospheric O_3 depletion, the accelerating loss of biodiversity (with knock-on effects on crop and livestock pest species) and the perturbation of several of the great elemental cycles (N, S and P). Further, the impacts will not be simply additive; many of these processes will interact with one another. For example, the probability of crop infestations by pests may be influenced multiplicatively by changes in climatic conditions, the weakening of photosynthesis and plant biology by both increased u.v. irradiance and micronutrient deficiencies, the depletion of predator species and water shortages.

The time trends, and projections, in world population and food production are shown schematically in Fig. 1, which indicates three broad time periods of interest. In the first half of the twentieth century cereal grain yields were increasing in response to the advent of modernised production methods. Populations were also growing, as developed

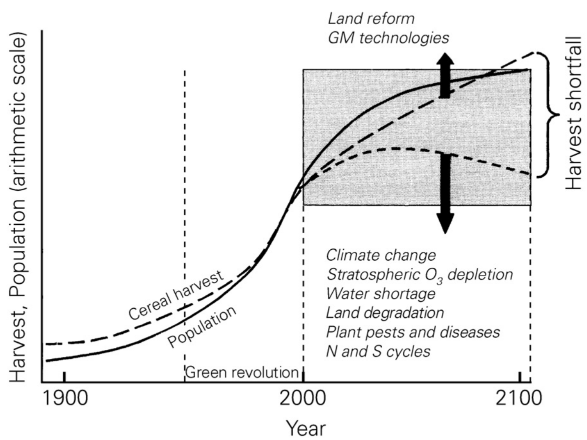

Fig. 1. Schematic representation of three consecutive eras over the past and coming centuries, showing the changing balance between cereal-grain production (– –) and world population size (—). Over the coming century there will be tension between yield-enhancing science and policies (↑) and yield-diminishing environmental forces (↓). GM, genetically-modified.

countries approached the completion of their demographic transitions and as populations in poorer countries began their demographic transitions (partly in response to increases in food availability, and partly in response to enhanced infant and child survival from the gradual introduction of basic sanitation, domestic hygiene and life-saving medical care). Life expectancies at birth in India, for example, underwent a marked increase after about 1920 (Powles & McMichael, 2001). This factor could be thought of as evincing the Malthusian process, wherein the growth in food production potentiates the growth in population.

In the latter half of the twentieth century population growth rates accelerated; indeed, the world passed through its highest-ever annual growth rates, > 2 %. The pressures to boost food production were therefore increased, and this situation was heightened by the political pressures of the Cold War. Newly-independent nations had to be courted and supported. Accordingly, the green revolution occurred, with massive effort and investments particularly in Asia and much of Latin America. This period could be regarded as displaying a rather more Boserupian process, with the pressure of population numbers stimulating increases in food production (Boserup, 1981). Note, however, that in approximately the final decade the rate of increase in cereal-grain production fell below the (gradually declining) rate of increase in world population. *Per capita* production peaked in 1985 (King, 1999). The contemporary situation in the world is summarised as follows:

1. the proportion of the world population that is hungry and malnourished is slowly declining. However, because of the continuing growth in population the absolute number of hungry and malnourished people is not obviously declining. The estimated number is approximately 830 million, one-quarter of them children below age 5 years;
2. *per capita* food production has increased over the past four decades (particularly because of the successes of the green revolution during the period of the 1960s–1980s). In part, those gains in yield were achieved via intensive inputs of energy, fertiliser and water, and at the expense of soil vitality and groundwater stocks;
3. an estimated one-third of the world's arable land is significantly degraded. During the 1980s and 1990s the combination of erosion and nutrient exhaustion, plus irrigation-induced water-logging and salination, rendered unproductive about one-fifteenth of the world's readily arable farmland. Much more land was seriously damaged;
4. *per capita* grain production (which accounts for two-thirds of world food energy) has plateaued since the mid-1980s. The reasons for this situation are not clear. Recent cross-bred high-yielding strains may yet provide further gains in yield;
5. the annual harvest from wild fisheries peaked at about 100×10^6 t/year in the 1970s, and has subsequently declined by about 20 %. Many fisheries, particularly in the northeast, northwest and southeast Atlantic, have been over-exploited and are in decline;
6. aquaculture now accounts for approximately one-quarter of the world's total fish and shellfish production. However, it entails particular ecological difficulties that might limit its diffusion;
7. the promise of genetically-modified food species, while potentially great, is subject to resolution of concerns about unexpected genetic and ecological consequences. This modern biotechnological venture should be pursued as a cooperative public–private partnership, and directed at important environmental, social and public health objectives.

