Critical Consumption Trends and Implications

Degrading Earth's Ecosystems

by

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Preface

All too often, discussion of consumption issues and their environmental effects is either polarized or focused exclusively on lifestyle issues. This report takes a different perspective. It argues that production and consumption patterns are integrally linked: that the entire use cycle must be considered if environmental effects are to be understood, potential interventions identified, and effective policy approaches articulated.

Furthermore, this report argues that industrialized and developing countries have many common or overlapping interests in the environmental impacts of present production-consumption patterns. This common interest is especially evident in the examples examined in this report – food, fiber, and fishery products, the major natural resource-based economic sectors.

Finally, this report suggests that the urgency of addressing consumption in this systemic fashion becomes clear when consumption trends are considered. Within a decade, plausible demand forecasts suggest a marked escalation of environmental impacts, if the present production-consumption patterns are not altered.

If we can find common ground for addressing consumption issues, then the opportunities for shared approaches and more rapid action are improved. That at least is our hope.

E.M.
A.H.

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Executive Summary

Introduction

Natural resources – fuels, materials, water and food commodities – form the basis of all human activity. They are the essential inputs to both subsistence economies and the most advanced technological societies. Resource consumption in the world is rising rapidly, driven by population growth and rising wealth. Technological change and urbanization also fuel consumption, by creating new patterns of human needs and aspirations. In recent years, much has been written about the environmental and social impacts of modern consumption patterns. Many studies have focused on the environmental damage caused by the consumption patterns typical of industrial economies – high fossil fuel use, polluting emissions and waste volumes. Others detail the environmental degradation which can be induced by poverty – soil erosion and desertification, deforestation, water contamination. Developmental studies have highlighted the inequality of consumption levels between industrialized and developing countries, and between rich and poor inhabitants within countries.

This report adopts a different perspective, and seeks to place consumption at the center of policy-making for socio-economic development and ecological sustainability. Through a survey of broad resource use trends over the past 30 to 40 years, it demonstrates how both the level and distribution of consumption have changed radically in many parts of the world. By presenting the best available forecasts of consumption over the next ten to twenty years, it makes clear just how much more we will have to coax the earth to provide. Past and future consumption trends are then placed in their environmental context: what pressures have our consumption habits placed on the earth's capacity to provide the goods and absorb the wastes? What emerges from this analysis is that fundamental changes are taking place in global biological processes. Our attention has perhaps been focused too much at the local and regional level – on specific polluting emissions, or loss of specific habitats and species – and too little on whole ecosystems. Our understanding of how complex ecosystems function remains relatively limited, but the evidence of serious disruption is now widespread. Chronic, human-induced imbalances in major biological systems – for example, nutrient cycling, inter-species relationships and food chains – are more insidious than acute incidents of pollution or other damage. Their consequences, however, may be much harder to reverse, and more serious for the developmental and security prospects of every country.

Consumption Trends and Ecosystem Impacts

The report examines consumption trends, and the associated impacts on natural ecosystems, for three key resources – food (cereals and meat), wood fiber, and fish. These resources have been selected because they are of universal importance and interest to countries in all geographic regions and income groups. Additionally, consumption of all three is rising everywhere and demand is being fuelled in part by basic needs such as nutrition and literacy, not merely by "lifestyle" preferences. Finally, none of these resources is easily substituted. Demand management and technological advances can therefore do only so much to slow demand: consumption will inevitably increase in coming years.

Cereals and Meat

World cereal consumption has more than doubled in the last 30 years, while meat consumption has tripled since 1961 and is increasing at a linear rate. The agricultural success story is that rising demand has been met; more people are now better fed than they were a generation ago. One of the many environmental consequences, only now becoming clear, is significant disruption of the global nitrogen cycle. In the past half century, the application of inorganic nitrogen fertilizers world-wide has increased more than ninefold, and the number of livestock has more than doubled since 1960. Fertilizers and animal manures have increased and concentrated, respectively, the amount of nitrogen entering soils, freshwater and marine ecosystems. Human activity has actually doubled the natural annual rate of nitrogen fixation, and by far the largest single cause is agriculture.

Most agricultural experts believe that increasing global demand for cereals and meat can be met, and forecast that grain production will rise by about 15 percent by 2010, and by 25 to 40 percent by 2020. More fertilizer will be needed to produce the additional cereals and fodder crops for animals. Looking ahead just 12 years, if current practices persist, global fertilizer consumption will increase by at least 55 percent by 2010. In some under-fertilized regions, such as South America and Africa, this could be an entirely positive development. In others, notably parts of South and East Asia, nitrogen saturation will approach the levels already experienced in northwestern Europe and parts of the United States. The incidence and severity of nitrate contamination of drinking water, ground-level ozone formation, crop damage, forest die-back, and damage to coastal fisheries from algal blooms (“red” and “brown” tides) can all be expected to increase dramatically.

Wood fiber

Global wood consumption has risen by 64 percent since 1961. Demand for fuelwood and charcoal rose by nearly 80 percent and more than half the world’s wood fiber supply is now burned as fuel. Consumption of sawlogs, veneers, pulp for paper-making and other industrial forms of wood fiber rose by nearly 50 percent over the same period. Rising demand for industrial wood has encouraged widespread planting of industrial plantations and, today, they account for nearly 25 percent of supply. However, the bulk of wood fiber for all uses still comes from old-growth or secondary-growth forests. Demand for wood fiber is a major, though by no means the only, cause of deforestation. Commercial logging has accelerated the clearance of old-growth tropical hardwood forests; since 1960, more than one-fifth of the world’s entire tropical forest cover has been removed. Logging is also the primary cause of conversion of old-growth coniferous forests in temperate regions to managed forests with more uniform structure and lower biodiversity.

Demand for industrial wood fiber is projected to rise by between 20 and 40 percent by 2010. Most forestry analysts expect that demand will be met at the global level, but that regional shortfalls will occur, leading to higher fiber prices. If current patterns of production are not changed, pressure of demand will result in supplies being drawn from the world’s last remaining “frontier” forests. The tropical forests of the Amazon and equatorial Africa and the boreal forests of Siberia and Canada will not survive in their current form. Projections of future woodfuel consumption range more widely, due to poor data and uncertainties over the difference between what people actually consume and what they *would* consume, if their needs were fully met. Consumption might rise by only 1 percent by 2010, if supplies are constrained by lack of availability. Consumption could more than double, if constraints were removed. Many studies predict that critical shortages will affect parts of Africa and Asia, unless more effort is made to establish woodfuel plantations.

Fish and Fishery Products

Consumption of fish and fishery products (such as fish meal and fish oils) has risen by 240 percent since 1960 and more than fivefold since 1950. Intensive fishing effort has led to the collapse of many important commercial fisheries in the northern hemisphere and pressures are now mounting on southern fisheries. Overfishing, pollution, and disturbance of marine habitats have reduced the productivity of many coastal zones, where some 90 percent of the world’s fish harvest is caught. Marine harvests of fish appear to have peaked and now account for a declining share of total production. Aquaculture, or fish farming, has become increasingly important and now provides more than one-quarter of all fish destined for human consumption.

Demand for food fish is projected to increase by at least 34 per cent, and probably by nearer 50 per cent, by 2010. Analysts are virtually unanimous that this level of consumption cannot be met if current production trends continue unchanged. The world's few remaining productive fishing grounds will be fished out in their turn and total marine harvests are expected to fall from today's levels. Aquaculture production, even under the most optimistic growth projections, would not be able to fill the gap. Scarcity will cause fish prices to rise and encourage more international trade. This, in turn, will favor subsidized industrial fishing fleets which supply relatively wealthy markets, at the expense of small-scale, subsistence fishers. Nearly one billion people, most of them in developing countries, currently depend on fish for their primary source of protein. This source is likely to dwindle away within a generation. The outlook for food security and employment among low-income coastal countries could hardly be more serious.

Opportunities for Change

These three examples from the agriculture, forestry, and fisheries sectors demonstrate how current practices are undermining the biological systems which support key renewable resources, exploiting them in such a way that potentially everlasting supplies are being depleted. Other examples could have been chosen: fossil fuel use is changing the global climate, water engineering projects have profoundly altered freshwater habitats. In many cases, wasteful, inefficient or short-sighted production and consumption patterns are putting at risk whole ecosystems, disrupting their normal functioning and reducing their potential productivity, now and for the future. This is perhaps the most unsustainable aspect of human economic activity today.

This report also looks at the possibility of change through policy reform. Policy interventions can be made at the point of resource production, or at any point in the processing and distribution chain, or they can target end-use behavior by the consumer. The report reflects these differences among, and within, the sectors under discussion and suggests where policy interventions might be most effective in each case.

Policy Directions for the Next Decade

In the case of food consumption, some reduction of consumer demand for meat might be possible, particularly where per capita consumption is high enough to generate some health concerns. Greater public awareness of over-fishing and destructive fishing practices could influence which fish are consumed and how they are caught, at least among wealthy consumers. Equally, consumer concerns over tropical deforestation could further develop the market for sustainably produced hardwood products.

The wood fiber sector offers considerable scope for efficiency improvements, if regulatory and economic incentives are applied. Technological advance has already improved the efficiency of fiber utilization and enabled some substitution of non-wood materials. The proportion of wood fiber which is recovered during processing and manufacture, and the percentage of paper made from recycled fiber have risen impressively over the past 30 years and could rise further.

However, the drivers behind rising food, fish, and fiber consumption are in large part fundamental: a growing population's need for adequate nutrition and literacy (paper consumption has risen faster than any other use of wood), energy, and shelter. Woodfuels and construction timber can certainly be substituted but not, realistically, within the time frame covered in this report. Grain and fish for direct human consumption can hardly be substituted at all, especially in rural economies. The demand curves projected for the next decade are not likely to be altered much. Given this reality, the report urges a reorientation of production methods.

Agriculture: Currently, well under half the nitrogen applied to crops world-wide in fertilizer is actually utilized by growing plants. The rest becomes a pollutant, wasting farmers' money and imposing heavy costs on society in terms of clean-up requirements and lost productivity. Animal manure, rather than substituting for inorganic fertilizers, is increasingly added to them, or simply disposed of as a waste product. Economic and regulatory incentives for more timely and efficient use, research which improves understanding of fertilizer application and uptake by crops, agricultural extension and outreach programs which encourage farm management practices to reduce nitrogen run-off are all urgently needed so that food production can rise without further contamination of soils, water supplies, and coastal zones.

Forestry: In theory, the world's entire current demand for industrial wood could be met from intensively-managed plantations covering an area equivalent to less than 10 percent of today's natural forests – even after allowing for extensive environmental protection measures. In practice, a very substantial part of the forecast increase in consumption could be supplied from plantations, if legal protection of old-growth forests were strengthened, forestry management standards were tightened, thus raising costs, and financial incentives for plantation establishment, and good management, were increased. Community plantations to provide fuelwood have proved successful in a number of developing countries and represent the most realistic short-term policy option until rising wealth enables the transition from woodfuels to commercial alternatives.

Fisheries: Again in theory, the world's oceans are estimated to be capable of providing a sustainable annual fish catch 17 per cent, or even 24 per cent, higher than 1996 levels. This can be achieved only if international agreements to protect declining fish stocks are honored and if individual countries improve the management of their national fisheries. The capacity of the global fishing fleet is currently at least 30 per cent, and possibly 150 per cent, greater than is required to catch the current annual harvest. Economic packages which phase out incentives to enter, or continue in, an over-capitalized industry must be implemented more widely, along with adequate compensation for fishers who abandon the profession. Substantial technical and financial cooperation among governments representing industrial and artisanal fishing interests will be required. Equally importantly, stronger pollution control and conservation measures should be enforced to safeguard marine habitats, particularly fish spawning grounds in coastal areas.

Conclusions

It is notable that, in thinking about more rational ways of meeting demands for key natural resources in the future, it is necessary to think about the entire use cycle, from production to final consumption and disposal. It is also notable that no line can easily be drawn between the developed and developing countries. Consumption is rising in every major world region, although at different rates; ecosystem damage is occurring in many regions, although it has progressed further in some; the economic and social impacts are being felt by people everywhere, either directly in their daily livelihood or, less directly, in the form of higher prices and reduced quality of life.

The scenarios for 2010 presented in the report are daunting. At the same time, they are not inevitable. The purpose of this report is to suggest that rising consumption needs can be met, but that they should be met in more imaginative ways. The possible solutions set out in the following pages utilize, for the most part, familiar policy concepts and currently available knowledge and technologies. Imagination is required only to summon the will to put them into effect. Attempting to meet the world's future consumption by simply doing "more of the same" will accelerate ecosystem degradation and will undermine the very productivity we are striving to increase.

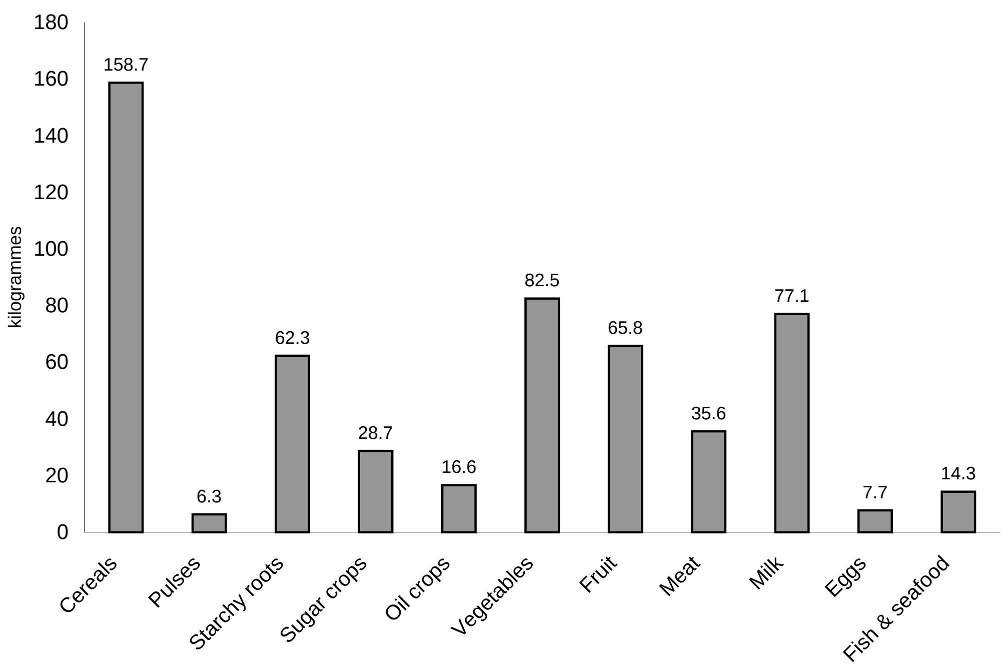
I. Food Consumption and Disruption of the Nitrogen Cycle

1. Patterns of World Food Consumption and Production

After water, food is our most vital item of consumption. About three-quarters of the human food supply comes from agriculture (the balance being supplied by fishing, hunting and gathering). Cropland and permanent pasture cover some 37 percent of the world's land area and a much higher proportion of the habitable land area.[1] Food production is by far the dominant form of land use. The human diet varies widely in different parts of the world, but Figure 1 illustrates the composition of the average food intake in 1996. Some items, such as alcoholic beverages derived from cereals and fruits, are excluded.

Cereals remain the mainstay of the human food supply, but significant changes have taken place over the past four decades. Per capita consumption of cereals and meat rose 17 percent and 36 percent respectively, while per capita consumption of fish and seafood rose 57 percent. Consumption of leguminous plants such as rice and soybeans, valued for their high protein content, rose in absolute and per capita terms. Vegetables, starchy roots (such as potatoes) and pulses all declined in

Figure 1. World Food Consumption, 1996 (kg/capita/year)



Source: FAOSTAT
Notes: Sugar crops include sweeteners; oil crops include vegetable oils

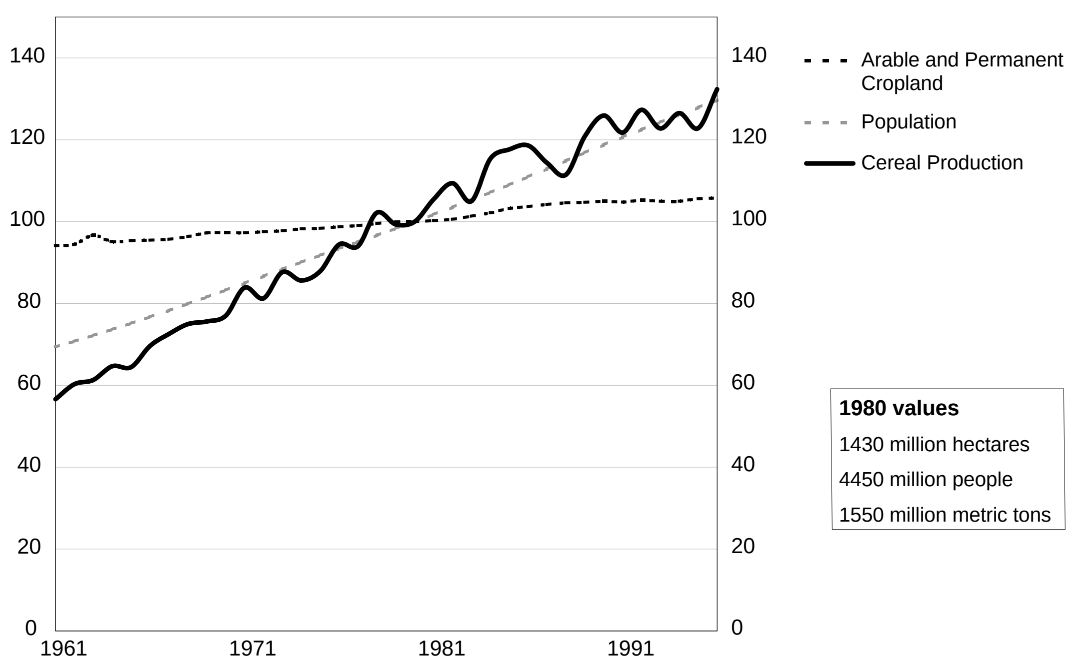
importance on a per capita basis, though total consumption increased. Also significant has been the increase in consumption of what might be termed "lifestyle" products such as coffee, tea and alcoholic beverages. Coffee production, for example, has risen by 37 percent since 1961 and the harvested area now accounts for about one percent of total arable land.[2] Rising incomes, together with the development of sophisticated food processing and distribution systems and a liberalized world trade regime, have enabled consumers in the industrialized countries, and many affluent centers in the developing world, to enjoy unprecedented choice in the foods they eat. As a result, many countries have re-oriented part of their agriculture sector towards export products including "exotic" food items, and feedstuffs for livestock.

Population Growth and Food Production

Between 1960 and 1996, the world's population rose from 3 billion to 5.8 billion, an unprecedented rate of increase which posed a major challenge to food producers. Historically, as the human population has grown, the area of land used to produce food has simply been expanded. By 1960, however, most of the world's best soils were already in use and new land could be brought into cultivation only at a relatively slow rate. The area of cropland available to feed each person therefore fell dramatically, from about 0.43 hectares per capita in 1961 to about 0.26 hectares per capita in 1996. Despite this handicap, food production kept pace with population growth, more than doubling between 1961 and 1996.[3] The relative increases in world population, cultivated land area, and cereal production are shown in Figure 2. Humans eat many things other than cereal, but cereals account for about half of our total calorie intake, and are usually accepted as a good proxy for food production.[4]

Both developed and developing countries raised their cereal production after 1961, but growth rates were highest in the developing countries, where cereal production rose at an annual compound rate of 3.3 percent. This contributed greatly to improved nutrition; the average calorie supply to people in less developed regions rose by over 30 percent and the proportion of hungry or under-

Figure 2. Population, Cultivated Land, and Cereal Production, 1961-1996, Indexed to 1980



Source: UN Population Division and FAO nourished people in the world fell from 35 to 21 percent. Nevertheless, because of population increase, the absolute number of undernourished people fell only slightly, and now stands at about 840 million people.[5]

The world's revolution in agricultural production was made possible in large part by irrigation and the increased use of inorganic nitrogen fertilizers.[6] (The precise contribution of fertilizers to raising yields is still unclear, but is estimated at between 35 and 50 per cent.[7]) Fertilizers contribute to increased crop production in several ways: by replenishing nutrients used by growing plants, by increasing the amount of biomass in the soil, which improves moisture retention and nutrient use efficiency, and by enabling the adoption of more productive varieties of cereal. New, high-yielding varieties of wheat and rice have been bred specially to utilize more nitrogen and convert it into more grain. Increased yields have accounted for more than 80 percent of the growth in cereal production in the developing countries, while expansion of cultivated land has accounted for just 20 per cent.[8]

2. Agriculture, Environmental Impacts, and the Global Nitrogen Cycle

The intensification of agriculture has reduced the need to expand cultivation into marginal and ecologically fragile areas but there have been other, considerable, environmental costs. Poor soil management, over-grazing, and inappropriate use of pesticides and herbicides are associated in many parts of the world with soil erosion, desertification, fertility declines, and contamination of soils and water supplies. This paper, however, focuses on the environmental impacts of increased nitrogen levels in soils, water, and the atmosphere, for two key reasons.

Firstly, modern agriculture is the leading source of anthropogenic (human origin) nitrogen entering the environment. Inorganic nitrogen fertilizers are an essential input to maintaining high crop yields. They cannot readily be substituted and fertilization must probably *increase* in the future if we are to feed a still-growing world population. In addition, meat consumption is rising world-wide and the numbers of livestock, and associated volumes of nitrogen-rich manure, will rise too.

Secondly, in the past decade, we have greatly advanced our understanding of the global nitrogen cycle, and it has become clear that human addition of nitrogen to the environment is disrupting entire ecosystems across a wide geographical range. What have usually been considered as distinct problems – for example, eutrophication of surface waters, or acidification of lakes and forest soils – should be seen as symptoms of a more universal assault on the global environment.