Today we are entering the third of the three periods shown in Fig. 1. Will world production of cereal grains keep pace with the increased population growth and the increased consumer demand (as more grain is diverted into livestock production)? The outcome will depend on the balance achieved between the positive and negative influences illustrated in Fig. 1. Global environmental changes loom as a major source of potentially-negative influences.

Population, food and health: current and emerging issues

There has been long-running debate about the capacity of the growing world population to continue to feed itself (Cohen, 1996; Dyson, 1999; King, 1999). As indicated earlier, world food production has outpaced population growth over most of the past half-century. However, there are serious questions about the extent to which those successes have been achieved by depleting and damaging natural resources and thus borrowing against the future. Two questions therefore arise. What types of food production will be ecologically sustainable in future? Offset against that question, what types of diet will be acceptable in a world in which consumer expectations in urbanising lower-income countries are evolving towards the meat-enriched highly-processed freight-intensive diets of today's high-income countries?

Given that the world population will reach an estimated nine billion by 2050, and assuming that economic development continues in today's low-income countries, then the total global demand for food will increase approximately threefold over the coming 50 years. Forecasts by most international agencies remain optimistic; they foresee future food production matching increased population size and rising consumer demand at the global level over the next two to three decades. At the regional level, however, the prospect is for worsening food security in sub-Saharan Africa and for only marginal improvement in South Asia. Whatever else, it seems clear that cereal-grain exports from North America, Europe, Australia and Argentina will have to rise to meet the increased demand in many developing countries as their populations continue to grow (Dyson, 1999).

Most of the recent gains in food production have been due to the use of improved high-yielding variants of rice, wheat and maize in combination with great increases in synthetic fertiliser and pesticides. The rate of recruitment of new land has slowed; there is little good land not already in use (with some notable exceptions in South America). Irrigation continues to be extended. Currently, it accounts for one-sixth of all arable land, while it yields two-fifths of farm production. However, increasing awareness of the ecological costs and the social costs (e.g. via population displacement with dam construction) of irrigation may limit that option, as also must the recognition that fresh-water supplies are dwindling.

Now, on top of the evidence that components of the world's food-producing terrestrial ecosystems have been impaired over recent decades, comes an additional dimension of potential detriment to world food production, i.e. the hazard posed by global environmental changes such as global climate change. The evidence that human-induced global warming is occurring became firmer during the 1990s (Intergovernmental Panel on Climate Change, 1996). The globally-averaged warming is anticipated to be of the order of 2–4°C over the coming century. The warming would be greater at higher latitudes than at low latitudes, greater on land than at sea, and greater in winter than in summer. Overall, rainfall would increase because of the intensification of the hydrological cycle at higher temperatures, with increased evaporation. There would, nevertheless, be considerable regional variation in patterns of change in temperature and rainfall. This factor has potentially great implications for future food production.

Climate change will entail not just shifts in mean temperatures and seasonal rainfall levels; climatologists also foresee an increase in climatic variability. This change would result in an increase in extreme weather events in many regions of the world. Indeed, Dyson (1999), who has mostly been optimistic about the prospects for feeding the world, has recently stated: 'a worrying recent development is the increasing volatility of harvests in North America, which is possibly caused by climate change occurring as a result of carbon dioxide emissions.'

Food yields, especially of agricultural crops, are likely to be affected by shifts in mean climatic conditions. Those shifts would entail warmer temperatures, changes in growing seasons, altered patterns of precipitation and (in many rain-dependent regions) reduced soil moisture. The impacts of a change in mean climatic conditions may not all be adverse. Regions with a temperate or cold climate might undergo increased yields in response to increased temperature. However, many mid-continental and semi-arid regions would be vulnerable to crop failures caused by small increases in warming and soil drying. Irrigation-dependent agriculture would be vulnerable to reduced rainfall, exacerbated by heightened evaporative losses. Less predictably, climatic changes would influence the ecology of plant pests and pathogens. Further, a less-quantifiable risk arises from the likely increase in extreme weather events under a climate change regime. Floods, droughts, storms and fires all pose episodic, sometimes severe, risks to regional food production.

The main ways in which climate change would affect terrestrial food production are listed in Table 1. Another view of the main pathways by which climatic conditions affect terrestrial food production is presented in Fig. 2. Of particular importance are the 'positive' feedback paths by which livestock production, land clearance, irrigated rice production and the use of fossil-fuel-powered mechanisation generate the greenhouse gases CO_2 and CH_4; i.e. various of the processes that are intrinsic to the way we currently produce food are also sources of additional atmospheric radiative forcing, resulting in global warming.