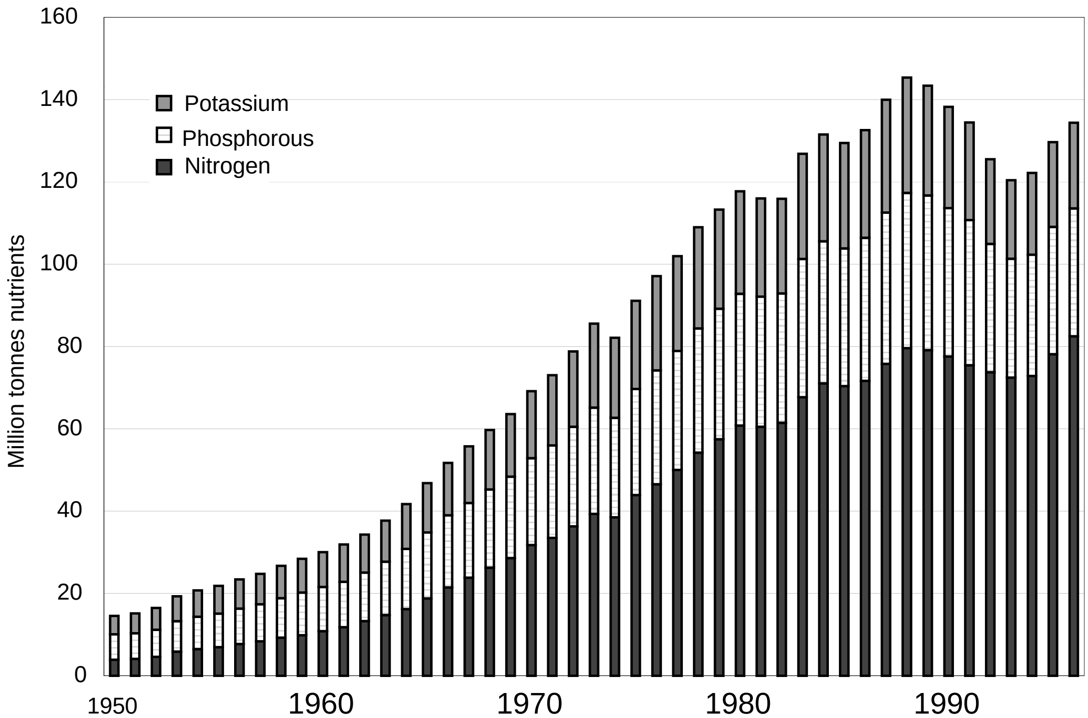
The global scale of nitrogen pollution is, at present, under-appreciated. Policy responses to the challenge of meeting future food needs without further unbalancing biological systems remain under-developed. There is a need for more long-term and coordinated thinking, and the closest analogy lies with the emergence of international efforts to manage the world's energy system and excessive emissions of carbon. Disruption of the global nitrogen cycle now appears to warrant the same degree of attention.

Trends in Nitrogen Fertilizer Use

Global consumption of fertilizer has risen spectacularly, increasing tenfold between 1950 and 1989 *(Figure 3).* The steep drop in consumption after that date was due principally to collapsing demand in the former Soviet Union, and Central and Eastern Europe, but there was also a substantial fall in Western Europe, caused by grain surpluses, low crop prices, and saturated markets. The increasing share of nitrogen in the global fertilizer mix becomes clear after about 1960, and the bias is most strongly pronounced in the developing countries, where nitrogen now accounts for 66 percent of fertilizers consumed, compared with 55 percent in the developed countries.[9]

The bias towards nitrogen fertilizers has been encouraged in part by increased production in areas where cheap natural gas is available (including major consuming regions such as South Asia and

Figure 3. Global Fertilizer Consumption, 1950/51-1996/97



Source: International Fertilizer Industry Association

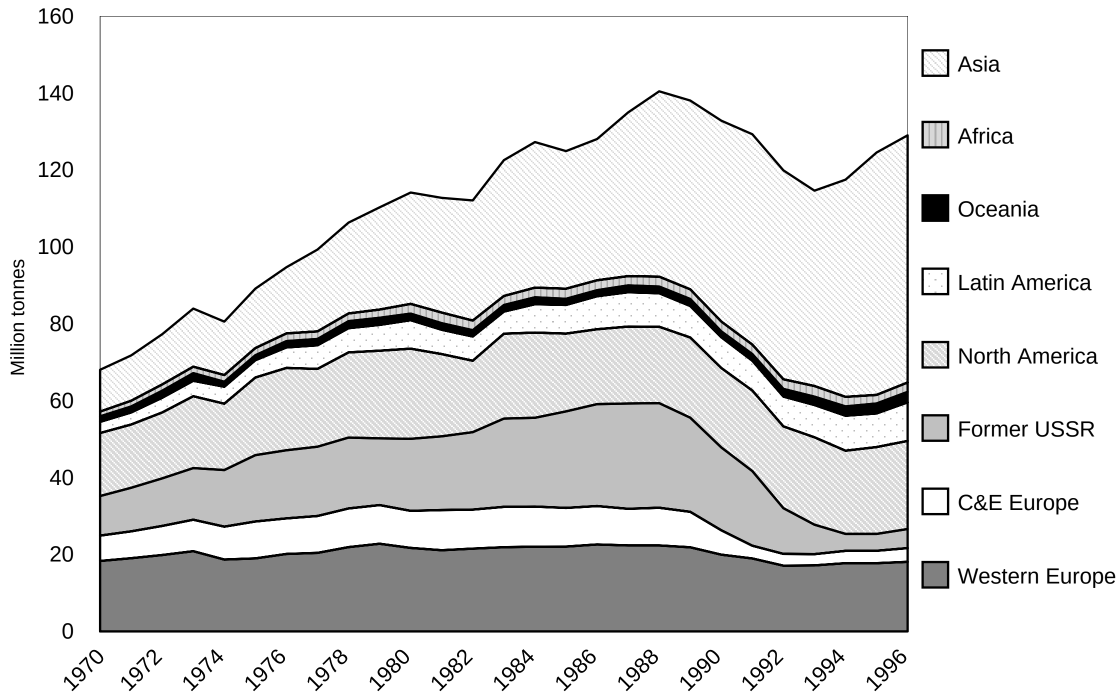
China) and in part by the perception that nitrogen delivers the most spectacular yield gains, at least initially.

The pattern of global fertilizer consumption has changed markedly over the past 30 to 40 years *(Figure 4)*. In 1960, the developing countries accounted for just 12 percent of all consumption; today the figure is nearly 60 percent. Fertilizer use in the developing world has been fuelled by rapid population growth and growing demand for food grains. This is especially true of Asia, where the scope for land expansion is limited. By contrast, the industrialized countries (with the exception of the former Soviet Union) increased their fertilizer consumption only marginally after 1980; population growth was low, most people were adequately fed, and world agricultural exports had stagnated due to economic problems in many importing countries. Asia is now the dominant player, accounting for 50 percent of world fertilizer consumption, and 86 percent of developing country consumption.

Fertilizer application rates vary widely among the major world regions and, perhaps surprisingly, are not strongly correlated either with national income or with need (as indicated by low soil fertility or food insecurity). Fertilizer use varies from a low of 10 kg/hectare in sub-Saharan Africa to a high of about 216 kg/hectare in East Asia (by nutrient weight). The world average application rate is about 83 kg/hectare; the developing countries as a whole just exceed this figure, and the developed countries as a whole fall just short of it.[10]

Fertilizer consumption has been strongly promoted in the industrialized countries and in Asia by investment in production capacity and a policy and fiscal framework encouraging liberal fertilizer use. Latin America has experienced wide fluctuations and modest overall growth, due to an unstable policy environment and economic crises throughout the 1980s. Production and consumption in sub-Saharan Africa remain very low, despite the urgent need to raise yields. Growth has been hindered by

Figure 4. Fertilizer Nutrient Consumption (NPK), 1970-1996



Source: International Fertilizer Industry Association

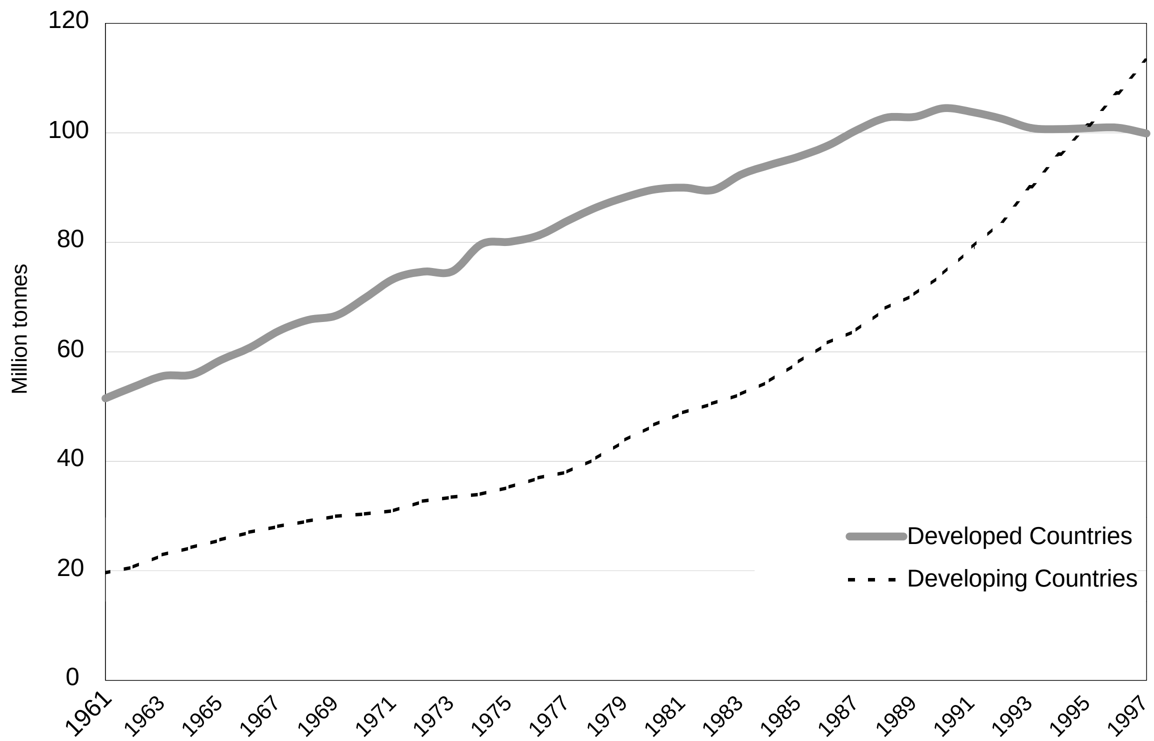
foreign exchange shortages, low crop prices, policy instability, and inadequate physical and institutional infrastructure. More than half the countries in the region are wholly dependent on fertilizer aid to meet their requirements.[11]

Livestock Farming

A second trend of key importance in the story of food consumption and the nitrogen cycle is the growing popularity of meat and dairy products in the human diet. With rising income, consumers choose to eat more meat; still greater affluence and concerns for a healthy lifestyle seem to encourage a shift from red meat to poultry. Meat production world-wide has tripled since 1961, reaching 213 million tonnes in 1997 *(Figure 5)*, with output gains concentrated in the United States, the European Union, and China. Individual consumption remains highest in the industrialized world. Average per capita meat consumption in the United States was 118 kg/year in 1996, while the average for the developed world as a whole was 76 kg/person/year. Average per capita consumption in the developing countries was 24 kg/year but the picture is rapidly changing in many parts of South America and Asia. For example, the Chinese each consumed 41 kg of meat in 1996, up from 20 kg/year just a decade earlier. Total meat consumption in the developing countries just exceeds that in the developed world and, in internationally traded meat and meat products, there is a small net inflow to the developing countries.[12]

To meet growing demand, the world's livestock population has boomed. Cattle numbers rose by 40 percent between 1961 and 1997, pigs by 130 percent and chickens by 246 percent. The world today is home to 13.5 billion chickens.[13] In industrialized countries, animals traditionally reared on rangelands or in farmyards are now increasingly concentrated in intensive feedlots, where they are fed on cereals and commercial preparations of grain, animal protein, and fish meal. This trend, in turn, is leading to the concentration of huge

Figure 5. World Meat Production, 1961-97



Source: FAOSTAT

volumes of manure, which cannot economically be redistributed back to areas where the cereals were originally grown. The nitrogen component of manure varies according to the animal and its diet but a crude global estimate is that approximately 32 million tonnes of nitrogen (derived from fodder crops and forage) are deposited into the environment via manure each year.[14]

Where animals are still free-ranging, manure may act as a fertilizer. Where animals are concentrated in feedlots, manure is increasingly viewed as a waste disposal problem. Data for the United States indicate that, of nearly 160 million tonnes of manure produced annually, some 60 percent is excreted directly onto pasture and cropland, while 40 percent is collected from animals in confinement and must somehow be disposed of.[15] Manure volumes have reached a critical point in parts of Northwestern Europe, where nitrogen deposition far exceeds the absorptive capacity of crops *(Table 1)*. Concentration of livestock in feedlots is not yet the norm in developing countries, though industrial-scale chicken farms are becoming more common, for example, in some South American countries.

3. "Fertilizing the Earth"

Great uncertainties are involved in measuring the global distribution and transport of nitrogen, how much is being stored, and where, because reactive nitrogen in its many forms is highly mobile, moving easily between terrestrial, freshwater and marine ecosystems, and the atmosphere *(Figure 6)*. But enough is known to be certain that human domination of the nitrogen cycle is responsible for serious pollution and disruption of biological processes which underpin – among other important functions – food production. Human activity is now fixing nitrogen (creating reactive nitrogen from non-reactive N_2 in the atmosphere) at least as fast as natural terrestrial processes *(Box 1)*. To some extent (which varies according to ecosystem characteristics) additional nitrogen can be utilized by plants and their productivity will be enhanced.

Table 1. Nitrogen (N) input from animal manure and fertilizer in selected countries

Country	Manure	N Supply Fertilizer	Total	N Uptake by crops	Residual N[2a]	Per hectare
		(1000 tonnes)				(kilogrammes)
Belgium[b]	380	199	580	211	369	240
Denmark	434	381	816	287	529	187
Netherlands	752	504	1,255	285	970	480

Source: Bumb and Baanante, see note 8
Notes: Totals may not add due to rounding.
[a]Because N is lost to the atmosphere, only a part of the residual N stays in the soil for possible nitrate leaching
[b]Includes Luxembourg

Beyond that point, excess nitrogen will accumulate in the environment, changing the chemistry of soils and often reducing their fertility, displacing grassland species, suffocating aquatic plants and fish, and touching off toxic algal blooms.

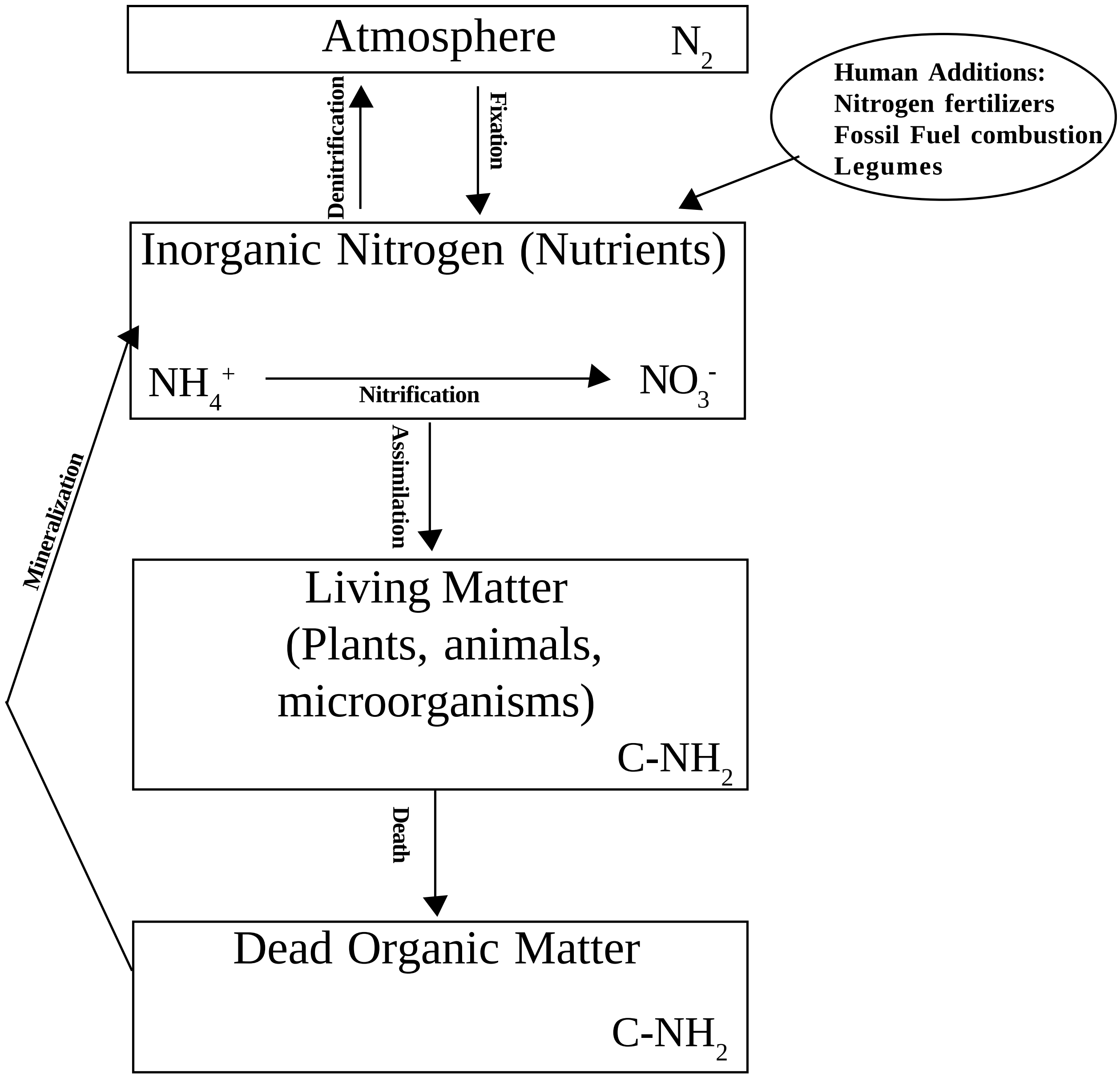
Forests, Soils and Grasslands

Increased deposition of nitrogen into the environment has two principal effects. Oxidized forms of nitrogen (NO_x and nitrates) acidify natural ecosystems and generally degrade them. For example, scientists now report that acid rain leaches forest soils of up to 50 percent of their calcium, potassium, and magnesium – crucial minerals which buffer or neutralize acids and are essential for plant growth. When soil chemistry is changed dramatically in this way, it is likely to take many decades for all the linked ecosystems to recover.[16] A related potential impact is toxification. Leached soils acidify and lose their ability to bind and sequester heavy metals, these metals are thus released for uptake by plants. Much of the "forest death" which struck Germany and other Central European countries in the 1970s may have been caused by aluminum poisoning. Toxics accumulated over decades may continue to be mobilized and leached into ground and surface waters, or taken up by plants and into the food chain.[17] The same applies in acidified lakes, where aluminum and other metallic ions which were formerly bound to soil particles can be mobilized.

In contrast, reduced forms of nitrogen (ammonium ions) fertilize whole ecosystems, increasing their net primary productivity but also disrupting them. Some forests in Europe are reported to be growing much faster in the second part of this century than they did in the first half.[18] The disturbing explanation appears to be that trees are absorbing nitrogen directly from the air into their leaves and bark. It is estimated that, in northern Europe, such above-ground uptake now accounts for 60 percent of the nitrogen found in broad-leaved trees. While the extra nitrogen increases growth, trees cannot regulate their intake as they can with nitrogen taken up via their roots; acidification of the soil also tends to leave them weak and vulnerable to insects and mildew.[19] Another consequence of over-fertilization is loss of species diversity, as nitrogen-responsive plants crowd out others with lower tolerance. In the Netherlands, intensive livestock production and high human population density have generated the highest nitrogen deposition rates in the world; the conversion of species-rich heathlands and pastures to species-poor grasslands and forests is well documented.[20] Similar trends have been reproduced on experimental grasslands in both the United Kingdom and the United States.

However, there is a limit to the amount of nitrogen which plants can absorb. At some point, other nutrients become the limiting factor, no more nitrogen can be taken up, and additional deposits are simply dispersed into surface or ground water and the atmosphere. This state is known as nitrogen saturation; it has already been reached across large areas of northern Europe, and to a lesser extent in

Figure 6. Simplified Version of the Terrestrial Nitrogen Cycle



Source: Adapted from Ann P. Kinzig and Robert H. Socolow, "Human Impacts on the Nitrogen Cycle," *Physics Today*, November 1994, figure 4, pp. 24-31. Note based on Socolow, Robert, H., "Nitrogen Management and the Future of Food: Lessons from the Management of Energy and Carbon," *Proceedings of the National Academy of Sciences*, forthcoming, 1999.

Note: Nitrogen is found in four forms. It is bound to itself in a two-atom molecule, *dinitrogen*, or N_2, which is abundant in the atmosphere but almost unavailable to life until broken down by specialized bacteria. Nitrogen is bound to carbon, as *organic nitrogen*, in a wide variety of organic molecules, critical to life and present long after death, including proteins and their component amino acids. And it is bound neither to itself nor to carbon, in *nitrogen nutrients* and *nitrogen gases*. The two principal nitrogen nutrients are ammonium (NH_4^+)and nitrate (NO_3^-) ions in water. The nitrogen gases include ammonia (NH_3) and various oxides of nitrogen, including nitric oxide (NO), nitrogen dioxide (NO_2) and nitrous oxide (N_2O). A specialized vocabulary describes the transformations from one form to another. *Fixation* is the process of making atmospheric N into nitrogen nutrients, and *denitrification* is the process of rebuilding N from nitrogen nutrients. *Assimilation* is the process by which nutrients become organic nitrogen in living matter, and *mineralization* is the process by which organic nitrogen is decomposed, after death, back into nitrogen nutrients. Most of these processes occur in the soil but both air routes and water routes connect nutrient systems across large distances.

Box 1: How Humans Have Doubled the Rate of Nitrogen Fixation

Although nitrogen is the most abundant element in the atmosphere, it cannot be used by plants – and the animals that depend on them – until it is chemically transformed, or fixed, into ammonium or nitrate compounds that plants can metabolize. In natural systems, this function is performed by nitrogen-fixing bacteria in the soil and, to a much lesser extent, by lightning. Such biological nitrogen fixation is believed to provide somewhere between 90 and 140 million tonnes of nitrogen to terrestrial systems each year. Humans have wrought major changes over the last 50 years. The advent of intensive agriculture, increasing fossil fuel combustion, and the cultivation of leguminous crops and other nitrogen-fixing plants have led to huge additional quantities of nitrogen deposited into terrestrial and aquatic ecosystems and the atmosphere. It is estimated that human activities have more than doubled the amount of nitrogen available for uptake by plants. Land clearance, wetland drainage and burning of biomass also liberate nitrogen from long-term biological storage pools such as soil organic matter and tree trunks; these activities could emit up to another 70 million tonnes of nitrogen each year.

Anthropogenic Sources of Nitrogen	**Annual Release of Fixed Nitrogen (million tonnes)**
Fertilizer	80
Cultivation of legumes, rice etc.	40
Fossil fuel combustion	20
Total from human sources	**140**
Natural Sources of Nitrogen	
Soil bacteria, blue-green algae, lightning etc.	90-140

Source: Based on Peter M. Vitousek *et al.* "Human Alteration of the Global Nitrogen Cycle: Causes and Consequences," *Issues in Ecology,* No. 1 (1997), pp. 4-6.

northeastern USA. It is now known that a substantial portion of atmospheric nitrogen deposited in the former region moves directly from air, to land, to water, without ever being taken up by any living organisms or playing any role in biological systems.[21]

Freshwater Ecosystems

Fertilizer is the dominant source of nitrogen washed into the world's water courses, though domestic sewage is another important source (the human diet is rich in protein). Deposition from the atmosphere is another major source in some parts of the world *(Box 2).* An ironic aspect of intensive fertilization is that, on average, only half the additional nitrogen is taken up by plants, due to saturation, or local weather conditions, or because nitrogen is applied at an inappropriate point in the plants' growing cycle. As a result, nitrogen runs off the soil. It is either carried out in eroded soil, or leached out in the form of dissolved nitrate, carrying with it positively-charged minerals such as potassium and calcium. Much of the nitrogen is later denitrified by bacteria, that is, "unfixed" back into the atmosphere, while other nutrients are washed away. The net result is that nutrients can be "mined" from the soil, leaving it more impoverished than before.[22] Nitrogen run-off has doubled since pre-industrial times, which represents both a loss of nutrients and an economic loss to farmers.

Nitrogen concentrations in freshwater, so far, have been studied most intensively in industrialized countries. For example, a 1994 national survey in the United States revealed that nearly 40 percent of the country's lakes and rivers were too polluted for basic uses such as fishing or swimming; the leading source of pollution in both categories was agricultural run-off.[23] However, nitrogen is fast accumulating in developing countries too. In China, nitrate concentrations in the Yangtze River (Chiang Jiang) increased fourfold between 1963 and 1980, while concentrations of ammonium approximately doubled.[24] Much of this increase is attributable to the use of inorganic nitrogen fertilizers, which rose by a factor of about 12 over the period.[25]

Nitrogen run-off contributes to the phenomenon of eutrophication of freshwater lakes and rivers – essentially fertilization in the wrong place. Elevated loads of nutrients, chiefly nitrogen and phosphorous, stimulate abundant growth of algae and other aquatic plants. When the extra plant matter dies, it sinks to lower depths and decays, depleting the water's supply of dissolved oxygen, and killing other aquatic organisms such as deep-dwelling fish. The result is scum-covered, malodorous water, unfit for drinking or recreational activities. In many freshwater systems, phosphorous, not nitrogen, is the limiting growth factor. However, phosphorous is also supplied by agricultural fertilizers, as well as by industrial and household effluents. Eutrophication is increasingly well-documented world-wide, and is of particular concern where freshwater fish are an important source of local food. According to the FAO, some 18 percent of the global annual fish catch comes from freshwater sources (*see Chapter 3: Fish Consumption and Aquatic Ecosystems*).

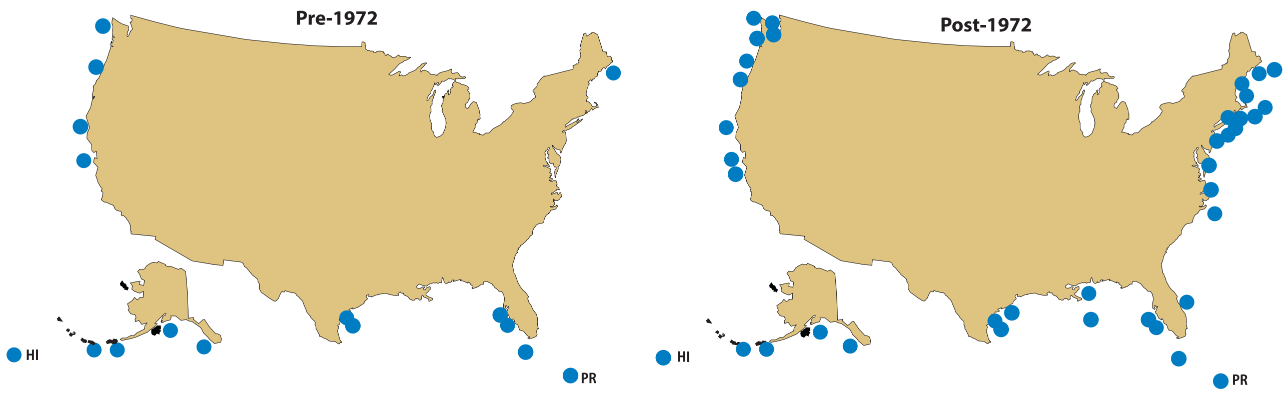
Nitrate contamination of drinking water supplies is widely recognized as a serious health threat. If exposed to high nitrate levels, young infants may develop the potentially fatal "blue-baby" syndrome, where their red blood cells cannot function properly, and fail to deliver sufficient oxygen. Adults risk contracting a variety of cancers, although the risks remain unclear. Levels of nitrates in drinking water have been closely monitored for many years in the industrialized countries, and the data confirm a historic rise in nitrogen levels in surface waters. In major rivers of the northeastern United States, nitrate concentrations have risen three- to tenfold since the beginning of the century. Nitrate contamination is also the USA's most widespread groundwater pollution problem; in a national survey, 22 percent of wells in US agricultural areas contained nitrate levels in excess of the federal limit.[26] Some communities in the worst affected States now provide free bottled drinking water to at-risk households (those with infants under six months and pregnant women) when local nitrate levels rise too high, and many are beginning to install costly purification systems.[27] Nitrates are a prime contaminant in Europe, where the European Commission has enacted a Directive establishing maximum permitted levels in drinking water and requiring costly purification or mitigation measures. In 1,000 lakes in Norway, nitrate levels doubled in less than a decade. Nitrate pollution is also widespread in Australia, and in parts of Africa, Asia, and the Middle East. No global assessment has been undertaken of nitrate pollution, but individual

Box 2: Nitrogen Deposition From the Atmosphere

World-wide, fossil fuel combustion emits more than 20 million tonnes of nitrogen (as NO_x) to the atmosphere every year. Less well known is the fact that agriculture contributes more than double this amount – some 47 million tonnes – to atmospheric emissions of nitrogen, through direct volatilization of ammonia from fertilized fields, biomass burning and animal wastes.[1] Nitrogen in various chemical states contributes to a number of environmental impacts in the atmosphere, including global warming, destruction of the stratospheric ozone layer and formation of ground level ozone (smog). Most reactive nitrogen in the atmosphere is short-lived, and is soon deposited back onto the oceans or, more seriously, into aquatic and terrestrial ecosystems. Increased nitrogen levels can both eutrophy *(see text)* and acidify. Acidification is a well documented phenomenon in Scandinavia, in Western Europe – where high fossil fuel combustion levels combine with intensive agriculture – and eastern North America. Acidification of soils, lakes and streams has caused extensive defoliation and dieback among trees, and is responsible for major fish kills. For example, studies in Norway reveal that areas with damage to fish stocks grew fivefold between 1960 and 1990; of 13,000 investigated fish stocks, 19 percent were completely lost.[2] While acid sulphur emissions in industrialized countries have been dramatically reduced over the past 30 years, fossil-fuel related NO_x emissions have remained relatively constant and agriculture-related emissions have risen. Ecosystems are not recovering as quickly as had been expected.[3] Acidification is now emerging as a major problem in the developing world, especially in parts of Asia and the Pacific region, where fossil fuel combustion and fertilizer applications are rising faster than anywhere in the world. Deposition is also increasing over Africa and South America, due to biomass burning.[4] The effects of rising nitrogen deposition are already being felt in the agriculture sector. For example, researchers in Pakistan found that crops growing in sites exposed to high ozone levels yielded between 32 and 62 percent less seed than control crops treated with a protective chemical.[5]

[1] Galloway, J.N. *et al.*, "Nitrogen Fixation: Anthropogenic Enhancement-Environmental Response," *Global Biogeochemical Cycles*, Vol. 9, No. 2.
[2] Norwegian Ministry of Environment, *State of the Environment Report 1995*. (MoE, Oslo, 1995).
[3] Likens, G.E., C.T. Driscoll and D.C. Buso, "Long-Term Effects of Acid Rain: Response and Recovery of a Forest Ecosystem," *Science*, Vol. 272, 12 April 1996, pp. 244-245.
[4] Galloway, James N., "Anthropogenic Mobilization of Sulphur and Nitrogen: Immediate and Delayed Consequences," *Annual Review of Energy and the Environment*, 1996. 21: pp. 273-274.
[5] "Rampant Urban Pollution Blights Asia's Crops," *New Scientist*, 14 June, 1997.

Figure 7. Major or Recurring Harmful Algal Blooms, Before and After 1972



Source: Donald Anderson, " Expansion of HAB Problems in the U.S.," National Office for Marine Biotoxins and Harmful Algal Blooms, Woods Hole Oceanographic Institution.

country reports indicate that nitrates are now one of the most common chemical contaminants found in drinking water.

Marine Ecosystems

Eutrophication of estuarine and coastal zones has emerged as an immense and growing problem in recent years. Over 40 million tonnes of nitrogen, in dissolved and particulate form, are transported by the world's rivers into estuaries and coastal waters each year – double the pre-industrial rate.[28] Unlike freshwater systems, where phosphorous is usually the limiting growth factor, nitrogen is usually the limiting growth factor in saline waters. Additional nitrogen can therefore promote huge algal blooms and significant oxygen depletion (hypoxia) in lower-depth waters. Some of the best-documented examples of coastal eutrophication come from the United States. According to a recent survey, 52 percent of the nation's estuaries suffer from some degree of oxygen depletion.[29] The worst affected area is the Gulf of Mexico, where 85 percent of estuaries are affected. In the most dramatic example, a so-called "dead zone" of 16,000-18,000 km^2 has developed where the Mississippi River discharges into the Gulf. Fish and shrimp have disappeared from the area, threatening the local fishing industry, while less mobile life-forms, such as starfish and clams, have died. Scientists have linked the growth of the dead zone to nitrogen fertilizers and livestock manure from farms hundreds of miles upstream. More than half the 11 million tonnes of nitrogen added to the Mississippi Basin annually comes from fertilizer, and only about 50 percent is taken up by plants. Nearly 2 million tonnes of nitrogen flow down the Mississippi each year, more than triple the amount 40 years ago[30] and the dead zone has ebbed and flowed consistently with peak river discharges and the associated nutrient flux.

The Mississippi dead zone is one of more than 50 similar oxygen-starved coastal regions which now exist world-wide, a threefold increase over the past 30 years.[31] Figure 7 illustrates the increase for the United States. Since coastal zones are among the world's richest fishing grounds, unchecked agricultural run-off poses a serious threat to commercially important fish stocks. Nitrogen pollution is blamed in part for the collapse of the Baltic Sea cod fisheries in the early 1990s,[32] as well as major fish kills (and associated human illness) following outbreaks of *Pfiesteria*, such as that affecting the Chesapeake Bay, in the United States, in the summer of 1997. Toxic algal blooms, known as "red tides" or "brown tides" are growing world-wide in frequency and severity, damaging offshore fisheries and causing losses to aquaculture enterprises.[33]

Conclusions

It is fair to say that, for the past 30-40 years, humans have been "fertilizing the earth" in a global-scale and largely uncontrolled experiment. Agriculture, through the use of nitrogen fertilizers, cultivation of leguminous crops, and deposition of animal wastes, is the leading contributor to a doubling of natural nitrogen levels in the environment. Local and regional impacts, particularly acidification and eutrophication, have been intensively studied. However, the truly global consequences of the environmental imbalances that are being set in motion currently receive scant attention; far less than the risks attending climate change, for example. Yet, if current trends continue, all these nitrogen-related problems are likely to worsen, with consequences as severe and potentially more immediate than those associated with global warming.

4. Looking Ahead: Growing the Food We Need

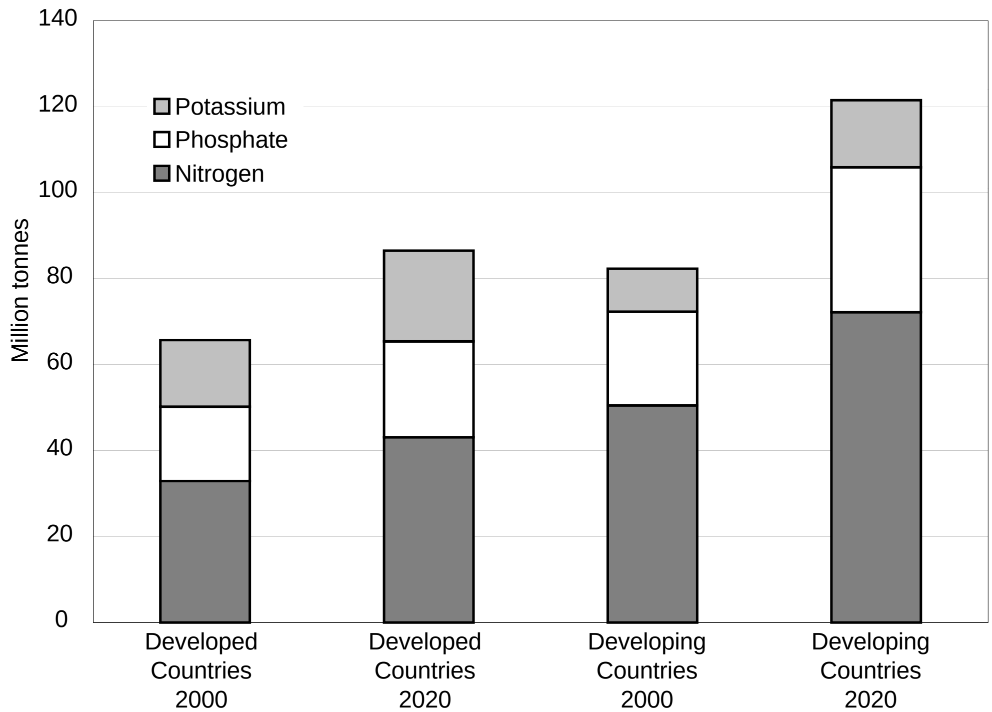
The world's population is projected to grow to about 7.3 billion by 2020, with over 90 percent of the increase occurring in developing countries.[34] More people will eat more food, and more protein since, as already described, people almost invariably choose diets which are richer in meat and dairy products as their incomes rise. This will require more cereal to be grown per capita: nearly 40 percent of total grain production is already fed to livestock[35] and the grain-to-protein conversion efficiency is low, lying between 2:1 (chickens) and 7:1 (feedlot cattle).[36] The International Food Policy Research Institute has recently projected that global demand for cereals will increase by 41 percent between 1993 and 2020, and that meat demand will rise 63 percent to 306 million tonnes.[37]

Most projections of agricultural output assume that demand for food will be met, at least at the global level, though regional and local shortages are likely to persist. A scenario developed by the Stockholm Environment Institute forecasts cereal production of just over 3 billion tonnes in 2025,[38] while the FAO has produced a shorter-term production forecast of 2.3 billion tonnes in 2010.[39] Given current production of just under 2 billion tonnes, these and other estimates indicate that production increases of up to 50 percent will be required over the next 25-30 years. How will this be achieved?

The scope for expansion of the agricultural land base is limited. Potentially fertile land still exists to be opened up for cultivation, but gains will be partially offset by the loss of productive land to soil erosion, degradation, and urban development. The FAO suggests that an additional 90 million hectares of land might be brought into production by 2010, mostly in South America and Africa, which amounts to a modest increase of barely 6 percent on today's cropland area. This alone will not be enough to offset the present trends under which both available cultivated land area and grain harvest on a per capita basis are declining sharply. In 1984, the grain harvest per person peaked at 346 kg; by 1995 it had fallen to 295 kg, the lowest level since 1967.[40] Given circumstances of a rising population, a growing appetite for meat and dairy foods, a static or declining cropland base and declining per capita cereal production, the imperative of increasing yields becomes clear.

Agricultural science has, to date, relied on three means of achieving higher yields: genetic improvements of crops, advances in agronomic practices, and synergies between the two. As an example of genetic improvement, plants have been bred to raise the share of photosynthetic product going to the seed, rather than to leaves, stems or roots. Today's wheat, rice, and corn have a "harvest index" of about 50 per cent, compared with 20 percent before improvement. Further gains appear limited, since scientists believe the theoretical maximum for photosynthetic redistribution to the seed is about 60 per cent.[41] Agronomic practices have focused on increased levels of external inputs, chiefly fertilizers, but also pest and weed control agents, and water, delivered by irrigation. Synergies have occurred, for example, new dwarf varieties of cereal, with short stalks, are able to utilize two or three times the "normal" amount of nitrogen and develop rich, heavy heads of grain without collapsing. This synergy explains the doubling and tripling of yields achieved during the first phases of the Green Revolution.

Figure 8. Fertilizer Demand Projections (NPK), 2000 and 2020



Source: Bumb and Baanante, see note 8

However, scientists have not found it possible to maintain this momentum, and the rate of yield growth in all major cereals has either plateaued or declined over the past decade. It is often argued that increased fertilizer application in the developing world will overcome yield stagnation and raise harvests closer to the theoretical maximum. More fertilizer will certainly be part of the answer, but inherent environmental constraints, especially water scarcity, as well as infrastructural and institutional shortcomings, are likely to prove a greater obstacle to the world-wide advent of "industrial" farming, with its dependence on external inputs.

5. How Much More Fertilizer Will the World Consume?

Analysts at the International Fertilizer Development Center (IFDC) have made detailed projections of future fertilizer demand, and come to a problematic conclusion. Their "real world" projection takes into account various economic and non-economic variables, such as foreign exchange availability, crop and fertilizer prices, the development of irrigation and other infrastructure, and the impact of policy reforms. On this basis, global consumption of fertilizer is projected to rise from 134 million tonnes today to 208 million tonnes in 2020 *(Figure 8*). The strongest growth is expected in Africa (2.4 percent annually), Latin America (2.2 percent annually), Asia (1.8 percent annually) and Central and Eastern Europe (2.2 percent annually). These rates of increase are far below those experienced between 1960 and 1990, reflecting a higher baseline, and changed economic and policy environments. Nitrogen consumption would rise from 82 million tonnes to 115 million tonnes, an increase of about 40 per cent. This projection is comparable with another recent estimate of 134 million tonnes, which assumes higher growth rates in Africa and Latin America.[42]

This substantial increase might not be enough, however. The IFDC's second projection is based on food production needs, that is, the amount of fertilizer needed to grow 2.5 billion tonnes of cereal or more. This leads to global fertilizer consumption in 2020 of 263 million tonnes, and nitrogen consumption of some 160 million tonnes (assuming today's NPK ratio does not change). The fertilizer "shortfall" in developing countries might be as much as 64 million tonnes. A third projection is based on "sustainable farming" needs, or the amount of fertilizer needed to maintain nutrient reserves in the soil at their initial levels. The projection is based on assumptions about nutrient uptake efficiency for various crops, expected improvements by the year 2020 in different world regions and the proportion of crop residues which are returned to the soil. Under this scenario, producing enough grain to feed the world, without mining the soil of its nutrients, would require application of 366 million tonnes of fertilizer; the proportion of nitrogen would probably decrease but would still be substantial. The fertilizer shortfall in developing countries is estimated at 130 million tonnes.[43]

6. Possible Solutions

Globally, fertilizer consumption must grow, but it must grow in a far more managed and thoughtful way than it has over the past 40 years. The objective of agriculture in coming decades must be to optimize soil productivity while preserving its capacity to function as a healthy, complex ecosystem. Fertilizer consumption will remain essential to food security in coming decades, but disruption of terrestrial and marine ecosystems could be greatly reduced if greater efforts are made to control the flows of nitrogen through the environment. On the production side, inorganic fertilizers should be priced and regulated more in accordance with their environmental impacts (removal of perverse incentives) and used more efficiently (innovative and integrated farming practices, new crops, nitrogen recycling). On the consumption side, the choices we make about diet and the sources of food we buy could, over time, help to reorient the world's food industry to a less nitrogen-intensive base.

Economic and Regulatory Incentives

Fertilizer use by farmers is too often typified by wasteful and careless practices, which are encouraged by artificially low product prices. Fertilizers receive heavy subsidies from governments worldwide, whether at the point of import, or manufacture, or supply to farmers. They are justified by governments on the grounds of protecting domestic producers, shielding manufacturing interests from competition, or ensuring national food security. Subsidies have often worked "too well." Many areas in the industrialized countries, and some parts of Asia, have already reached the point of diminishing returns on fertilizer application, where plants are unable to take up the additional nutrients they are given and ecosystems become saturated and degraded. Over-applying fertilizer represents both an economic and an environmental waste. Recent research has shown that using reduced amounts of fertilizer at just the right time can cut costs by up to 17 percent for farmers in developing countries, as well as reducing nutrient losses to the environment by up to 50 percent.[44] At the national level, subsidies constitute a heavy burden on the economy. For example, in India, fertilizer subsidies amounted to US$1.4 billion, or 3 percent of the national budget, in 1993-94.[45] Low fertilizer prices also tend to inhibit the development of production capacity and of competitive marketing and distribution systems, which works against the interests of farmers, and to reduce research interest and investment in alternative plant nutrient systems.

With the implementation of economic reform programs in the 1980s, the number of countries subsidizing fertilizers decreased significantly, but not uniformly. As of 1996, China, India, Indonesia, and Saudi Arabia still provided subsidies, for example, while Ghana, the Philippines, Thailand, and Venezuela did not.[46] Experience with energy policy has shown clearly that pricing policies which begin to incorporate environmental damage into the cost of fossil fuels are effective in encouraging more efficient use and the adoption of alternative energy sources. The same is true of fertilizers. The adjustment of distorted input prices to market level can be painful and politically sensitive, however, and high fertilizer prices can discourage fertilizer use altogether, with damaging consequences for food security. Rational pricing policy must aim to eliminate price distortions over the long term, while continuing to generate adequate incentives for fertilizer use by small farmers. Currently, however, policy in many countries seems to be directed towards increasing fertilizer application as fast as possible. The Chinese Academy of Agricultural Sciences, for example, has estimated that the country must raise average crop yields per hectare by 60 to 80 percent within the next 30 years, and that this will require a doubling of current nitrogen application rates.[47] Rather than pursuing unfettered growth, policies in countries which already tend to over-fertilize should be aiming to optimize agricultural production through incentives for responsible nitrogen management.