It is important to note also the potential impacts of climate change on food yields from the marine and fresh-water aquatic environment.

Approximately one-sixth of all protein consumed by the world population is of aquatic origin, and in many developing countries it accounts for the majority of animal protein. Globally, *per capita* consumption of fish and shellfish has increased by about 50 % during the past four decades. This increase has been accompanied by an over-exploitation of wild fisheries and an increasing reliance on aquaculture. However, aquaculture faces some ecological constraints: (1) unlike agriculture, the energy inputs are not sunlight but are plant or animal feedstuffs; (2) the fish are prone to infectious (often viral or fungal) diseases; (3) the feeding, use of antibiotics and accumulation of excreta result in water pollution; (4) local ecosystems are often damaged or eliminated (e.g. mangroves); (5) domesticated fish stock may genetically contaminate wild stocks.

The Intergovernmental Panel on Climate Change (2001), in its impending *Third Assessment Report*, has noted that, while weather impacts and seasonal rhythms have long been recognised by the global fishing industry, decadal-scale shifts in climate have only recently been acknowledged as a factor in fish and marine ecosystem dynamics. In fact, various life stages of fish populations are sensitive to temperature: spawning, growth rates (in part because of temperature influences on food availability), migratory

Table 1. How might climate change affect terrestrial food yields?

Temperature effects on plant physiology
Soil moisture effects on plant physiology
CO_2 fertilisation effects: gains in plant water-use efficiency
Climatic influences on plant disease occurrence
Climatic influences on crop losses via pest species
Damage due to extreme weather events: floods, droughts, etc.
Sea-level rise: salination and inundation of coastal land

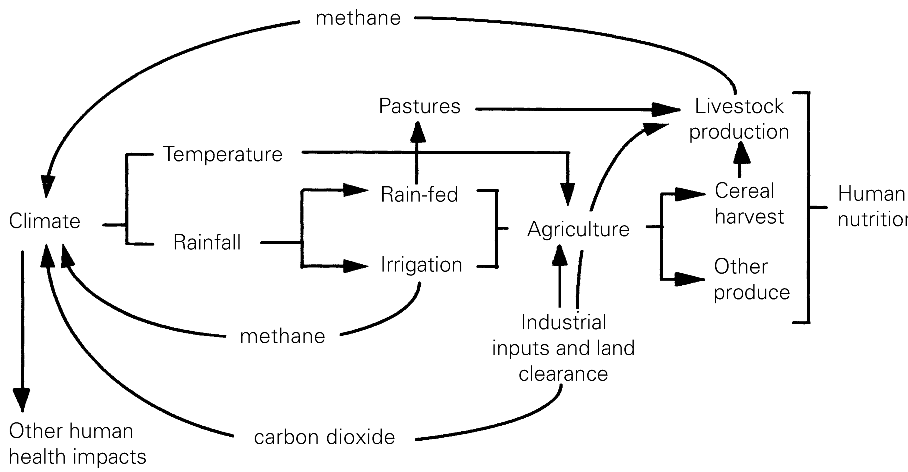

Fig. 2. Influence of climatic conditions on terrestrial food production, and ways in which that production produces feedback on the climate system via the increased emission of greenhouse gases.

patterns and breeding routes. The influence of temperature is evident in the fluctuation of catches of Pacific salmon and sardines in synchrony with large-scale climate variations and ocean processes, and the fluctuations in catches of Atlantic cod, Peruvian anchovies and, in the mobile western warm pool of the Pacific, of skipjack tuna.

Climate, famines and hunger in history

Before examining how global climate change might affect world food production, it is instructive to review the long history of climatic influences on famines, hunger and health. Further, it is helpful to consider climatic effects on two very different timescales, i.e. long term and short term.

Long-term changes in climatic conditions can alter the geographic boundaries and the viability of a society. For example, the inhabitants of the African Sahel have long lived with this reality as the southern fringe of the Sahara Desert advances and retreats from quarter-century to quarter-century. This fluctuation occurs partly in response to climatic cycles and the associated northwards reach of the great southwest monsoon that brings moist air from the southern Atlantic.