Direct regulation is increasingly being used to alter farmers' behavior in order to reduce environmental damage which has already occurred. It should be no surprise that nitrogen-related policy in the industrialized countries is beginning to develop along similar lines to carbon controls, involving emission ceilings, performance requirements, and incentives/penalties levied on users. Vigorous efforts are now being made in some countries in an attempt to reverse the nitrogen saturation afflicting intensively farmed land. The nitrogen fertilizer management plan of Minnesota, in the United States, recommends that a nitrogen budget based on the residual nitrogen in the soil, crop uptake, and supply of nitrogen from all sources should be prepared to develop more sustainable fertilizer recommendations.[48] In northwestern Europe, the problem, and controlling actions, are still more advanced. The European Union Nitrates Directive of 1991 (effective from 1999) is framed to control the net supply of nitrogen (supply minus uptake) to the soil. Planning authorities must take account of emissions from all sources, when recommending fertilizer application levels. It has become clear that the biggest adjustments must, in fact, come from the livestock sector; nitrogen emissions from animal manure exceed those from fertilizer by 14 to 91 percent in Belgium, Denmark, and the Netherlands.[49] Some individual countries in the region have gone further, introducing mandatory nutrient accounting schemes under which farmers must prepare fertilization plans, based on crop, nutrient input and output levels, and admissible losses. Fertilization above the agreed level is subject to heavy fines (Germany) or nutrient taxes (the Netherlands). In Denmark, the amount of fertilizer that may be applied to each crop is regulated, and 65 percent of the cultivated area must be covered by a green crop in winter to reduce leaching and run-off.

Efficient Nitrogen Management on the Farm

The efficiency of nitrogen fertilizer use today is very low. The proportion of nitrogen taken up by plants varies widely with crop, climate conditions, and agricultural practices, but field trials at experimental stations indicate plant uptake levels of 50 to 70 percent during the fertilizer application season.[50] On farms, nitrogen losses can be much greater. Numerous studies indicate that nitrogen loss rates of between 20 and 50 percent are still common in the industrialized countries, while nitrogen uptake by crops in Indian and Chinese rice paddies has been measured at 25 to 30 percent, principally because of rapid losses to run-off, erosion or gaseous emissions. Such wastage represent a substantial economic loss, as well as an environmental hazard. Given that over 80 million tonnes of nitrogen were applied to fields in 1996, a (conservative) 50 percent loss at a wholesale price of US$0.66 per kg of nitrogen in urea, amounts to US$26.4 billion.

Improved on-farm practices can significantly reduce nitrogen pollution. Fertilizer use efficiency has been improving in some developed countries, where farmers are being encouraged to plant cover crops in winter, avoid poor cropping practices, and plant "buffer" vegetation between fields and water courses to trap nitrogen run-off. In the United States, for example, corn production per kg of nitrogen applied increased from 18 kg in 1985 to 22 kg in 1995.[51] Precision "drilling" application of fertilizers is increasingly practised. Similar improvements have been achieved in western Europe, where agricultural production has continued to increase despite reductions in fertilizer use. Further improvements might be expected from more widespread adoption of slow-release fertilizers and urease inhibitors which can reduce the leaching of nitrate and/or emissions of nitrous oxide and losses of ammonia through volatilization. Currently, use of these products is inhibited by low prices for conventional fertilizers. Synthetic slow-release fertilizers are inherently more expensive to manufacture and only about half a million tonnes are applied annually world-wide, mostly to high-value crops and in non-agricultural sectors such as golf courses and gardens. Fiscal instruments which reduce the price differential between slow-release and conventional fertilizers could speed market penetration by the more efficient product.

In the longer-term, a significant contribution to improved nitrogen management would seem possible with new crop varieties and changes in the global balance of crops cultivated. Bio-engineered crops such as wheat and corn which can fix their own nitrogen could reduce the need for fertilizer application. More research is needed to understand the potential benefits and drawbacks of cultivating leguminous plants such as alfalfa and soybeans. Currently, legume planting world-wide adds about 40 million tonnes to the total amount of nitrogen fixed annually. Legumes are “free” natural fertilizers and their introduction into crop rotations, and ploughing of residues back into the soil, if more widespread, could assist in maintaining soil structure and fertility. Integrated farming practices, which seek to maximise soil fertility and stable yield gains through crop diversity and adaptability to local conditions will also have a role to play in reducing dependence on high levels of fertilizer application.

In many developing countries, fertilizer application levels at present are too low to cause significant eutrophication or acidification damage and a different policy approach is required. However, while nitrogen saturation might seem a far distant prospect in most of Africa and South America, tropical soils are fragile – often thin and light – and nitrogen is more readily lost to run-off or volatilization to the atmosphere. The potential for losses and environmental damage is therefore high and the agronomically optimum level of application may be lower than in temperate regions.

A priority area of attention should be the correction of unbalanced fertilization. Most fertilizers used in the developing world are nitrogen-based, because of their low cost per unit of nutrient and the quick and evident response of the plant. However, increased yields deplete the soil of other major and micro-nutrients which are removed with the harvested crop. These nutrients become deficient unless they are replenished. Excessive nitrogen applications, relative to potassium and phosphates, can lead to nutrient “mining” and loss of soil fertility. In many countries, especially in sub-Saharan Africa, nutrient removal already exceeds nutrient replacement by a factor of three or four.[52] Yields can also be reduced due to “lodging” (where the crop is unable to support its own weight), and greater competition from weeds and pest attacks. In much of Asia, rice yield losses of between 20 and 50 percent have been recorded as a result of disproportionate applications of nitrogen.[53] Significant yield increases could thus be achieved through the encouragement of inorganic fertilizers which provide a more balanced mix of nitrogen, phosphates, and potassium.

In many developing areas, however, lack of access to capital, lack of roads and rail links which could ensure timely delivery of fertilizers, and inadequate information, are likely to mean that soils continue to be gravely under-fertilized. The concept of managing a global nitrogen cycle helps to illuminate the fact that intensive agriculture and high protein diets are tending to concentrate nitrogen in some parts of the world, while impoverished farmers, without fertilizers, burning their crop residues and animal wastes for fuel, see their soil nutrients disappearing. The trend is accelerated by the growth of international trade in food, especially grains, which redistributes nitrogen from net producer to net consumer countries.

Economic development and poverty alleviation are the best long-term redress. In the shorter-term, internationally-funded research efforts into alternative methods of plant nutrition and support for traditional agricultural practices which help to maintain soil would be well repaid in terms of enhanced food security, reduced financial losses, and avoided environmental damage. Complementary measures include greater use of organic fertilizers (animal manure, human wastes, crop residues), applications of lime on the acid soils which are typical of tropical regions, alternating the growth of shallow-rooted and deep-rooted plants to hold nitrogen in the soil, and the use of crop rotations incorporating leguminous plants. Integrated plant nutrition systems (IPNSs) could prove important in effective management of plant nutrients as an element of broader agricultural development. IPNSs are designed to balance the nutrients available to the farmer from all available sources for their optimal productive use, and to minimize "leakage" of minerals into the wider environment.[54] Systems are tailored to meet the needs of specific farming types, yield targets, the physical resource base, and the farmer's socio-economic background. Implementing such systems would involve a formidable improvement in average levels of service to low-income farmers, in terms of technical advice, inputs, credit, marketing facilities, and public investment in agriculture.

The Role of Consumers

The scope for consumer action initially appears limited in comparison with that of farmers. Nevertheless, three areas of behavior appear especially amenable to some change, and evidence of change is already underway in many industrialized countries. Dietary preferences in the wealthy countries are again shifting, as consumers' concern with healthy eating encourages lower red meat consumption. In the United States, for example, per capita consumption of beef fell from a high of 89 pounds per year in 1976 to 65 pounds per year in 1996.[55] However, this was more than offset by increased poultry consumption. Interest in environmental and animal welfare issues is also encouraging vegetarianism, which is no longer the eccentric lifestyle choice it was a generation ago. According to a recent poll, 5 percent of Americans eat no red meat and about 1 percent eat no meat, poultry or fish at all.[56] Some European figures are higher: over 6 percent of British consumers claim to be vegetarian, as do over 4 percent of the Dutch.[57] Evidence that the trend is strengthening can be found in the increased range of vegetarian foods stocked by mainstream supermarkets and the wider choice of vegetarian meals offered in non-vegetarian restaurants. The minority trends towards reduced meat consumption, and the selection of meat produced under extensive conditions, could be reinforced with information highlighting the environmental impacts associated with intensive livestock farming. Perhaps more effectively, higher prices for fertilizers, and emission charges on feedlot operations would translate into higher meat prices and encourage still greater selectivity.

Consumers can also contribute substantially to "closing the open loop" which currently allows nitrogen to be deposited on the land, washed into water courses and flushed out to sea. A number of governments, at the local and national levels, have now introduced voluntary or mandatory recycling schemes for organic (kitchen and garden) wastes, whereby organic material is composted and returned as fertilizer to agricultural land rather than being landfilled. Households should also be encouraged to compost their own waste where feasible. Finally, the use of fertilizers on household lawns represents a small but significant contribution to nitrogen in urban run-off, which could be discouraged by information campaigns and product taxes.

Notes

1. FAOSTAT, Agriculture on-line database.

2. FAOSTAT on-line database (production data). Heilig, Gerhard, K., *Lifestyles and Global Land Use Change: Data and Theses*. Working Paper WP-95-91 (International Institute for Applied Systems Analysis, Laxenburg, Austria, September 1995), table 5, p. 16 (harvested area).

3. World Resources Database 1998-99 (on disk), (World Resources Institute, Washington D.C., 1998).

4. Cereals consumed directly account for about half the human calorie supply. When consumed indirectly, in the form of animal products, cereals account for approximately two-thirds of calorie supply.

5. Food and Agriculture Organization of the United Nations, "Food, Agriculture and Food Security: Developments Since the World Food Conference and Prospects," World Food Summit: *Technical Background Documents*, Vol. 1, Paper 1 (FAO, Rome, 1996). p. viii.

6. Inorganic fertilizers are an industrial product, which chemically synthesize the nutrients nitrogen (N), phosphorous (P_2O_5) and potassium (K_2O); organic fertilizers comprise animal manure and human waste, crop residues etc.

7. Isherwood, K.F., *Fertilizer Use and the Environment*, UNEP/IFA Project (International Fertilizer Industry Association, IFA, Paris, France). Internet reference: http://www.fertilizer.org/PUBLISH/PUBENV/env7984.htm

8. Bumb, Balu L. and Carlos A. Baanante, *The Role of Fertilizer in Sustaining Food Security and Protecting the Environment to 2020* (International Food Policy Research Institute (IFPRI), Food, Agriculture and the Environment Discussion Paper No. 17, 1996), p. 2.

9. International Fertilizer Industry Association. On-line database, internet reference: http://www.fertilizer.org/STATSIND.

10. *Op. Cit.* note 8, p. 5.

11. *Ibid*, p. 9.

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II. Wood Fiber Consumption and the World's Forests

1. Global Forestry and the Forest Products Sector

Wood fiber is one of our most important raw materials. Forests, woodlands and scattered trees supply wood for a huge range of human needs, from cooking fuel and housing to railway sleepers, furniture, and newspapers. In 1997, the world consumed a total of 3.4 billion cubic meters of wood, of which more than half (about 1.9 billion m^3) was burned as fuel.[1] The other broad category of use was as industrial roundwood, which comprises logs and sawnwood for construction (about 26 percent of total wood consumption), processed wood products such as veneers, chipboard and plywood (about 9 percent), and pulp for paper-making (about 11 percent). This last figure is supplemented by the re-use of wood manufacturing residues like sawdust and chippings.[2]

In the early 1990s, production and manufacture of wood products contributed about $US 400 billion to the global economy, or about 2 percent of global GDP.[3] This omits the uncounted value of fuelwood, which is barely included in national energy accounts but nevertheless underpins many rural economies. In the last three decades, international trade in forest products has increased roughly threefold in terms of value, adjusted for inflation, and now accounts for 3 percent of world trade. The greatest increases in trade have been in wood-based panels, and paper and paperboard, as many developing countries have reduced their exports of logs and instead developed their own processing capacity. At the global level, about one quarter of all production of sawnwood, wood-based panels, paper and paperboard now enters international trade, compared with 12-17 percent in 1961.[4]

Forests are also the source of a wide range of "non-wood products" including medicinal plants, nuts, fruits, mushrooms, and other edible plants. Many of these products never enter a formal market and their monetary value world-wide is hard to assess, but it is likely to be considerable. In the Pacific Northwest of North America, for example, wild greens, Christmas boughs, and floral decorations contributed some $US 130 million to the regional economy in 1989.[5] A survey of 24 studies of the value of non-wood products in tropical countries reported a median per hectare value of $US50; however, the studies tended not to take into account the costs of extraction, or to distinguish between extraction from natural forests and harvesting from agro-forestry.[6] In many cases, the greater value of non-wood forest products may lie in their contribution to supporting indigenous livelihoods and cultures.

The global forestry industry has traditionally concerned itself with the production of wood and wood products. However, the agenda has changed considerably over the past 20 years, under pressure from public dissatisfaction with forest management practices, growing understanding of the numerous ecological services performed by forests, and greater concern for the rights of people who live in, or around, forests and who look to them to supply a wide variety of economic, social and even spiritual needs. The amenity value of forests, which includes their use for tourism and recreational activities and, more intangibly, their ability to add beauty to a landscape and provide a peaceful refuge from urban life, is also hard to quantify, but has become impossible for forest managers to ignore in most industrialized countries.

2. Where Does Our Wood Come From?

Industrial Roundwood

The three main sources of industrial wood supply are old-growth ("virgin") forests, secondary-growth forests, and plantations.

- Large tracts of old-growth forest are still found in a number of regions, including Russia and Canada, the Amazon Basin, and parts of other countries with tropical rainforest.
- Secondary-growth forests are natural forests which have been cut but have regrown, or been partially replanted, and are now managed more or less intensively for wood production. Secondary-growth forests have replaced virtually all the original forests of eastern North America (including most of the United States), Europe, and large parts of South America and Asia.
- Plantations are generally defined according to the extent of human intervention in a forest's establishment and/or management. Because there is an extensive range of silvicultural practices applied in intensive forest management, the difference between a semi-natural and plantation forest is essentially arbitrary. This is especially the case in parts of Europe, the United States, and China. In tropical and sub-tropical countries, plantations are usually more easily identifiable, since they tend to have been established relatively recently or because they consist of fast-growing and often exotic (non-native) species. Nearly half the world's plantations are found in Asia. The former Soviet Union, and North and Central America account for another 30 percent.

It is estimated that industrial wood plantations currently provide nearly 25 percent of the world's industrial roundwood supply;[7] there are no reliable breakdowns, at global level, of the proportions coming from old-growth and semi-natural forests.

Woodfuels

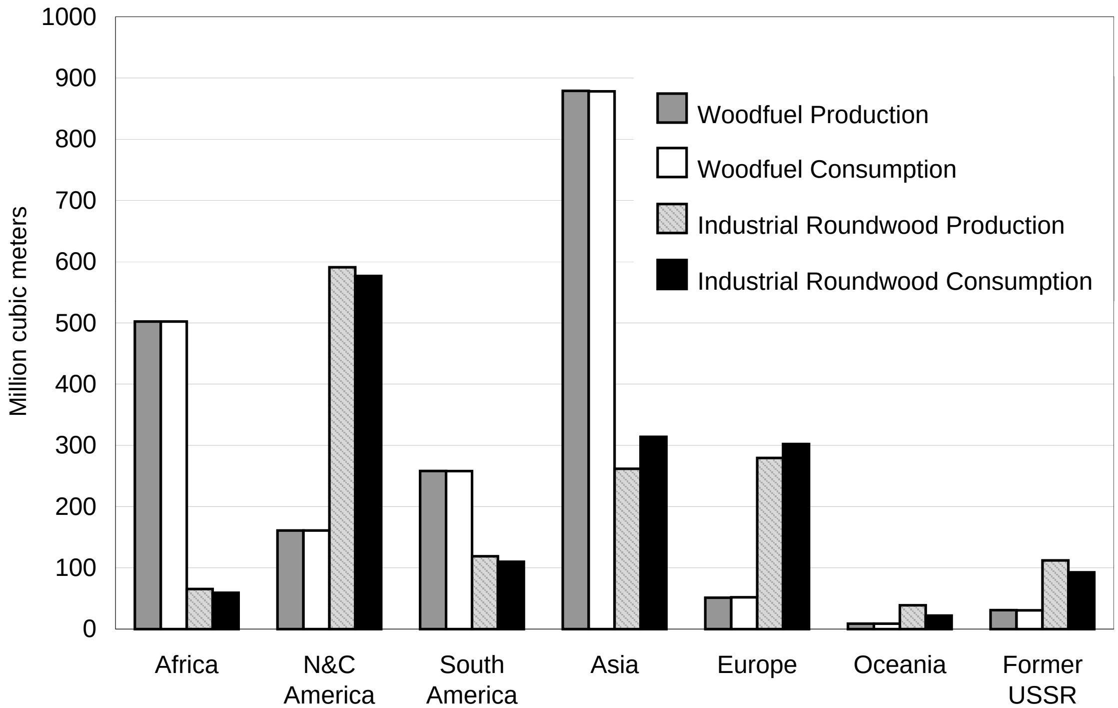
Despite the importance of wood as an energy source in developing countries, it is still rarely considered by policy-makers who often regard its use as backward and unimportant. Relatively little effort has gone into collection and analysis of statistics. Information on sources of fuelwood and charcoal (known collectively as woodfuel) is therefore limited and of poor quality. It may be the case that the majority of woodfuel – perhaps more than 50 percent in many countries – comes from outside forest areas.[8] Non-forest sources include logging and wood industry residues, agro-industry residues (for example, from rubber and oil palm plantations), sparsely wooded and brush land, roadside vegetation, gardens, and community wood lots. Fuelwood plantations provide only an estimated 4.4 percent of supply world-wide,[9] though they assume greater importance in parts of China, India, and South America. In industrialized countries, wood energy is supplied primarily from wood industry residues.

Major Producers and Consumers

Three major world regions, North America, Europe, and Asia, dominate the market in industrial wood products. North America alone accounts for about 40 percent of both production and consumption. The industrialized countries trade extensively with each other and, as a whole, (with the major exception of Japan) are largely self-sufficient in softwood fiber. Consumption in Asia is rising dramatically, and the region is now a net importer of wood products, especially pulp for paper-making. At present, the richly forested countries of Brazil and the Russian Federation, which between them account for some 38 percent of the world's forested area, produce only about 5 and 8 percent respectively of all industrial roundwood, and they consume even less *(Figure 1).*

Production and consumption of fuelwood and charcoal is concentrated in the developing world, with five countries – India, China, Brazil, Indonesia, and Nigeria – accounting for about 50 percent of the total.[10] (Since international trade in woodfuels is almost non-existent, national level data on production and consumption are considered here to be one and the same.) In developing countries, consumption of industrial roundwood is rising rapidly with economic development. Booming construction sectors in industrializing countries require sawnwood, and rising literacy levels among the public are stimulating demand for pulp and paper, though per capita consumption

Figure 1. Total Roundwood Production and Consumption, 1994



Source: FAOSTAT

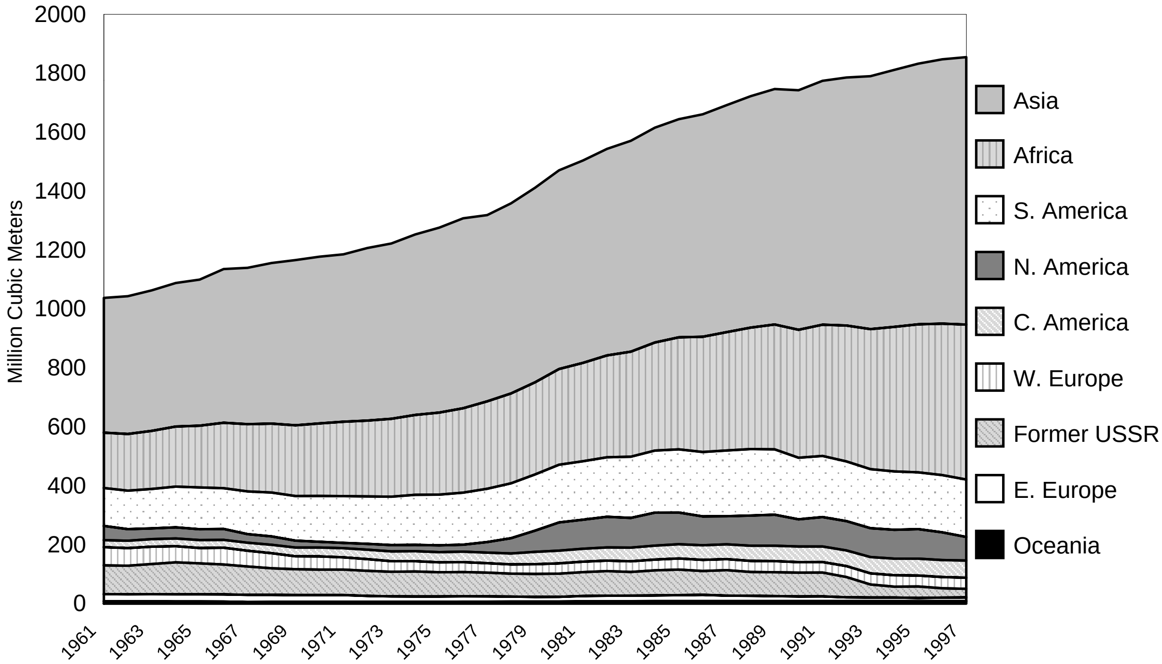
levels remain very low by Western standards. Production and export of tropical wood products, such as plywoods and veneers, have also grown two- to threefold in the last 30 years.[11] World-wide, the rate of increase in production of industrial hardwoods has exceeded that for production of soft-woods; these differential trends reflect a shift of the timber production base towards the developing countries, and towards the tropical countries in particular.

3. Key Trends in Wood Fiber Production and Consumption

Between 1961 and 1997, global consumption of industrial roundwood grew by 48 percent, while global consumption of woodfuels rose by nearly 80 percent.[12] It should be noted that woodfuel consumption data are modelled estimates based on limited consumption survey data and population growth rates. The principal factors involved in rising demand are population numbers and economic growth, but the interplay between the two drivers is far from simple. Over time, patterns of consumption have shifted significantly, between woodfuels and industrial roundwood, and among different industrial wood products.

Demand for fuelwood and charcoal is driven primarily by rising numbers of rural poor, who are dependent on wood for their cooking and heating needs *(Figure 2)*. Charcoal, often consumed in the form of briquettes, is an important fuel among the urban poor, whose numbers are expanding rapidly, and is an industrial energy source in some Latin American countries. Increasing prosperity, often accompanied by urbanization, encourages a switch to commercial fuels such as kerosene. Therefore, demand for fuelwood and charcoal should be inversely related to income growth. Rapid economic growth in many developing countries has brought about just such a shift for millions of people; however, rapid population growth and unequal distribution of wealth has meant that demand for traditional woodfuels has remained high.

Figure 2. Global Woodfuel Consumption, 1961-1997



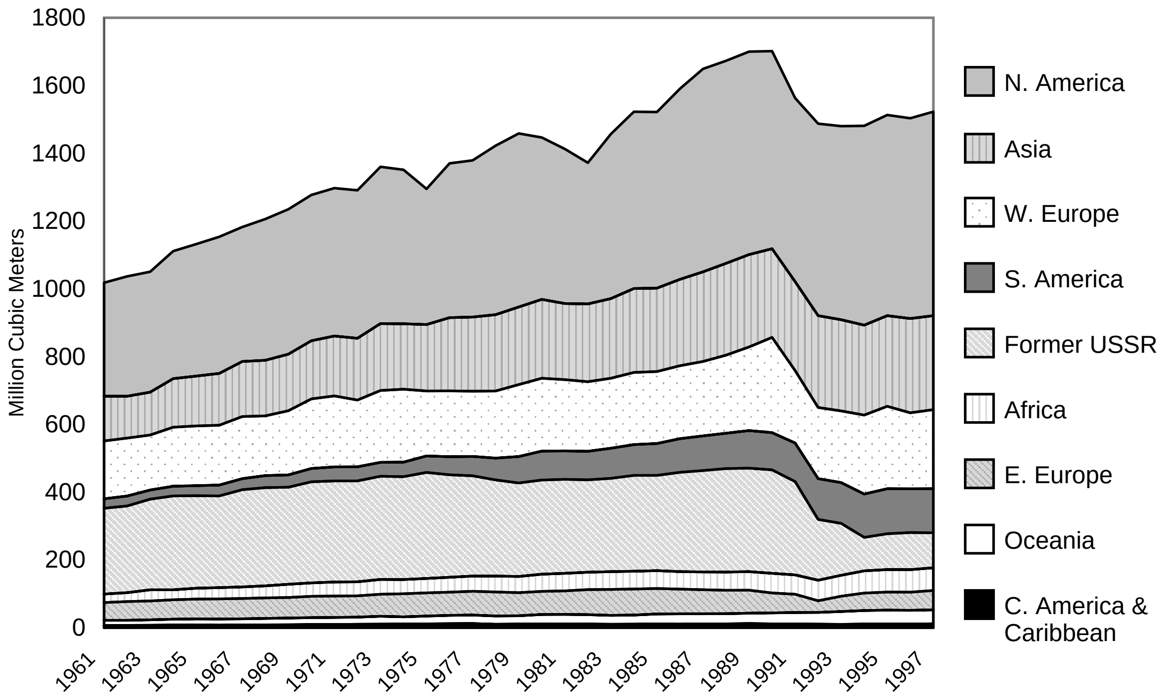
Source: FAOSTAT

Demand for industrial roundwood, by contrast, is directly related to income. The bulk of industrial roundwood production and consumption remains concentrated in the wealthy countries of the OECD, though consumption in the region is levelling off, due to saturation of demand for some products (such as lumber for construction) and the use of more efficient technologies *(Figure 3)*. However, these declines are partially offset by strong demand for paper and some hardwood products, which continues to rise broadly in line with GDP. Industrial roundwood consumption is rising fastest in the rapidly growing economies of Asia and Latin America.

Of all industrial roundwood products, paper and paperboard are growing the most rapidly *(Figure 4)*. Globally, paper consumption has increased by a factor of 20 this century, and has more than tripled over the past 30 years.[13] In addition to the traditional products of newspapers, books, magazines, and printing/writing paper, consumption is kept buoyant by a new world of mail order catalogues, marketing and promotional materials, "junk mail," and household and sanitary papers, which has developed over recent decades. The advent of computers and other electronic equipment has actually fuelled demand and the "paperless office" remains a distant prospect. Personal computers alone are estimated to consume over l15 billion sheets of paper annually.[14] Communications, however, account for less than half of the world's paper use; a bigger share is now taken by the booming packaging industry.[15]

In the developing world, paper consumption is growing very rapidly, at over 7 percent annually between 1980 and 1994, but average per capita consumption remains low at about 15 kg/year.[16] This is well below the 30-40 kg of paper considered the minimum necessary to meet basic needs for communication and literacy.[17] However, total paper and paperboard consumption in Asia already exceeds that of Europe, and is projected to grow at a rate of nearly 4 percent a year till 2010, when the region will be the biggest paper consumer in the world.[18]

Figure 3. Global Industrial Roundwood Production, 1961-1997



Source: FAOSTAT
Note: The drop in industrial roundwood consumption after 1990 is due to collapsing demand in the former Soviet Union and the countries of Central and Eastern Europe

4. Wood Fiber Consumption and Environmental Impacts

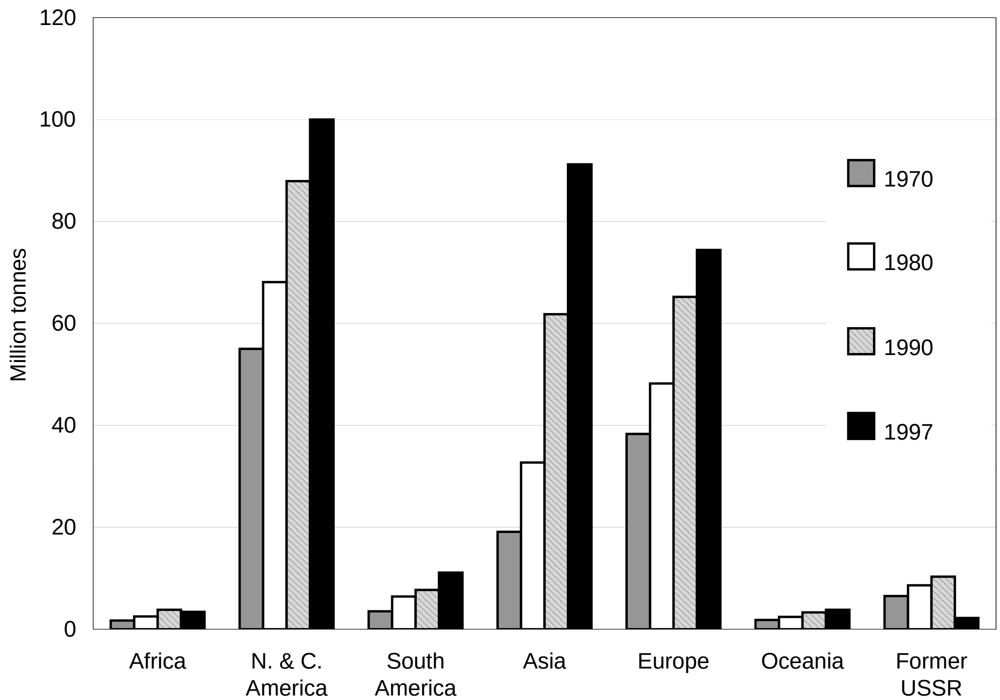
The primary cause of annual tropical deforestation world-wide is clearance for agriculture.[19] However, as a recent report by the World Resources Institute makes clear, it is logging which poses the most serious risk to the great "frontier forests," that is, the old-growth forests which remain ecologically intact over significant areas.[20] Once forests have been opened up by logging operations, agriculture and settlement swiftly follow.

Population growth and the advent of a global market have caused the pattern of conversion of forests to agriculture, settlement, logging, and export growth to be replicated globally and at much greater speed than in the past. Despite new planting, net deforestation continues today at the rate of about 12 million hectares annually.[21] Figure 5 summarizes the net deforestation/afforestation rate on a regional basis between 1980 and 1995.

Losses of forest area have been greatest in the tropical countries. Between 1960 and 1990, some 450 million hectares were cleared – a fifth of the world's entire tropical forest cover.[22] An estimated one-third of this loss was due to logging.

Numerous environmental impacts flow from the removal of forest cover. Though the environmental services provided by forests are neither fully understood nor valued, they are known to include: protection of soil and water resources; support to agricultural productivity and sustainability, especially by slowing desertification and resource degradation in arid and semi-arid lands; and protection of coastal areas and fisheries. These services are provided at the local and regional levels. Globally, forests play an important role in climate regulation, through their capacity to store carbon, and they provide the world's richest habitats for biodiversity.

Figure 4. Global Consumption of Paper and Paperboard, 1970-1997



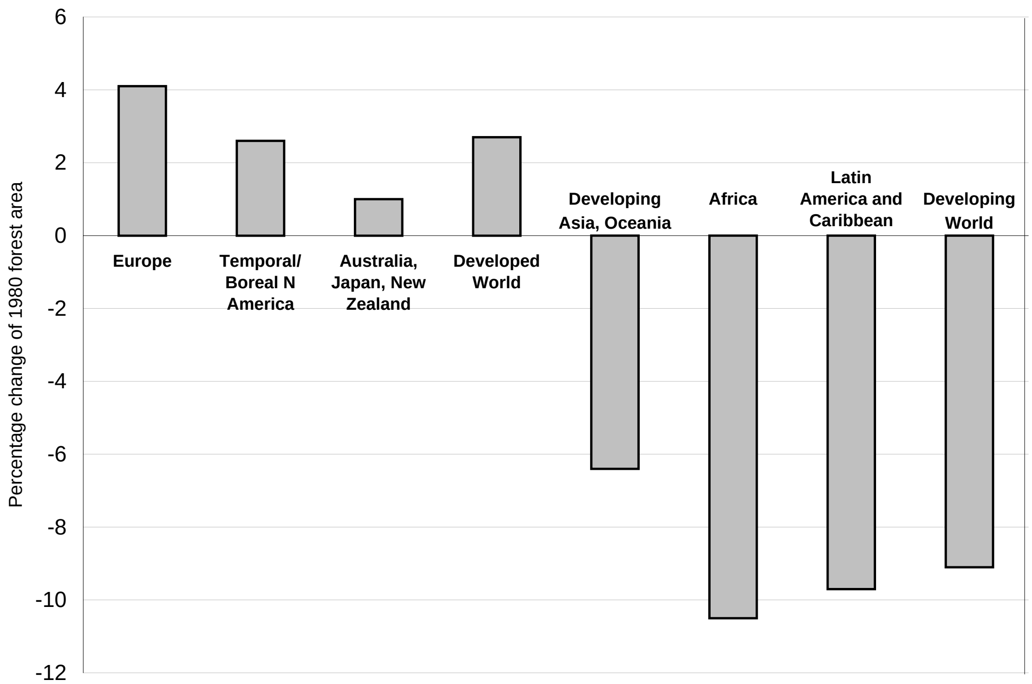
Source: FAOSTAT

Soil and Water Protection

Forests in upland water catchment areas stabilize soil on sloping land by breaking the impact of falling rain and binding soil structure in their extensive root systems. Forests also regulate water flow by soaking up moisture and releasing it in a controlled, regular supply. Deforestation often disrupts the hydrological cycle, causing year-round water flows in downstream areas to be replaced by destructive flood and drought regimes. Water that has not passed through the slow forest "filtration" process also tends to be more impure; drinking water supplies for downstream communities then require additional treatment. In addition, irregular water flows seriously disrupt supplies to urban populations and irrigated farmland. Bangkok, for example, derives about one-third of its water from one river, which rises in mountains 1200 kilometers away from the city. Deforestation and erratic water flow have forced the city to depend more on groundwater supplies. Over-pumping from these wells, in turn, is causing the city to subside at a rate of 5-10 centimeters per year.[23]

Soil erosion rates increase sharply with logging, though removal of ground cover, rather than canopy cover, appears to be the chief determinant of erosion. According to a summary of 80 erosion studies, erosion rates under slash-and-burn agriculture in the tropics are 10 times higher than in natural forest. In plantations where weeds and leaf litter have been removed, erosion is more than 100 times as great as in natural forest.[24] In many cases, erosion may result from road construction associated with logging in the forest, rather than from the loss of trees. A study of Palawan, in the Philippines, found that erosion rates increased fourfold as a result of logging, but the conversion of uncut forest to road surface increased erosion by a factor of 260. Roads accounted for only 3 percent of the area studied but for an estimated 84 percent of surface erosion.[25] Even in more temperate regions, deforestation has increased the rate of mudslides and landslips. In the Pacific Northwest of the United States, many hundreds of landslips

Figure 5. Comparison of 1980 and 1995 Forest Areas



Source: State of the World's Forests 1997, based on figure 4, p. 17.

now occur annually; one recent study claimed that 94 percent of such slips resulted from clear cuts and logging roads.[26]

In addition to the lost fertility of eroded lands and damage from mudslides, soil washed away in watercourses adds tremendously to the sediment burden carried by major rivers. Siltation in the Ganges River system, for example, is causing some riverbeds to rise at the rate of nearly half a meter a year.[27] Shallower rivers, together with uncontrolled run-off after heavy rain, increase water flow rates and the risk of flooding. India, Bangladesh, and China have experienced recent devastating floods, causing thousands of deaths and losses of billions of dollars in agricultural and property damage. Following the 1998 floods along China's Yangtze River, the Chinese Government banned further logging in the upper reaches of this and other major rivers and promised tree-planting programs on a massive scale. The mountainous western parts of Sichuan, Yunnan, and Gansu Provinces were about 20 percent forested in 1950; logging and agricultural expansion have since reduced forest cover by half and much of what remains is slowly recovering secondary-growth forests or plantations, which are less effective in conserving soil and water.[28]

Sedimentation is also a growing problem for some of the world's major dams and reservoirs. The Mangla and Tarbela dams in Pakistan, the Ambuklao dam in the Philippines, and the Poza Honda Reservoir in Ecuador, are all receiving so much silt from deforested catchment areas that their operational lives are being reduced by 40 to 50 percent or more.[29] The final downstream impact of sedimentation is damage to coastal habitats and fisheries. Coral reefs and mangroves are prone to "smothering" by silt, which reduces their capacity to support spawning and adult fish populations. Reduced catches have been reported in a number of tropical countries including the Philippines, where coral reefs supply about 10 percent of the country's commercial and subsistence fish harvest. Siltation is also blamed for damage to salmon spawning runs in the Pacific Northwest of North America.

Climate Regulation

At continental and regional scales, large tracts of forest help to regulate rainfall. Research indicates that between 50 percent and 80 percent of the moisture in Amazonia is “held” in the region by its forest. That is, water is constantly recycled between plants and the atmosphere, where it gathers in storm clouds before being precipitated back onto the forest.[30]

Forests also play a major role in regulating the global climate. The observed warming of earth’s atmosphere is generally attributed to increased concentrations of greenhouse gases, of which the most important is carbon dioxide (CO_2). The vegetation and soils of the world’s forests lock up huge quantities of carbon – more than the total contained in the atmosphere – and serve as “sinks” for much of the carbon emitted by fossil fuel combustion and other human actions. Around half of forest carbon is located in boreal forests, and over one-third in tropical forests. Siberia’s forests alone absorb an estimated 10 percent of human carbon emissions annually.[31] However, deforestation, burning, and forest degradation in the tropics are responsible for releasing approximately 1.6 billion tonnes of carbon per year, more than 20 percent of all anthropogenic carbon emissions.[32] Only partially offsetting this, forest expansion and growth in the temperate regions sequester approximately 0.7 billion tonnes of carbon. Surprising as it may seem, therefore, the world’s forests today are a net *source* of carbon.[33]

Further deforestation will both reduce available carbon sinks and contribute to carbon emissions, as well as other greenhouse gas emissions associated with burning biomass. The threat is not confined to the tropics. Clear-cut logging and burning in the boreal forests of Siberia have destroyed over 250,000 square kilometers in recent years and it is believed that, between 1988 and 1993, the region switched from being a net carbon sink to a net carbon source.[34] If such patterns of exploitation could be checked world-wide, the Intergovernmental Panel on Climate Change (IPCC) has suggested that the conservation and regeneration of forests, especially in the tropics, could offset between 12 and 15 percent of projected CO_2 emissions from fossil fuel combustion to the year 2050.[35]

Biodiversity

The earth’s genes, species, and ecosystems are the product of over 3 billion years of evolution, and are the basis for the survival of the human species. Approximately 1.7 million species have now been catalogued: numbers are relatively precise for birds and mammals but, for the vast majority of groups, numbers remain unknown. Estimates of the earth’s total species count range between 5 and 30 million. Such diversity is valuable because future practical uses and values are unpredictable, because variety is inherently interesting and attractive, and because our understanding of ecosystems is insufficient to be sure of the impact of removing any component.

What is known with reasonable confidence is that forests provide habitat for about two-thirds of all species on earth.[36] Tropical rainforests are the most biologically diverse ecosystems, harboring perhaps half of all known plant and animal species.[37] Temperate forests also provide rich and important habitats. In the United States, for example, forest ecosystems may be home to more than 50 percent of the country’s terrestrial species.[38] A written record of animal extinctions has been maintained since at least 1600, demonstrating the impact of human activities upon, first, island species and, increasingly, continental species. Numbers are inexact, but it must be presumed that the actual number of extinctions is greater than indicated, simply because the vast majority of species are unrecorded. Loss and fragmentation of forest area, and simplification of forest ecosystems under intensive management regimes, have led to numerous species extinctions and reduced genetic diversity in other species through reduced population size. This kind of broad-based destruction of biodiversity differs markedly from earlier extinctions, which were largely confined to megafauna, the large mammalian species who represented our closest competitors, or individual species prized for their meat or fur.

Given what is known about documented species' density and endemism, the world's leading biologists have attempted to infer rates of species extinction from various human activities. Estimates of losses of total global species per decade due to deforestation range from 5 to 9 percent. Projections of species loss, extrapolated to the point of total loss or conversion of forested areas, indicate that between 15 and 50 percent of the world's biodiversity would become extinct.[39]

Conclusion

The unprecedented scale and rate of deforestation and human-induced changes to forests is leading to the loss of immensely valuable ecosystem services. Soil conservation, flood control, provision of clean water, climate regulation, and maintenance of biodiversity are fundamental to human activity. Unlike goods and services traded in the market, they are assigned no monetary values, or none which are widely accepted.[40] Yet these services cannot easily be substituted by human ingenuity and, even where substitution is possible, the economic costs are likely to prove prohibitive for many countries.

5. Looking Ahead: How Much More Wood Fiber Will the World Need?

During the 1990s, a variety of studies estimating future wood fiber demand have been carried out by research organizations and the forest products industry, most focusing on the next 15 to 20 years. This section draws on some of these studies,[41] as well as the recent Global Fiber Supply Model developed by the FAO,[42] and a quantitative, scenario-based consumption model developed by the European Forest Research Institute,[43] both of which take a longer-term view.

Fuelwood and Charcoal

Published woodfuel consumption data are based largely on estimates and are highly uncertain. It is not known with any accuracy how much woodfuel people consume, nor where it comes from. Equally, projections of future demand are sometimes based on estimates of how much wood will actually be available for consumption; others consider how much people would consume if all their needs were fully met. As a result, projections of global woodfuel consumption in 2010 range from just under 2 billion m^3 to 4.25 billion m^3. (1997 consumption was 1.9 billion m^3.)

Industrial Roundwood

Differences in the outlook for industrial roundwood are also common, given different assumptions about economic growth, fiber prices, and available technologies. A number of long-term scenarios serve to show the powerful effect of prices. Higher fiber prices lead to significantly lower industrial roundwood consumption, whereas a projection of constant per capita consumption at 1990 levels, without any price increases, produces a more than 50 percent rise in consumption by 2050. Projections of global industrial roundwood consumption in 2010 range from about 1.8 billion m^3 to about 2.1 billion m^3. (1997 consumption was 1.5 billion m^3.)

Total Roundwood

All the studies reviewed in this paper conclude that consumption of both woodfuels and industrial roundwood will increase, though the estimates of overall rate of increase vary from well under 1 percent per year to nearly 2 percent per year. Today's total wood harvest stands at 3.4 billion m^3. Total wood consumption in 2010 is likely to be somewhere between 3.6 and 6.3 billion m^3, with 4.6 billion m^3 being the mean projection. It is therefore obvious that, if consumption rises in line with even the more conservative projections, the world's forests, woods and shrublands areas will be required to provide more timber and fuel from a shrinking area.

At the regional level, differing levels of population and economic growth will lead to very different supply and demand situations. Europe and Scandinavia, for example, appear relatively secure. Asia, on the other hand, is facing a significant shortfall in wood supply, despite having the world's fastest rate of increase in local production of wood fiber. The region has already surpassed Europe in industrial roundwood, fiber, paper and paperboard consumption, and is beginning to approach North American consumption levels of other products.[44] The greatest uncertainties concern demand and sources of supply for woodfuels. At the global scale, talk of a "fuelwood crisis" is probably exaggerated, but shortages may become critical in some parts of Africa and Asia.

Those studies which have looked specifically at both supply and demand forecast "hypothetical gaps" between global fiber demand and availability of between 400 million and nearly 800 million m^3 by 2010. While gaps, in practice, are closed by market forces, they are an indicator of possible dislocation in markets and pressure to change policies. While most studies do not explicitly warn of an impending crisis of fiber supply, they suggest that "more active management" of the world's forests is a likely and necessary development in order to ensure availability of both commodities and services. What might this mean in practice?

6. How Much More Fiber Can the Earth Provide?

Relatively little analytical work has been carried out on future availability of woodfuels. Some forecasts are based on projections of past consumption trends, which are themselves supply-driven. Consumption estimates therefore tend to be used as production estimates. This approach probably underestimates both real production levels (one study claims that fuelwood collection in India is ten times greater than officially reported)[45] and real future needs. Bearing these shortcomings in mind, various estimates of global fuelwood and charcoal availability in 2010 range around the 2.3 billion to 2.4 billion m^3 mark.[46] These figures represent a 30 percent increase on today's harvest level, but still barely meet, or fall short of, estimated consumption levels in 2010: 2.4 billion m^3 (FAO), 3.1 billion m^3 (World Bank) and 4.3 billion m^3 (Nilsson). The picture is brightened by growing awareness that non-forest areas are an important source of woodfuels, and that various "doom scenarios" under which biomass-dependent countries would lose all their forests to fuelwood collection have not come to pass.[47]

Since the market takes more interest in industrial wood than fuelwood availability, forestry experts have produced a range of estimates concerning future industrial wood supplies. Many of these recent estimates have been harmonized by Sten Nilsson in an attempt to provide a comprehensive picture of industrial fiber availability over the next two to three decades *(Table 1)*. There is a surprisingly large range among the estimates. Partly, this is due to insufficient inventory information. Partly, there are uncertainties surrounding the speed and extent of economic recovery in Russia's forestry sector. There are still greater uncertainties concerning how changing values in society will affect the utilization of forests, particularly those which are still largely undisturbed. For example, between 1970 and 1990, the total forest area placed under legal protection for conservation purposes increased by nearly 140 percent, to some 12 million hectares.[48] The total availability of industrial roundwood in 2010 is thus estimated to be somewhere between 1.5 and 2.0 billion m^3, the latter figure representing a more than 30 percent increase over today's harvest levels.

7. Where Might The "Extra 30 Percent" Come From?

The main sources of wood fiber supply, as already described, are old-growth forests, managed secondary-growth forests, and plantations. Important additional sources of fiber are recovered wood wastes from wood processing industries and – for pulp and paper-making – non-wood fibers such as straw and recycled fiber obtained from waste paper. This section examines the potential supply from all these sources.