Climatic fluctuations can also disrupt food supplies on a much shorter timescale, leading to famine, deaths and social unrest. Indeed, acute famines have long been characteristic of pre-industrial agricultural societies everywhere. The climate is less irregular in Europe and North America than in most other regions of the world, particularly tropical and subtropical regions. Floods and famines in China and famines in India have been notorious killers over the centuries (Bryson & Murray, 1977; Fagan, 1999). In China, where vegetables and rice have long accounted for nearly all the energy intake by the toiling peasantry, famines have been recorded (by China's long-centralised bureaucracy) in one or more provinces in over 90 % of all years between 108 BC and 1910 AD. Great famines have occurred once or twice every century in India over the past thousand years. Smaller famines have occurred more often, usually in association with the weakening of the monsoon system induced by El Niño events. In the great Indian famines hundreds of thousands, sometimes millions, of deaths occurred. The last great peacetime famine in India, following hard on the heels of a moderately-severe famine in 1896–9, occurred in 1899 and probably caused over four million deaths (Fagan, 1999).

Potential impacts of global climate change on food production

Climate change is expected to cause a mixed global picture of regional gains and losses, reflecting the local balance of effects due to changes in temperature, soil moisture, CO_2 'fertilisation' and alterations in crop pest and pathogen activity. Yields of food, especially cereal crops, are sensitive to temperature, rainfall and soil moisture. Pest and pathogen activity is also sensitive to these climatic variables.

Scientists have used dynamic crop growth models to simulate the effects of climate change, in conjunction with increased atmospheric CO_2, on cereal crop yields. These models represent the important physiological processes responsible for plant growth and development. They also include other major factors that affect yields, i.e. climatic conditions, soil characteristics, management practices and genotypic features. The models can be used to predict both rain-fed and irrigated crop yields. Note, however, that none of the models yet in use include consideration of the climatic modulation of pest or pathogen activity.

One widely-cited study has estimated that standard scenarios of global climate change, linked with a range of plausible future trajectories of demographic, economic and trade-liberalisation processes, would result in a mixed picture of changes in cereal-grain production (Parry *et al.* 1999). There would be yield gains of 5–10 % in several temperate regions (much of Western Europe, Argentina, Japan, China and Canada), and downturns of similar magnitude in various already food-insecure regions, including South Asia, parts of the Middle East and North

Africa, and Central America. Overall, the estimated impact that an additional approximately seventy million of the population of the world will be hungry by the 2080s (equivalent to about a 40 % increase on the background expectation for that decade). Regionally, most of this nutritional adversity would occur in sub-Saharan Africa. The resultant additional hunger and malnutrition would increase the risk of infant and child mortality, and cause physical and intellectual stunting. In adults energy levels, work capacity and health status would be compromised.

The uncertainties inherent in this sort of attempt to model future climate change impacts on world food production are well illustrated by the spread of estimates obtained in other global studies (Rosenzweig & Iglesias, 1998; Winters *et al.* 1999). There have also been approximately twenty other modelling studies conducted in relation to the impacts of climate change on food yields in specific regions, nations and subnational locations (Intergovernmental Panel on Climate Change, 2001). One such national assessment of the impacts of warming and extreme weather events (due to climate change) on productivity, plant diseases and pests in US agriculture concludes: ‘The combination of long-term change (warmer average temperatures) and greater extremes (heat spells, droughts and floods) suggest that climate change could have negative impacts on US agricultural production. Economic losses in some US agricultural regions could rise significantly due to great climate variability, and to increases in insects, weeds, and plant diseases.’ (Rosenzweig *et al.* 2000).

Water is an essential input to agriculture and animal husbandry: for example, currently four-fifths of water usage in India is for agriculture. In many regions water supplies may be adversely affected by climate change. Reductions in rainfall are most likely in South Asia, the Middle East, North Africa and Central America. Tensions over fresh-water shortages would be exacerbated by climate-related changes in rainfall where adjoining countries share river basins, particularly in North Africa, the Middle East, South Asia and Southeast Asia. Conflict and public health crisis might then result.

In the ongoing assessments by the UN’s Intergovernmental Panel on Climate Change, the consensus view is that climate change will affect agriculture, causing a mix of losses and gains, ranging from particular species or local populations of plants and animals, to regional yields, and to global trade networks (Intergovernmental Panel on Climate Change, 2001). Nevertheless, against this background of some anticipated climate-induced downturn in yields, the Intergovernmental Panel on Climate Change (2001) foresees a continuing reduction in real food prices during at least the first two decades of the twenty-first century. This outcome however, is contested by some scientists who argue that the downward trend in food prices over the past half-century is misleading because the supply of the best arable land is dwindling and rates of yield growth are now declining. Since most yield increases in the first decades of the twenty-first century will have to come from conventional plant and animal breeding techniques, then the simple linear extrapolation of recent productivity trends may be overly optimistic. This area is manifestly one of great scientific uncertainty.

There has been some optimism about the prospect of CO_2 fertilisation as a source of increased crop yields. However, recent studies with rice and wheat have shown that gains in carbohydrate synthesis are offset by declines in protein content and in concentrations of Fe and Zn (Conroy *et al.* 1994; Rogers *et al.* 1996). In livestock forage the accelerated growth of C_3 grasses would entail some reduction in N concentration, thereby lowering the protein value of the forage. Further, experimental studies show that the CO_2 fertilisation effects are attenuated at higher temperatures.

Sea-level rise is another environmental consequence of global warming. Oceans would thermally expand and most glaciers would shrink in a warmer world. In consequence, the sea level is forecast to rise by approximately 40 cm by 2100 (Intergovernmental Panel on Climate Change, 1996). This rate of rise would be several times faster than that which has occurred over the past century. Since over half the world’s population now lives within 60 km of the sea, a rise in sea level could have widespread impacts on public health, especially in vulnerable populations. A 0·5 m rise (at today’s population) would approximately double the number who experience flooding annually from about 50 million to 100 million. Some of the world’s coastal arable land and fish-nurturing mangroves would be damaged by sea-level rise. Rising seas would also salinate coastal freshwater aquifers, particularly those beneath small islands.

Seeking ecologically-sustainable food production

The prospect of climate change and other large-scale environmental changes, and their anticipated range of impacts on food production, population health and social well-being, add a new dimension of urgency to our need to find ways of living sustainably. With respect to food production, the goal is to improve crop yields while leaving the natural resource base intact. The production of animal foods should also be ecologically sustainable, and we should seek to optimise the use of world plant-food energy; currently about 40 % of all maize produced is used as animal feed. Crop and livestock production do not necessarily compete with each other; ruminants such as cows and sheep can graze on land that otherwise would not be useful for growing crops. However, grazing animals can have other heavy impacts on the environment, resulting in soil erosion, competition with indigenous animal species and eutrophication of waterways.

We have recently seen dramatic evidence of the hazards to human health that can result from intensive forms of meat production. For example, the outbreak of often fatal *Escherichia coli* bacterial infections in Scotland in 1996 apparently resulted from the routine use of antibiotics in animal feed, causing antibiotic-resistant bacteria within cattle that were transmitted to beef-eating human subjects. Another salutary example has been the UK’s outbreak of ‘mad cow disease’ in the 1980s, as the apparent cause of ‘new variant Creutzfeld-Jakob disease’ in human beef-eaters. Imprudent cost-cutting measures, occurring in response to the growth of a competitive mass market for beef products, led to feeding recycled mammalian offal as protein supplement to cattle. The fiasco thus resulted from the conversion of bovine herbivores to unwitting carnivores.

Consumer tastes in many developing countries are moving in the direction of increasing meat consumption. China, for example, has undergone a sixfold increase in consumption of animal protein over the past quarter-century. This increase is happening at a time when the more-educated strata of developed countries are, for health reasons, lessening their consumption of red meat and of saturated animal fats. It would be desirable to foster national food and nutrition policies that assist developing countries to avoid the dietary excesses and their adverse environmental (and population health) consequences that have characterised the recent past of today's developed countries.

Conclusions

Environmental influences on the production of food (crops and livestock on land, wild and cultivated fisheries) are diverse, complex and interactive.

We still know relatively little about how these various biotic food-producing systems respond to shifts in environmental and ecological circumstances. Nevertheless, under the influence of new questions about the impacts of large-scale environmental changes on food production, much new insight is being generated. The important question about how global climate change is likely to affect food production remains complex and riven with uncertainties. On balance, recent modelling-based estimates indicate that climate change (at least in the medium to longer term, if not over the next several decades) is likely to adversely affect crop yields, especially in food-insecure regions. The prospect of increased climatic variability further increases the risks to future food production.

In the light of these various uncertainties, and the possibility that climatic and other environmental changes could adversely affect world food production, there is a clear need to apply the Precautionary Principle. There are finite, and increasingly evident, limits to agro-ecosystems and to wild fisheries. Our capacity to maintain food supplies for an increasingly large and increasingly expectant world population will depend on maximising the efficiency and sustainability of production methods, incorporating socially-beneficial genetic biotechnologies, and taking pre-emptive action to minimise the future course of detrimental ecologically-damaging global environmental changes.

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