Forests

The world's old- and secondary-growth forests cover some 3.2 billion hectares (excluding some countries with very minor forest cover). However, the area available for wood supply under current

Table 1. Estimated Global Availability of Industrial Roundwood: Range of Projections (million cubic meters)

	1993[1]		2010		2020	
	Softwood	**Hardwood**	**Softwood**	**Hardwood**	**Softwood**	**Hardwood**
Canada	165.3	7.9	127-158	38-50	135-162	42-55
USA	285.8	116.7	245-289	117-140	265-317	125-155
Latin America	63.6	67.4	85-100	89-118	105-110	105-120
Africa	10.2	49.4	12-16	54-59	14-16	57-65
Oceania	23.6	13.3	33-41	17-18	53-58	19-21
China	63.3	35.5	50-60	30-35	53-60	32-40
Japan	18.8	6.8	20-55	8-9	22-55	9-10
Other Asia	2.0	133.2	14-16	65-124	16-19	65-129
Russia	86.2	31.7	130-194	30-70	175-235	30-80
Eastern Europe[2]	48.0	32.7	59-64	47-52	61-66	49-53
Western Europe	78.1	35.8	86-108	39-56	91-113	41-58
Scandinavia	85.0	9.6	89-108	11-14	89-116	12-15
World	**939.9**	**540.0**	**950-1209**	**545-745**	**1079-1327**	**586-801**
Grand Total	**1479.9**		**1495-1954**		**1665-2128**	

Source: Nilsson (note 46).
[1] 1993 figures based on estimated actual production
[2] includes the European countries of the former USSR

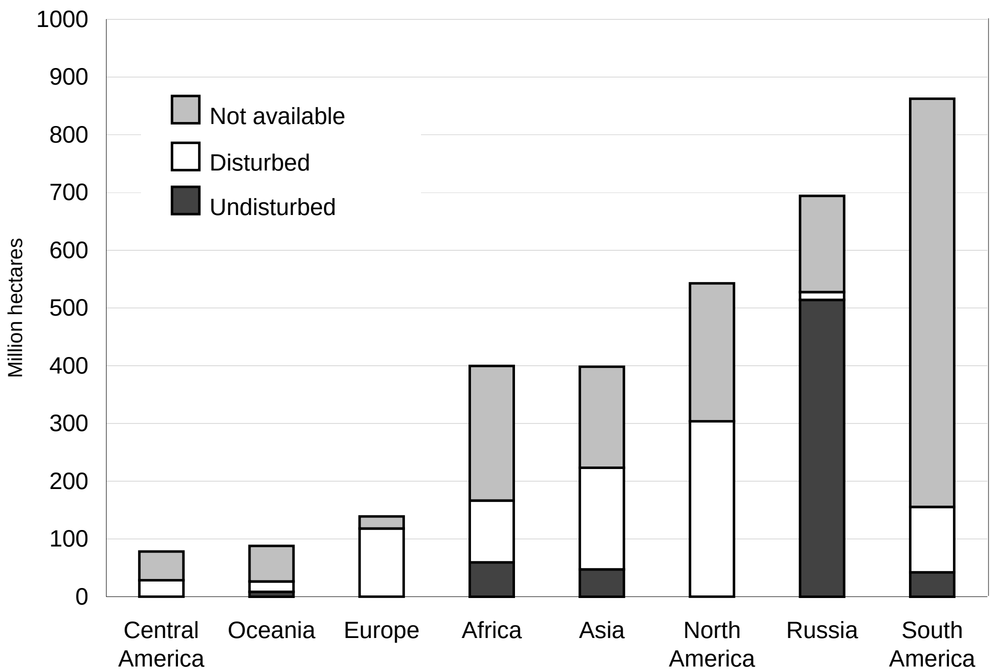
market conditions is much less – approximately 48 percent of the total. "Unavailable" forest area is defined by the FAO as that which is legally protected, or which is currently considered economically or physically inaccessible. Of the area available for wood supply, at least 44 percent is estimated to be undisturbed by man.

Figure 6 shows the regional distribution of the world's forests (excluding plantations), the area currently unavailable for wood production and, of the available area, the proportions which are already disturbed or still undisturbed by man. If recent consumption trends are anything to go by, the strongest demand will be for softwood fiber, for pulp and paper-making. Production of tropical hardwood products such as panels and veneers has also risen strongly. However, there is some evidence of a shift towards composite panels and away from veneer-based panels which, together with relative price changes, technology, and consumer concerns over tropical deforestation, may combine to reduce demand in future. Overall, however, rising fiber demand, leading to higher fiber prices, can be expected to result in more intensive management of existing available forest area, and in more currently inaccessible forests being opened up for development.

Two important environmental constraints exist to raising production from currently available forest area. One is ongoing deforestation. A number of recent studies have analyzed current deforestation rates, and the external parameters likely to influence future deforestation patterns in selected tropical countries, such as population growth, urbanization, agricultural trends, expansion of cash crops, development of infrastructure, and changes in land-holding and use patterns. Outcomes vary in different countries but, overall, accumulated tropical forest losses are expected to amount to an additional 550 to 650 million hectares between 1995 and 2045, unless new and additional policy measures are taken against deforestation.[49]

The second constraint is the advent of more environmentally and socially sensitive forestry practices. In most of the industrialized countries, public concerns over environmental damage caused by clear-cutting, loss of biodiversity, and the low aesthetic and amenity value of heavily managed forests and plantations, have forced a radical re-think of management objectives in the forestry sector. Demand for "non-wood" services such as recreation and nature conservation has risen dramatically since the early 1980s[50] and similar concerns may be expected to arise in

Figure 6. Natural Forest Area and Availability for Wood Production



Source: FAO, Global Fiber Supply Model
Note: “Natural” forest refers to both old-growth and managed, secondary-growth forests

those developing countries with fast-growing economies and an influential middle class. Quantifying the impacts of environmental and social considerations on future forest productivity is problematic, but they could be considerable. As one example, the adoption of “ecosystem management” and application of the Endangered Species Act in the United States have reduced annual timber harvests from federal lands from about 50 million m^3 to less than 20 million m^3.[51]

Given this situation, the huge economically “unavailable” forest resources of the Pacific Basin countries, including those of the Russian Far East and Latin America, are likely to be at the front line of the world supply/demand equation for the foreseeable future. As Table 1 above makes clear, these are the only regions where serious expansion of production looks feasible. Russia contains over 90 percent of Eastern European conifer production forests, and Brazil has nearly 70 percent of Latin America’s hardwood production forest. According to a recent report by the World Resources Institute, these are the forests which are most immediately at risk if rising prices make them more economically accessible.[52] Clearly, much of the additional fiber that the world will need could come from natural forests, but at a heavy environmental price.

Plantations

According to many forestry experts, the need for further exploitation of natural forests could be greatly reduced by expanding production from industrial wood plantations. Already, in Oceania, 78 percent of industrial wood is estimated to be sourced from plantations. Both Africa and Asia are also estimated to have more than 40 percent of industrial wood sourced from plantations.[53] Plantation yield data, at the global level, are both scarce and imprecise, but plantation productivity appears generally higher than that of natural forests. Eucalyptus growth rates of 25 cubic meters per hectare per year are not uncommon in South America, while trial plots in Brazil have recorded growth rates of 100 cubic meters per hectare per year. Plantations in the tropics are more productive than those in temperate regions, and are forecast to grow significantly in extent and productivity. A 1995 study estimates that growth in industrial forest plantations in Latin America alone could increase the global fiber supply by more than 100 million m^3 in 2010.[54] Even more ambitiously, the FAO estimates that the current plantation area of 55 million hectares in the southern regions has a potential annual growth of 1.1 billion m^3. In theory, the world's total current demand for industrial roundwood could be met from plantations on 0.15 billion hectares of land, equivalent to just 4 percent of global forest area (assuming average growth rates of 10 cubic meters per hectare per year).[55]

However, these exciting scenarios should be tempered by awareness of a growing number of studies which suggest that forest plantations are generally yielding below expectations and that both current and projected yields may have been greatly exaggerated in some cases. Juvenile tree mortality rates in tropical countries are often high (up to 70 percent). Low national planting success rates have been reported for several countries including the Philippines (26 percent), Laos (47 percent), and Colombia (57 percent). Sometimes, management and technical factors appear responsible: for example, large-scale plantations have often been started based on small-scale experiments, production costs are under-estimated, and the enterprises fail. In other cases, the environmental toll taken by fast-growing, non-native commercial species, which are often grown in relatively fragile soils, has been overlooked. It is known that eucalyptus plantations, in particular, are prone to "sulking" (decreased growth). It seems probable that more careful site selection, soil management techniques, and higher inputs of fertilizer, will be necessary to achieve yield levels sufficient to meet anticipated demand.

Non-Wood Fibers

Wood remains the most important input to the global pulp and paper industry, but non-wood fibers (mainly straw, sugarcane bagasse, and bamboo) play a significant role in a handful of countries in Asia.[56] Estimates of the proportion of pulp produced from non-wood fibers in 1993 range from 5 percent to 11 percent.[57] It seems likely that the use of non-wood fibers will grow, especially in China, which today accounts for nearly 80 percent of all non-wood fiber production. The FAO estimates that Asia has the capacity to produce 90 percent of the world's future non-wood fiber, and other recent studies suggest that the availability of non-wood materials suitable for pulp and paper-making could be as high as 2.5 billion tonnes, one thousand times greater than current production.[58] Nevertheless, this would be a long-term prospect, given problems related to the seasonal availability of most non-wood materials and the need for large-scale pulp mills to operate continuously to remain profitable. Competing uses for waste organic material, and high pollution levels associated with current, low-technology production methods are additional constraints. Pollution from non-wood fiber mills can be up to 20 times that from wood pulp mills and could prove an inhibiting factor in this sector. China, which produces nearly 10 percent of the world's paper, has suffered from especially severe water pollution and related human health problems. As a direct result, the Chinese Government has closed down nearly 50,000 small paper mills and other township enterprises which were causing heavy pollution.

Recovered Fiber

Recycled fiber currently accounts for about 20 percent of total industrial wood fiber consumption, and this share is expected to increase to 35 percent or more by 2010. Fiber recovery and recycling is furthest advanced in the industrialized countries. Europe, North America, and Asia account for over 90 percent of fiber production from waste paper. The total volume of recovered waste paper in 1995 was over 114 million tonnes, equivalent to approximately 287 million cubic meters of fiber.[59] The FAO expects this total to rise to about 180 million tonnes by 2010, continuing a rapidly rising trend evident since the 1960s.[60] Currently, however, all regions except North America consume more waste paper than they produce; in other words, North American exports of waste paper underpin the world's recovered fiber pulping industry. As North American domestic demand and pulping capacity increase, these exports will diminish, and other countries will need to upgrade their own paper collection and recycling systems. The speed at which recovered fiber continues to substitute for virgin fiber will be strongly influenced by prevailing prices for waste paper and its transportation. Great potential remains for fiber recovery in developing countries.

Summary and Conclusions

In its recent major study, the Global Fiber Supply Model, the FAO develops possible scenarios of future global industrial wood fiber supply by identifying and quantifying all potential sources – forests, industrial plantations, non-wood fibers, and recovered fibers. The study also tries to take into account likely rates of afforestation, yield gains, deforestation, and conversion of unmanaged to managed forest. The report is optimistic about the short-term supply situation, but it is clear that the scenarios of future fiber availability are dependent on far more intensive management of existing forests. Major possible changes presented in the study include the almost complete loss of undisturbed forest in Asia and accelerated harvesting of mature trees in Russia and Canada, as well as expansion of plantations in Asia and South America and greatly increased use of recovered fiber in Europe. The study does not consider the global demand/supply situation for fuelwood and charcoal. Therefore, if the world's natural forests are to be given a higher degree of protection than is foreseen in most of the scenarios presented in the study, there is clearly a need for a global reappraisal of how the world's demand for wood fiber should best be managed.

8. Possible Solutions

The world uses more wood every year and all forecasts expect demand to continue rising to the year 2010 and beyond. The desirable scenario is to ensure that pressure is taken off natural forests and that a rapidly increasing fraction of supply comes from fast-growing plantations. Market forces are already encouraging more production of industrial wood fiber, particularly pulp, from plantations. Some countries, such as India, have encouraged widespread planting of community wood lots to supply fuelwood needs. In addition, environmental and social concerns, together with technological advances, are helping to slow and reshape demand for some wood products in a variety of ways. This section briefly reviews some of these encouraging trends, and outlines policy approaches which could magnify their effect and so accelerate the process of re-orienting our current wood consumption patterns in a more sustainable direction.

Improving Management of Tropical Hardwood Forests

Destructive logging operations in many tropical forests are propelled in part by the need for developing countries to generate export revenues. In spite of this, a number of governments have attempted to slow their national deforestation rates by introducing economic incentives to loggers to replant (Costa Rica, Indonesia) or even banning logging in virgin forests altogether (Philippines). However, the adoption of sustainable forest management practices tends to involve more administrative oversight, higher operating costs, and potentially lower yields. Industrial-scale timber extraction agreements are sometimes awarded on the basis of coercion, corruption or inadequate oversight. In such circumstances, licences should be reviewed and, if found to be irregular, revoked. Licences should then be auctioned in a transparent manner, with some prequalification of eligible bidders based on a proven track record of responsibility. This system would encourage more sustainable patterns of investment. Clarification and strengthening of local and traditional property rights in many developing countries would also do much to stimulate local community input to the design and implementation of forest management schemes. Property rights that allow communities to receive medium and long-term economic benefits would encourage non-destructive logging practices. Rapid depletion of valuable forest resources could also be countered through consumer willingness to pay a higher price for tropical hardwoods, which would provide the incentive for producers to invest in the long-term future of their forest assets.

Appreciating Woodfuels

Fuelwood and charcoal consumption is too often neglected in global assessments of fiber supply and demand. Biomass (which includes animal dung and crop residues) currently provides about one-third of the energy consumed in developing countries and, even under the most optimistic scenarios of economic growth, over a billion people will be dependent on woodfuels as their primary source of energy for the foreseeable future.[61] Woodfuels are a renewable and carbon-neutral energy source, and deserve full integration into national energy policies, alongside commercial fossil fuels. If wood resources are to be managed sustainably, it is essential to base planning decisions on sounder information. Yet most experts today would agree with the statement that, "information on biomass production and use patterns is grossly inadequate even as a basis for informed guesses, let alone the making of policy and the implementation of plans."[62] Biomass data are difficult to gather and surveys can be costly and time-consuming. There is an urgent need for cost-effective sampling and analysis techniques in order to reduce the current huge range of uncertainty regarding consumption and future demand.

Even in the absence of better information, widespread planting of local, community-managed woodfuel plantations would not only reduce degradation of natural forests and other wooded areas, but would help to arrest desertification and relieve the hardship involved in fuel collection. Woodfuel production and harvesting systems can be, and often are, environmentally sustainable, and can serve other social objectives such as income generation.

Improving the Efficiency of Fiber Use

Technological advances in North America and Europe have significantly reduced the amount of waste associated with wood fiber processing. According to a recent North America Timber Trends Study, in Canada, the amount of roundwood required to produce 1 m^3 of sawnwood or plywood has fallen from an average of 2.67 m^3 in 1970 to 1.98 m^3 today.[63] In addition, new products such as mechanically engineered wood products are able to utilize residues which formerly were wasted. A chemical process developed in the Netherlands has proved successful in upgrading softwood into a product with all the attributes of tropical hardwood species.[64] Paper recycling has been increasing in many countries and, in 1995, the global waste paper recovery rate reached 41 percent.[65] This has enabled the proportion of wood fiber used in paper-making (that is, fiber made from pulpwood logs or chips) to fall by nearly one-third since 1970, as the input from recovered waste paper rose more than threefold. Numerous policy initiatives in the developed countries, notably "extended producer responsibility" legislation, have proved effective in raising the recycling rate above market-induced levels. These initiatives have been driven mainly by concerns over solid waste volumes, since waste paper accounts for between 30 and 40 percent of municipal solid waste in the OECD countries.[66]

Further improvements in efficiency are most likely to be stimulated by industry anticipation of rising fiber prices. Projections carried out by the European Forest Institute indicate that higher or lower fiber prices could induce a difference in consumption of about 13 percent by 2010 and 50 percent by 2050.[67] Raw material taxes are one option, but conferring protected status on broad areas of old-growth forest, and requiring the adoption of sustainable forestry practices in all secondary-growth forests, would both encourage higher prices and improve forest management. Nor would the adoption of such policies necessarily reduce long-term fiber supply. According to the FAO, sustainable forestry can be expected to reduce harvests in the short-term, and raise costs by between 5 and 25 percent but, in the longer-term, supply should increase, as a result of improved site maintenance and reduced damage to growing stock (damage caused by traditional, "high impact" logging practices).[68]

At a more fundamental level, efficiency of wood fiber use could be substantially improved by substituting alternative materials in many common applications. There is no compelling reason why low-value products such as shipping crates and pallets should be made of wood, other than the current low value of wood fiber. In the United States, 14 million trees are allegedly used annually in mail order catalogues, while one-fifth of the country's lumber goes into crates and pallets, most of which are discarded.[69] Similarly, even many construction uses could be substituted in some countries, with possible benefits for energy efficiency, durability or other qualities. Currently, many of our uses of wood fiber go unquestioned, for a host of institutional, historical, cultural and economic reasons. Efforts to diversify to other forms of fiber, or inorganic materials, could yield unexpected benefits. As one example, wood pallets currently serve as the major vehicle for the import of invasive species such as the Asian long-horn beetle, and they have been identified as a serious threat to biological diversity.

Consumer Choice and Timber Certification

There is ample evidence that many consumers in the industrialized countries are actively seeking paper products which are certified as coming from sustainably managed softwood forests, and timber importers in Germany, the Netherlands, and the UK have created buyers' groups to secure supplies of certified timber.[70] Certified tropical wood products are currently scarce in the market, despite high public concern over deforestation. The leading international accreditation body, the Forest Stewardship Council, has been able to bring together a range of environmental non-governmental organizations (NGOs), governments, and timber companies to work together constructively towards improved management of the world's forests. There are no available worldwide production figures for wood from certified forests. However, it is known that the total area of certified forest has increased dramatically in the last year. In October 1997, there were 3.8 million hectares certified in 17 countries.[71] By January 1998, the number had increased to 6.3 million hectares.[72] In August 1998, there were 10.5 million hectares certified in 26 countries; by October this had increased again to 12.3 million hectares in 27 countries.[73] This is more than a three-fold increase in a twelve-month period, with many additional forest owners and managers seeking certification. Certified forest products currently account for a negligible share of world trade, though the FAO believes that market share is likely to grow with consumer awareness of forest issues. The potential for change is great. For example, the European Union, where consumer interest in certified tropical wood products is demonstrably high, imports some 25 percent of the world's traded tropical timber.[74]

Encouraging Fast-Growing Plantations

In spite of the potential gains from demand side measures and improved efficiency outlined above, they are not likely to be enough to meet projected increases in demand, especially for certain product streams. Rising demand for pulpwood, for example, should not be discouraged when it is a fundamental requirement of growing literacy in the developing world. And, while efficiency gains in the developed countries have enabled a partial decoupling of wood fiber consumption from exploitation of forest resources, their industrial wood consumption still rose by some 23 percent between 1970 and 1990.[75] Industrial wood use in the developing countries is rising much faster and is not yet operating at comparable levels of efficiency. The most realistic prospect of meeting the world's demand for wood fiber in a sustainable manner lies in a determined effort to increase production by establishing new plantations.

The prospect of declining harvests from logged out, or protected, natural forests, and associated rising fiber prices, has already encouraged significant investment in industrial fiber plantations. Approximately 100 million hectares world-wide have now been converted to industrial wood plantations, of which just under half are in the tropical and sub-tropical regions. Plantations occupy an area equivalent to just 3.4 percent of total forest area but produce nearly 25 percent of total industrial wood supply. Intensive fiber production from plantations is opposed by some environmentalists, who cite the damage done to local biodiversity by monocultural production and the introduction of alien species, the degradation of soils and water systems due to chemical use and poor soil management, and the sheer ugliness of immense areas of geometrically aligned spindly trees. These objections deserve to be taken seriously, and they can be overcome. Environmentally sensitive plantation forestry is possible, and is already being practised in many countries. Good practices include selecting sites which are not crucial to biological conservation, planting "buffer zones" which protect water courses, leaving enclaves of natural forest to provide habitat for native flora and fauna – including beneficial predators – and adopting ecologically sound methods of pest management. Such practices can be required by law; Brazil, for example, requires that 30 percent of plantation area be left under natural management.

Environmental measures of this kind increase the total area needed to produce a given quantity of wood from a plantation. Even so, it has been estimated that the world's entire current consumption of industrial roundwood could be supplied from intensive plantations occupying an area equivalent to less than 10 percent of today's natural forest.[76] If demand for industrial roundwood increases by 30 percent by 2010, and by 50 percent by 2050, as most experts say it will, most of it could be supplied from about 500 million hectares of plantations. This will require concerted effort and determination that wood fiber can and will be produced from specialized areas, not simply harvested opportunistically from the world's remaining natural forests.

Notes

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III. Fish Consumption and Aquatic Ecosystems

1. Global Fish Consumption

In 1996, the global harvest of fish rose to a new record of 121 million tonnes.[1] This puts fish production well ahead of any one of the four main animal commodity groups (beef and veal, sheep meat, pig meat, and poultry meat).[2] In developing countries, fish production is not far behind the total production of all four animal commodities put together.[3] Fish and other aquatic foods thus play an under-rated role in the human diet. In 1993, the latest year for which all data are available, food fish accounted for 16 percent of animal protein consumed world-wide and, in some Asian countries, the proportion rises to between 30 and 50 percent *(Table 1)*. For about one billion people, seafood is the primary source of animal protein. Fish products are also an important source of protein in animal and fish feeds. More than 27 percent of the total 1995 fish catch, or 31 million tonnes, was processed into "non-food fish," that is, fish meal and fish oils.

Production, Consumption and Trade

The global fish supply comes from three main sources. Harvests from the sea, known as marine captures, accounted for some 72 percent of the total fish harvest in 1996, inland captures (from lakes, rivers and ponds) for about 6 percent. The remaining 22 percent came from aquaculture (fish farming), where fish are raised either in inland waters (13 percent) or in specially constructed ponds or cages along coastlines (9 percent).[4]

World fishing activity is highly concentrated, with just 20 countries accounting for about 80 percent of total production, and 10 countries for almost 70 percent *(Figure 1)*. By far the biggest producer is China, even allowing for the fact that just over 60 percent of production there now comes from aquaculture.[5] Today's situation represents a major change from the 1950s, when about 80 percent of the world's fish catch was taken by the developed countries.

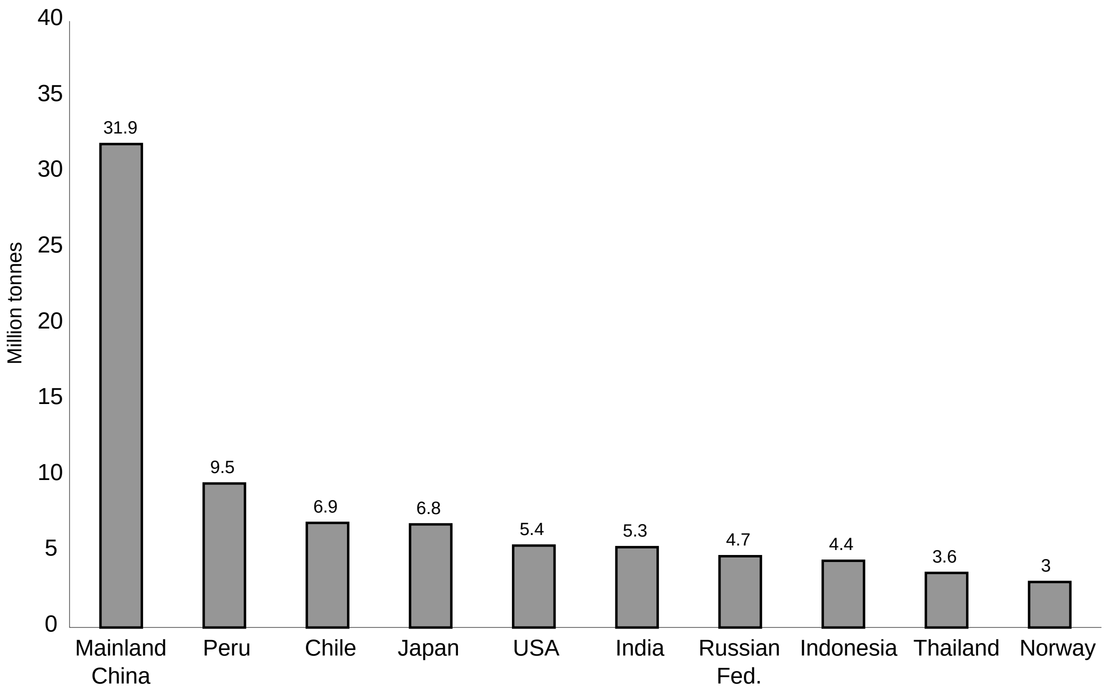
Perhaps surprisingly, in an age of factory trawlers and industrial-scale fishing, around half the fish eaten in the world today come from inshore and coastal areas that are dominated by small and medium-scale fishers.[6] Subsistence and local market fisheries therefore remain of key importance to the food security of coastal and inland populations in low-income countries. Developing countries account for the bulk of fish consumption *(Figure 2)*. However, they are becoming

Table 1: Fish Consumption in the Human Diet, 1993

Region	Per Capita Fish Supply (kg)	Fish Protein (as % of Animal Protein)
Africa	7	17.4
North America	18	7.5
South America	8.9	7.4
Europe	18.1	9.0
Former USSR	11.2	9.3
Oceania	20.1	8.6
Asia (exc. China)	13.9	25.7
China	14.3	21.5
World	13.4	15.6

Source: FAO

Figure 1. Principal Fish Producers, 1996 (capture fisheries and aquaculture)



Source: FAOSTAT

more active as exporters: international trade in aquatic products continues to increase in volume and value, reaching $US52 billion in 1995.[7] The developing countries' share of total seafood exports reached 56 percent by value in 1995, and net receipts of foreign exchange (exports minus imports) amounted to $US18 billion.[8] The industrialized countries, where average per capita fish consumption is higher than in the developing world, dominate imports of seafood products, accounting for 83 percent in value terms. Japan, with the highest per capita fish consumption in the industrialized world, accounted for about 30 percent of world imports in 1995.[9]

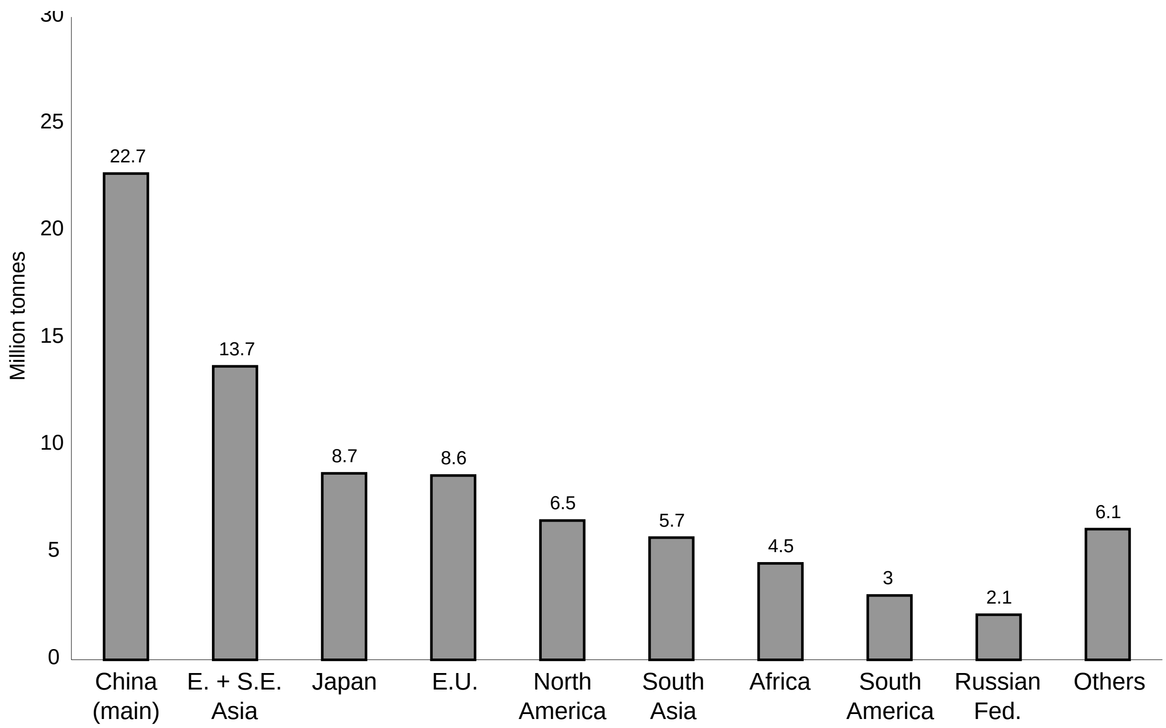
This pattern of production and consumption has been encouraged by two developments. The establishment during the 1970s and 1980s of Exclusive Economic Zones (EEZs), which grant coastal nations exclusive rights to use and develop fisheries within a 200-nautical mile boundary, shifted the balance of production to developing countries and forced many industrialized countries to import fish which they had previously caught with their own "distant water" fleets. Secondly, many developing countries have built up aquaculture industries which are almost entirely oriented towards exports, and the sector has assumed great importance in many national economies. Shrimp, for example, have become the most prominently traded aquaculture product internationally,[10] and over 99 percent of production is in developing countries.

2. Unfolding Trends in the Global Fisheries Industry

Rising Demand, Rising Production

The global fish harvest has increased more than fivefold from its 1950 level of 21 million tonnes and the growth in production has been relatively smooth, unmarked by the erratic ups and downs characteristic of many other food commodities *(Figure 3)*. Demand has been fuelled by population growth, and a greater concentration of people in coastal settlements; nearly 40 percent of the

Figure 2. World Food Fish Consumption, Average 1993-95



Source: FAOSTAT

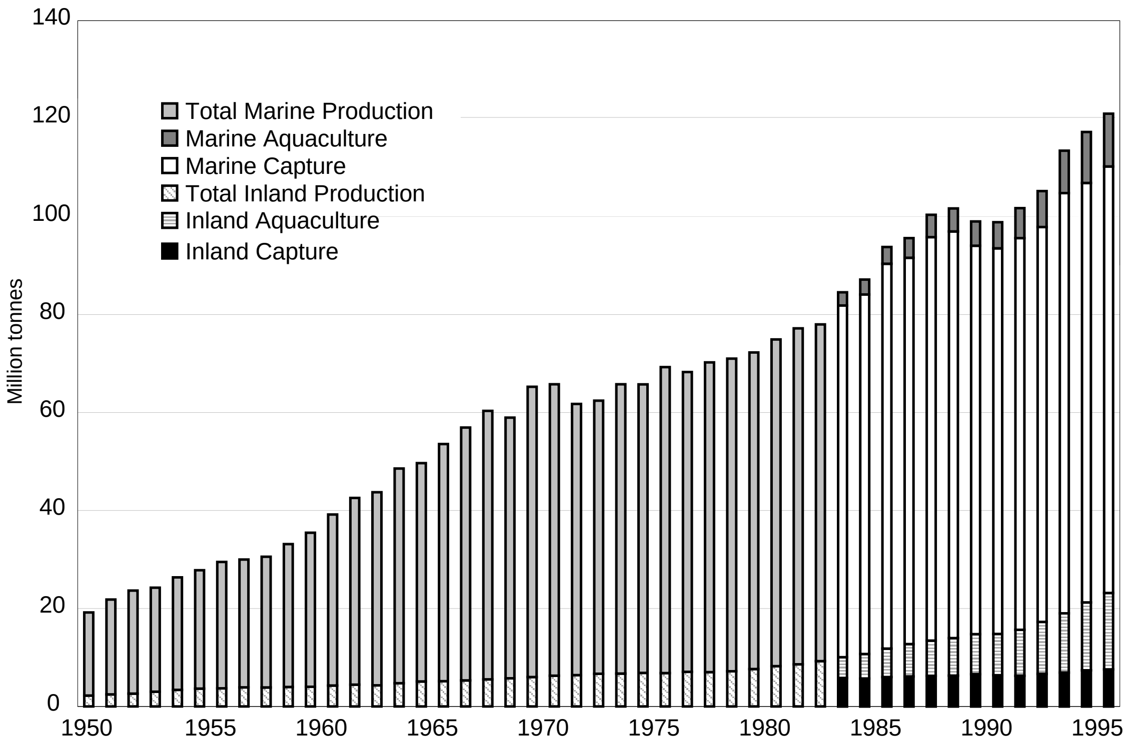
world's population now lives within 100 km of the sea.[11] Equally, rising income has stimulated greater consumption of higher-value seafood products, such as shellfish and salmon. Fish production has more than kept pace with population growth; per capita fish supply rose from 9.1 kg/year in 1961 to 14.4 kg/year in 1995.[12]

Fisheries growth has also been supply-led, encouraged by open access to marine resources, new technology, expanding national claims on fisheries, and economic development policies which invest in production capacity in order to provide employment and generate foreign earnings. Technological advances have brought the greatest change to the industry. Electronic navigation systems, sonar location devices, and satellite observation have made tracking fish a swifter and more efficient process. Gigantic trawl and drift nets, several kilometers long, can catch hundreds of tonnes of fish in a day. On-board processing and freezing facilities enable boats to stay at sea for weeks or months at a time.

The Rise of Aquaculture

One of the most striking trends of the past two decades has been the rise of aquaculture, which now provides 22 percent of global fish production. The sector has grown at an average annual rate of more than 10 percent since 1984, with growth accelerating in recent years, far exceeding the growth rate for capture fisheries or livestock meat.[13] Asia, with a long tradition of cultivating fish in ponds adjacent to farms, dominates the aquaculture industry, accounting for over 90 percent of world output. China, with huge areas of inland carp ponds, is the major player. Starting from a much lower production base, Southeast Asian countries and Latin America have rapidly expanded their output of farmed crustaceans to supply export markets, while Europe and the United States have increased their production of temperate finfish, notably salmon and trout, and molluscs.

Figure 3. World Fishery Production, 1950-1996



Source: FAOSTAT
Note: Disaggregated data for aquaculture are not available before 1984.

A Changing Harvest

The superficial picture of constantly rising fish harvests is not a reliable indicator of the state of aquatic ecosystems. Much of the production increase of the past decade or more has come from aquaculture. And the steady increases in annual marine captures mask a far more complicated picture in which regional fishing grounds, and specific fish stocks, have been successively exploited and depleted. The FAO has compiled data showing the sequence of dates at which peak demersal fish harvests (high-value fish such as cod and haddock) were taken in the various oceans of the world. Harvests clearly peaked in the Atlantic between the late 1960s and early 1970s and have declined ever since. Harvests in the Pacific peaked between the mid-1970s and late 1980s, and then in the Indian Ocean, in the early 1990s.[14] A similar sequential pattern can be seen in peak harvests of different fish species. Atlantic cod and haddock catches peaked by 1970, then came the turn of species including, successively, anchoveta and mackerel, sardines and pilchards and today, skipjack tuna, Chilean jack mackerel, and Pacific cod.[15] The overall trend has been a decline in the catch of high-value demersal fish, and their substitution by lower-value pelagic fish. Pelagic fish now constitute about 60 percent by weight of the global catch, and 40 percent by value.[16]

Global Fishing Fleet Capacity

The size of the world's fishing fleet nearly doubled between 1970 and 1992,[17] while technological improvements improved the catching capacity of each boat. Productivity increases are difficult to estimate for the global fleet, but a study of six fishery fleets in OECD countries indicates technical capacity increases of between 2.8 percent and 6 percent per year over different time periods between the 1960s and early 1990s.[18] Global advances in technical capacity have not brought proportionate gains, however; marine captures rose by about 30 percent between 1970 to 1992, equivalent to an average annual growth rate of under 1.4 percent. Fishing effort has continued to increase and, today, the FAO estimates that the global fleet is approximately 30 percent larger than it needs to be to fully harvest the available resources.[19] This estimate has been challenged as too conservative, since it treats all the world's fish as a single stock and does not reflect the historical pattern of serial overfishing of one species after another. A recent study, based on data since 1970 for 14 leading fishing countries, estimates a level of about 150 percent in global fleet overcapacity. In other words, there may be two-and-one-half times the level of catching power in the fleet needed to achieve a catch level that would not further deplete stocks.[20]

To summarize these trends, fish and other seafood (principally crustaceans, molluscs and aquatic plants) have provided an important and growing component of the human diet over the past 40 years. Production has outpaced population growth, thanks to major investments in global fishing capacity. This capacity now exceeds what marine fisheries can support. The total annual harvest of fish from the sea appears close to its peak, and many regional fisheries are in decline. So far, however, production has been kept up by exploitation of those few fishing grounds which still have potential and, to a greater extent, by expanding aquaculture.

3. A Renewable Resource in Decline

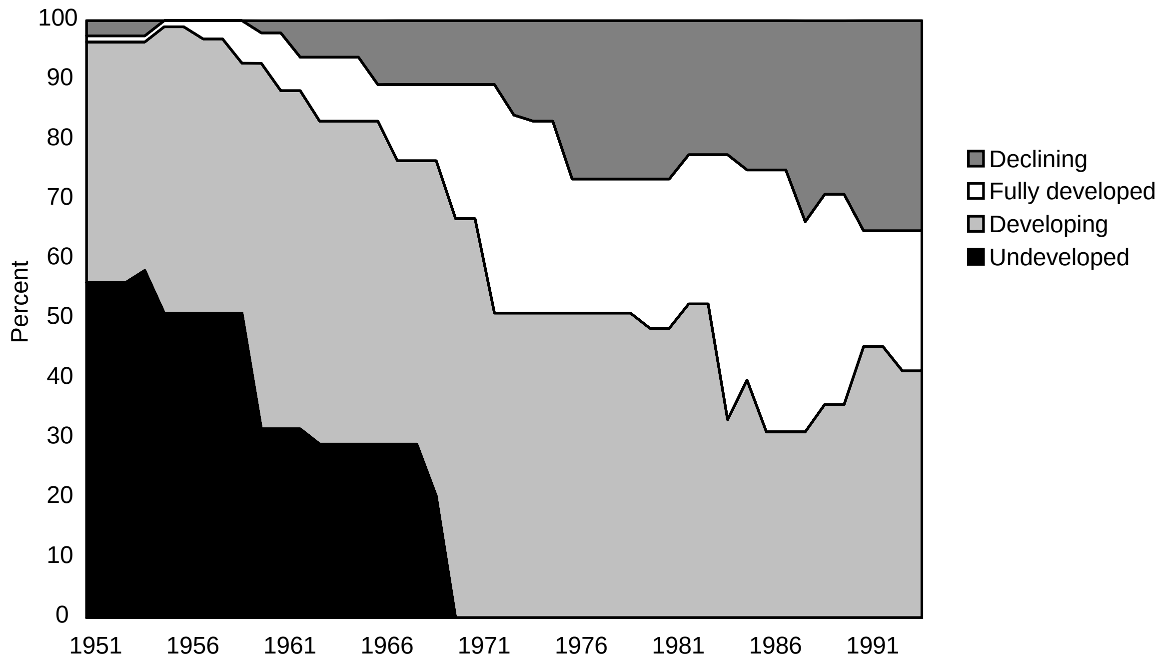
Overfishing has been formally recognized as a problem since the beginning of the century and was the subject of an international conference as early as 1947.[21] Scientific warnings, however, have met strong political and instinctual resistance to the idea that the ocean's bounty might be exhaustible. The world's oceans are indeed huge, but the area relevant to fishing activities is relatively small. Most productive aquatic ecosystems (in terms of harvestable primary production) occur within a narrow band, often less than 30 meters in depth, ringing the world's coastlines and coral reef systems, and in a few important "hot spots" scattered about in areas of upwelling or aggregation where fish feed or migrate. These areas are where fishing fleets concentrate their operations: about 90 percent of capture fisheries are found in coastal waters within the 200-nautical-mile zones of coastal states.[22]

Serial Exploitation

The FAO has conducted a detailed review of historic harvests from the top 200 species-area fishing resources, which together account for 77 percent of marine fish production. The study reveals a clear "boom and bust" cycle of exploitation in which fish stocks are rapidly developed, harvests peak, then decline with over-fishing. The results, published in 1994, indicated that 60 percent of the world's fisheries are being fished at or beyond their level of maximum productivity, and that none at all remain to be "opened up" *(Figure 4)*.[23]

In those fisheries classified as fully exploited or depleted, catches declined from a peak of 14 million tonnes in 1985 to 8 million tonnes in 1994 – about the same level as was obtained in the mid-1960s, with a far smaller fleet.[24] In some regions, declines have been even more spectacular. In the Southeast and Northwest Atlantic, demersal fish harvests have fallen by 66 percent and 75 percent respectively in the last 20 years.[25] Since the 1960s, the North Sea mackerel fishery has declined by 80 percent, while the herring fishery, though shut down entirely between 1977 and 1982, has not fully recovered.[26] Experience suggests that over-fished stocks can recover, given adequate protection, but that the process takes many years. The cod fisheries of the Grand Banks off the coast of Newfoundland were closed in 1992 after stocks collapsed; five years later, they were partially reopened but scientists, environmentalists and some fishermen warned that it was too soon.[27] One explanation for the slow recovery here, and in cod fisheries off the coast of Maine, appears to be the use of deep sea trawls which damage flora and fauna on the sea bed. These complex living communities provide food and shelter to young cod but, once lost, can take many decades to re-establish themselves.[28]

Figure 4. Major World Fisheries in Various Stages of Fishery Development

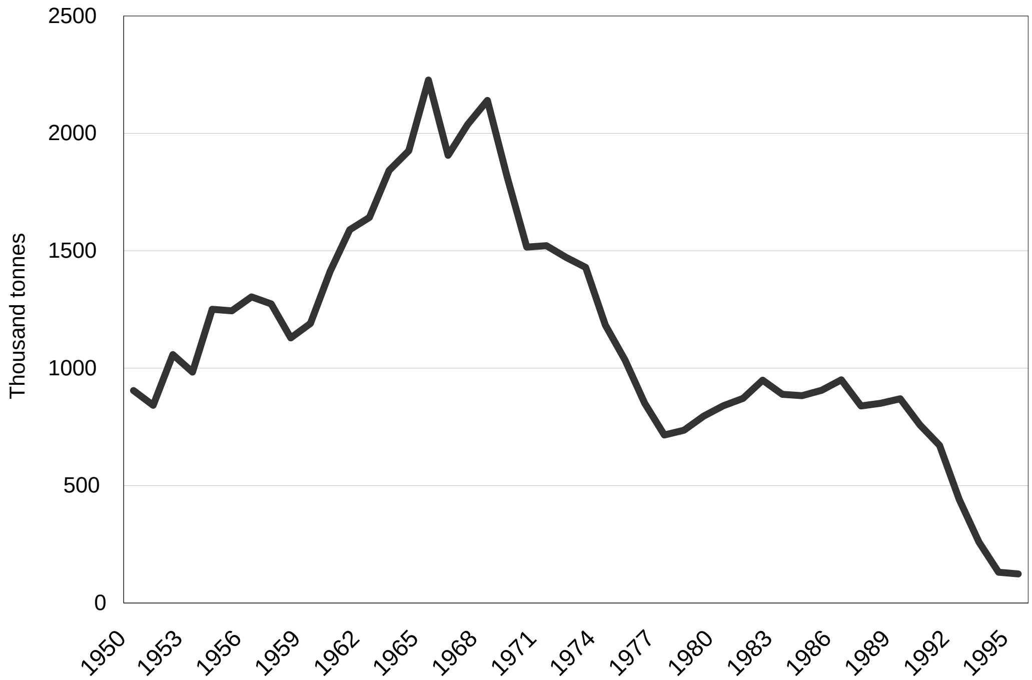


Source: Grainger and Garcia (note 15).
Notes: The chart provides a striking illustration of the intensification of fishing effort since 1951. In that year, some 95 percent of the world's marine fisheries were under-exploited and fish harvests were rising almost everywhere. By 1971, about 30 percent of fisheries were fully developed or already in decline, and the balance of 70 percent were being developed. None could be classified as undeveloped. By 1994, fish harvests were falling in 35 percent of fisheries and were at maximum exploitation levels in another 25 percent. Potential development remains in about 40 percent of the world's fisheries.

Some of the most profitable species of fish, such as Atlantic cod, haddock and bluefin tuna have been fished to the brink of commercial extinction in many areas *(Figure 5)*. In 1996, the World Conservation Union (IUCN) added these fish to its "red list" of endangered species.[29] In their place, the fishing industry has turned to inferior species – generally smaller, bonier, oily fish - such as anchovy, pilchard and mackerel. These too, have been subjected to over-exploitation, with the most notorious production crash hitting the Peruvian anchovy stocks in the early 1970s. Today's boom is occurring in the last relatively undeveloped areas of the Pacific and Indian oceans, with high harvests of, for example, skipjack and yellowfin tuna, Pacific cod, and Chilean and Indian mackerel.

The FAO has reported on numerous occasions that the rate of increase in the world's fish harvest is slowing and is approaching zero, indicating that the predicted maximum production from the world's conventional marine resources under current exploitation regimes (about 82 million tonnes) has been reached.[30] Sustainable maximum yields are theoretical and always subject to scientific uncertainty. Nevertheless, between 60 and 70 percent of global fisheries are considered to be in need of urgent management to prevent imminent decline or to rehabilitate depleted stocks. The aggregate picture of high yields in the 1990s thus hides the increasing occurrence of overfishing on a multitude of different stocks, compensated by intense exploitation of a dwindling number of developing stocks.

Figure 5. Annual Catch of Cod, Hake, and Haddock, 1950-1995



Source: FAO FISHSTAT

Overfishing is a more complicated phenomenon than simply taking too many fish out of the ocean. Which fish are taken, at what stage of their life cycle, are important factors, as are the methods used to take them. The “productivity take” from the world’s productive fishing grounds (how much biomass is removed) is between 25 and 34 percent, close to the percentage of plant matter removed in terrestrial farming systems.[31] Fisheries management, however, does not involve any equivalent of “planting,” or of soil maintenance. Much fishing has been carried out in a manner more akin to mining than farming. There is now a rapidly growing consensus among fisheries experts that the precipitous decline in so many of the world’s commercial fish stocks is the result of disregard for the complex functioning of aquatic ecosystems and repeated failures of management.

4. Current Fishing Practices and Ecosystem Impacts

Modern fishing techniques, both in capture fisheries and aquaculture, are disturbing many parts of an interlocking biological system that connects estuaries, coastal zones, continental shelves and banks, and the deep ocean. Inland fisheries are intimately linked to the ecology of surrounding soils, water courses and the atmosphere. Too many fish are being caught, or grown, in ways that are destroying natural habitats, wiping out key parts of the marine food chain, changing species balance, and degrading water quality. Coastal fishing activities also interact with other human stresses on the aquatic environment, notably pollution from sewage, industrial effluent, and agricultural run-off, while inland waters concentrate nutrients and toxics from terrestrial run-off and atmospheric deposition. The consequent disruption of biological balance in aquatic ecosystems is critically impairing the natural ability of fish to survive and reproduce.

Fishing Down the Food Chain

As already described, when overfishing depletes prized species like cod and tuna, fishing fleets turn to smaller species, further down the ecological food chain. These species often flourish when their natural predators have been removed, only to be scooped up in their turn. A recent study has quantified the extent of this global shift from higher level to lower level species.[32] The study classifies all commercially important marine species in four different trophic levels (steps in the food chain); predator species like tuna and swordfish are level 4, anchovy are level 2.2, while grass, detritus and algae are level 1. Since the 1950s, it seems that the mean trophic level of fish catches from all fisheries declined from more than 3.3 to less than 3.1 in 1994. The measured decline is probably an underestimate, as catch measurements in the tropics are poorly recorded. Since most fish suitable for human consumption fall between about 2.5 and 4, the scope for further downward movement is limited. The logical conclusion of fishing down the food chain is a diet of plankton (trophic level 2). There are more immediate risks to marine ecosystems. In the North Sea, for example, cod have been fished out and substituted with catches of their prey, the Norway pout. The pout, in turn, prey on tiny organisms called copepod and krill. But krill also eat copepod so, if pout are removed, the krill population expands and feasts upon the copepods. Because copepods, to come full circle, are the main food of young cod, cod stocks cannot recover, even though they may be legally protected.

Dumping the Parents, Eating the Babies

For every four fish caught, one is thrown away. When fishing nets are pulled in, they contain many individuals which are unwanted because they are too small, the wrong species or because the fishing vessel does not have a permit, or a large enough quota, to take them. Much of this "bycatch" is tossed overboard, and a high proportion of individuals do not survive capture, or the trauma of exposure and handling on deck.[33] The most recent and authoritative estimate is that 27 million tonnes of fish were discarded in 1994, equivalent to one-third of the total food fish catch. In addition, many hundreds of thousands of birds, seals, dolphins, turtles and other non-fish species were also killed as bycatch. This is far higher than earlier estimates, and represents a calamitous waste of resources. The volume of bycatch varies with target species; the trawl fishery of the Northwest Pacific, targeting pollock, sole, cod and mackerel, produced the world's largest volume of waste at over 9 million tonnes.[34] However, the shrimping industry is responsible for the highest catch:discard ratio, with an average of 1:5 world-wide. Because of small mesh nets and high species diversity in tropical waters, bycatch in tropical regions can exceed the shrimp catch by 15 to 1.[35] In the Gulf of Mexico shrimp fishery, for example, an estimated 12 million juvenile red snappers and 2,800 tonnes of sharks are discarded annually.[36] World-wide, shrimp fisheries account for fully 35 percent of commercial fishery discards.[37]

The ecological impacts of bycatch vary greatly in different fisheries, but a number of recent studies tends to confirm that populations of target and non-target species can be adversely affected. If too many juveniles are killed, the future breeding stock is diminished. For example, high discard rates of undersized fish were a contributing factor in observed population declines in the Gulf of Maine cod and haddock fisheries and in the skate fishery of the Irish Sea.[38] Discards thus aggravate the problem of catching fish too young – even the legally allowed catch does not always sufficiently protect the next generation. Overfishing of mature individuals, followed by overfishing of smaller fish, has caused the average age and size of fish harvested to decline markedly. As one example, the average size of swordfish caught has shrunk from 120 kg to 30 kg over the past 20 years and the breeding population has been reduced by half. Consumers are now eating primarily small, immature individuals.[39]

Destroying the Nurseries

The reproductive cycle of many commercially important fish depends on specific marine habitats for the protection of eggs and the nourishment of hatched larvae. Three of the most crucial habitats which are currently being degraded by various fishing techniques and fish farming are the benthic communities which live on the sea floor, coral reefs, and coastal mangrove forests.

Commercial fleets have increasingly invested in mobile gear – trawl nets and dredges – which are dragged along the sea floor of continental shelves. Today, it is even possible to trawl the continental slopes, at depths of up to 1,200 meters. Nets known as “rock-hoppers” are fitted with rollers which enable them to traverse the most uneven sea bed, scraping and sliding over boulders or other obstacles. The practice largely destroys the benthic community (life forms on the sea bed including sponges, tube worms, urchins, anemones and hydrozoans) which provide food and habitat for young fry. It has been argued that the sea bed is naturally subject to periodic disturbance by storms, but the impact of trawling is felt at much deeper levels and trawls tend to be repeated at much higher frequency. The intensively-fished Georges Bank off New England, where groundfish stocks collapsed in the early 1990s, was trawled 3 or 4 times a year between 1984 and 1991, with specific areas being revisited far more frequently.[40] Trawling for prawns in tropical waters is producing similar effects.

Coral reefs are comparable with tropical rainforests in their level of species diversity and biological productivity. About 4,000 species of fish and 800 species of reef-building coral have been described to date, and the total number of species may run into millions.[41] Coral reefs are currently under threat from a multitude of assaults, including development, pollution, tourism and overfishing. Two fishing practices are particularly destructive and, for once, are not the work of industrial-scale fishing fleets. Dynamite is increasingly used by local fishers as a quick and effective means to harvest fish from labyrinthine coral systems. Incidents of blast fishing have been reported with increasing frequency throughout Southeast Asia and parts of the Caribbean.[42] Dynamite blasting does irreparable damage to fragile coraline structures and rich habitats are lost. Another threat is the practice of fishing with sodium cyanide on the reefs of Southeast Asia. Cyanide is used to stun and capture fish live, either for sale as ornamental aquarium fish or to supply the Chinese restaurant market for large, live reef fish, available for selection by patrons. Choosing to eat rare and expensive species has become a status symbol to wealthy consumers in Hong Kong and other Asian and North American cities with large Chinese populations. Once confined to the Philippines (which is now taking action against the problem), cyanide fishing has spread throughout Indonesia and into Papua New Guinea, Vietnam, the Maldives and Fiji.[43] Cyanide is highly toxic to many non-target fish, and kills corals; systematic data are lacking but there is widespread anecdotal evidence of the physical and chemical damage caused by poison-fishing.[44]

Coastal mangrove forests are found in tropical and sub-tropical inter-tidal areas of the world. They provide rich habitat for a wide range of flora and fauna, from fungi, lichens, insects and crustaceans, to numerous fish, birds, reptiles, and mammals. Mangroves are important feeding, breeding and nursery grounds for numerous commercial fish, including wild shrimp. In some tropical countries, species that depend on mangroves at some stage of their life cycle make up 80 to 90 percent by value of the total catch.[45] Mangroves are currently threatened by various forms of exploitation and coastal development, of which conversion to coastal aquaculture is one of the more serious.

During the aquaculture boom of the 1980s, large tracts of coastal mangroves were dug up to make way for shrimp ponds. China, India and the Southeast Asian countries now have about 1.2 million hectares under shrimp ponds, and nearly 200,000 hectares have been converted in the Western hemisphere, chiefly in Latin America.[46] Many of these ponds were established in open salt flats or other relatively unproductive land. Many others, however, were dug out of mangrove forests. One estimate is that some 40 percent of small shrimp farms in Asia displaced mangroves.[47] World-wide, shrimp farming may be responsible for less than 10 percent of total mangrove loss, but in some countries, notably Thailand, the Philippines, Vietnam, and Ecuador, the proportion appears to be much higher.[48] The consequences for fishery production are serious. Various studies confirm that the loss of mangroves leads to a decline in wild fish harvests, as food and shelter for numerous species are removed.[49] Depleted catches, in turn, lead to unemployment and social hardship among artisanal fishers. Ironically, many shrimp farms, particularly those in Latin America, stock their ponds with shrimp larvae caught in the wild, because they are believed to be superior to those raised in hatcheries. Intensive collection of shrimp larvae from estuaries provides much-needed local employment, but is believed to have seriously depleted populations of post-larval wild shrimp in some areas. Thus, the farmed and wild-catch shrimp industries are placed in competition with each other.

Aquaculture

The environmental impacts of fish farming need to be taken seriously, because the sector is growing so fast, and because it is expected to provide much if not all the increase in fish production that will be required in coming decades *(see Section 5)*. Environmental concerns tend to focus on fish farming in coastal zones (which accounts for one-third of total aquaculture production) and particularly on the intensive cultivation of carnivorous species such as shrimp, prawn, and salmon.

In tropical and semi-tropical regions, the impacts associated with mangrove loss extend well beyond the damage to wild fishery habitats already described. Mangrove removal entails the loss of ecosystem services including mitigation of coastal erosion and flooding, and regulation of the drainage capacity of river systems, as well as a huge range of local goods including building materials, fuels, animal and plant foods, fibers, dyes and tannins.

Intensive aquaculture can also disrupt local farming with the demands it places on land and water resources. Shrimp farms require large volumes of fresh water to grow out their stock – raising one kg of shrimps requires 50 to 60 thousand litres of water.[50] Many paddy rice farmers in South and East Asia are finding themselves in a losing competition for land and water. For example, thousands of farmers in Bangladesh and India are reported to have suffered from invasion of their lands by aquaculture businesses and from damage to their crops by seepage of saltwater from shrimp ponds. Some hundreds of thousands may have been displaced, prompting violent clashes and protests to the government.[51] In 1997, India took the unusual step of ordering the closure of all commercial shrimp farms in five coastal states, after a long campaign by environmental groups and local fishing and farming communities.[52]

If improperly managed, intensive fish farms in both tropical and temperate zones can be highly polluting. Pond effluents can contain high concentrations of nutrients, pesticides, antibiotics and other wastes, which are flushed out into surrounding waters – ponds need frequent water exchange to remain healthy. Too many farms in one area can overwhelm the assimilative capacity of coastal ecosystems, leading to eutrophication of local waters *(Box 1)*. In closed ponds, sediments may build up, leading to depleted oxygen levels and a concentration of toxic metabolites. A number of Asian countries, including Taiwan, Thailand and Vietnam have suffered from sudden shellfish production crashes, caused by improper site selection (especially with regard to water supply and discharge), cumulative "self pollution" and disease. Viral infections, caused sometimes by the introduction of non-native hatchery larvae, often compounded by inadequate health management, have decimated shrimp stocks in some of the leading producer countries, including Vietnam, Taiwan, Thailand and Indonesia. Disease is now considered the most limiting factor in shrimp cultivation. Estimates of economic losses suggest that developing countries in Asia lost at least $US1.4 billion in 1990 and losses have since increased; the World Bank has recently estimated the global costs of shrimp disease at around $US3 billion.[53]

Further problems relate to the fact that aquaculture often involves the monocultural production of alien species. Introduced species can, and do, escape into the wild; others are deliberately released, and many experts have expressed fears over the potential loss of genetic diversity if interbreeding occurs between farmed and wild strains or species. This is a distinct possibility where hundreds of millions of hatchery fish are released annually, as in the salmon fisheries of the Northwest American coast. There are risks: for example, farmed salmon may be bred for traits such as faster growth, late sexual maturing, and high tolerance for crowding. These traits are beneficial in culture but may constitute a serious handicap to survival in the wild. So far, however, the actual genetic impact of such practices has not been adequately evaluated.

Widespread and costly damage has certainly been caused by some introductions, via farmed aquatic species, of new predators, parasites, and diseases. Crayfish "plague" was imported to the United Kingdom from North America, mollusc parasites have been disseminated by shipments of Pacific oyster seed, a lethal trout virus has been spread throughout the United States and into Japan.[54] The effects can cascade through the marine system. In 1989, the wild sea trout fisheries of Ireland collapsed, with catches down by 90 percent. The fish were killed by infestation by a species of lice, previously almost unknown, which was traced to farmed salmon in the area. Attempts to kill the lice with chemicals in turn led to reduced shellfish yields and were suspected in connection with a sudden increase in the number of cataracts in wild salmon and other fish.[55]

BOX 1: Fish Farms and Eutrophication

Carnivorous and omnivorous fish such as salmon, trout and shrimp are fed on high-protein fish meal. Only 20-30 percent of the nitrogen component in feed is assimilated into fish tissue. The balance, plus excreted ammonia and other nutrients, is eventually flushed out of the system during water exchange.[1] A 1982 study of cage-raised trout in Poland indicated that, for every kg of marketable trout produced, the lake was enriched by 0.75 kg carbon, 0.023 kg phosphorus and 0.10 kg nitrogen.[2] Salmon typically produce between 0.22 and 0.28 g of dissolved nitrogen per kilogram of fish annually.[3] In poorly flushed bays or inlets, water nutrient levels can be elevated to the point where eutrophication is enhanced; correlations between fish farms and harmful algal blooms have been documented in Japan. Few other clear correlations have been documented so far, and fish farms have more often been damaged by algal blooms triggered by sewage discharges and agricultural run-off. However, the volumes of sludge and effluents from fish farms should not be dismissed. It has been estimated that 30-35 percent of the total organic matter discharged into the waters of Jutland in Denmark stems from trout farms, equivalent to the untreated organic loading from about half a million people.[4]

[1] National Research Council, *Marine Aquaculture: Opportunities for Growth* (National Academy Press, Washington D.C., 1992), p. 96.
[2] Penczak, T. *et al*, "The Enrichment of a mesotrophic Lake by Carbon, Phosphorus and Nitrogen from the Cage Aquaculture of Rainbow Trout," *Salmo Gairdneri*, *Journal of Applied Ecology*, 19, 1982, pp. 371-393.
[3] *Op. Cit.* note 1.
[4] Warren-Hansen, I., "Methods of Treatment of Waste Water from Trout Farming," *EIFAC Technical Paper 41*, 1982, pp. 113-121.

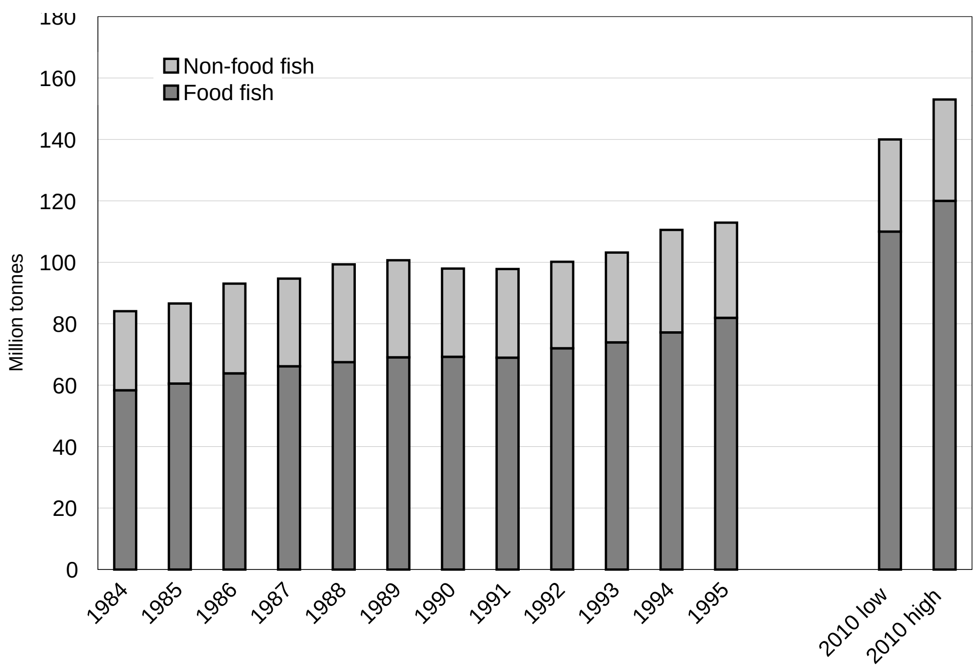
5. Looking Ahead: Future Demand and Constraints on Supply

The FAO has estimated the global demand for fish and fish products in 2010, based on constant 1990 prices and assumptions regarding population and income growth, and the pace of urbanization. Other factors likely to come into play include cultural preferences for fish in the diet, and technological developments in fish processing and packaging.[56]

Demand for fish for human consumption (food fish) is conservatively estimated at between 110 and 120 million tonnes in 2010, compared with actual production in 1995 of 82 million tonnes *(Figure 6).* Demand for non-food fish (fish meal and fish oils) is, somewhat optimistically, expected to remain relatively stable at between 30 and 33 million tonnes. This is because fish meal, the main non-food fish product, is one of the most expensive components of animal and fish feeds, and producers have a clear incentive to reduce the amounts used. Total demand for both food and non-food fish, therefore, may range between 140 and 153 million tonnes, an increase of up to 35 percent over the 1995 harvest.

Can this level of demand be met? The FAO believes that, *under current fishing regimes*, the potential world-wide harvest from marine capture fisheries is no more than 90 million tonnes, and that this could not be sustained indefinitely. It is difficult to estimate the potential increases which could be

Figure 6. Historic Fish Production and Alternative Scenarios for 2010



Source: Based on Food and Agriculture Organization of the United Nations, *The State of the World's Fisheries and Aquaculture 1996* (FAO, Rome, 1997), pp. 24-25

achieved through a combination of improved management, reduced wastage from discards and post-harvest losses, and recovery of depleted stocks. A cautious estimate is that, under much improved management conditions, capture fisheries might yield a sustainable additional 15 million tonnes, or a total of 105 million tonnes per year. This still leaves a gap between demand and supply of 35 to 48 million tonnes; the expectation is that this would have to be bridged by aquaculture.

Fish farms contributed 9 percent to global fish production in 1985 and nearly 20 percent a decade later. There is still scope for expansion, particularly in the form of fish ponds integrated into inland farming systems. The FAO's estimate is that, under the most favourable conditions, aquaculture production could rise by about one-third to 39 million tonnes in 2010. Thus, in the most optimistic scenario, where the oceans are wisely managed and aquaculture flourishes sustainably, the world's demand for fish will just be met *(Table 2).*

A point to bear in mind is that some of the more rapidly expanding forms of aquaculture actually involve "using fish to feed fish." Farm-made and commercially manufactured fish feeds are composed of animal, vegetable and fish proteins, the latter derived from pelagic fish. Feeds used in the intensive cultivation of some finfish species and shrimp account for an unknown fraction of the wild fish harvest *(Box 2).*

The outlook of the FAO is broadly confirmed by estimates conducted by other fisheries experts. The International Food Policy Research Institute (IFPRI) looks ahead to 2020 and foresees stable (at best) or declining harvests from capture fisheries and world aquaculture expanding, but insufficiently to meet demand.[57] The International Center for Living Aquatic Resources Management (ICLARM) prepared a Strategic Plan in 1992 which estimated that an increase in the global fish catch of just over 25 million tonnes might be possible, given ideal management conditions and full conservation of all critical habitats, including coral reefs.[58]

Table 2. Projected Supplies of Fish for Human Consumption, 2010

Source of Production	Pessimistic Scenario	Optimistic Scenario
Aquaculture	27	39
Capture fisheries[1]	80	105
Sub-total	*107*	*144*
Less (for non-food uses)	33	30
Available for human consumption	74	114

Source: Food and Agriculture Organization of the United Nations, *The State of the World's Fisheries and Aquaculture 1996* (FAO, Rome, 1997), table 2, p. 27.
[1] If capture fisheries management is not improved, it is likely that production will drop below current levels.

Will the optimistic scenarios be realized? A key difficulty in achieving maximum sustainable yields from capture fisheries lies in the huge uncertainties which still exist concerning the actual numbers, distribution and inter-species relationships of fish stocks. Devising the best fisheries management practices will be highly complex, with different measures needed in different regions, at different times, and subject to different climatic or other environmental conditions.

Environmental degradation is likely to prove the most important constraint on raising fish production. Pollution, sedimentation, mangrove clearance, wetland drainage, development, and tourism are all taking a heavy toll on the world's coastlines and, currently, the damage to spawning grounds and fish stocks is rarely considered in coastal development decisions. Degradation of freshwater ecosystems is widespread in both developed and developing countries, as pressures mount from urban and industrial wastewater streams, agricultural run-off and diversion of river flow by dams, canalization, and other water engineering works. Natural fisheries are threatened by pollution and disrupted water flow. Aquaculture is even more vulnerable to pollution; fish farm stocks, living at high population densities and unable to migrate, are highly sensitive to degraded water quality. This may be an under-rated threat, particularly to inland fish farming in rapidly developing countries.

Finally, climate change is one of the great unknowns affecting capture fisheries. Water temperature is an obvious variable that alters the behavior and viability of all organisms in the aquatic environment. Fish cannot regulate their own temperature and must migrate to areas where they can thrive. Even small temperature fluctuations have been shown to affect greatly the productivity of certain fish stocks, both positively and negatively.[59] Even greater changes might be wrought by rising sea level, since coastal habitats will be altered, and by disruptions in ocean currents and surface winds, which are of critical importance in delivering nutrients and transporting fish during their larval stages. All that can be predicted at this stage is that the distribution of major fish stocks is likely to shift and that certain species will change in dominance or commercial importance.[60]

The More Likely Scenario

In the short time available between now and 2010, it appears unlikely that the optimistic scenario proposed by the FAO and other analysts will be realized. Even if effective management were introduced immediately, it will take time for stocks to recover and production would grow only gradually. Given current fishery regimes, overfishing is likely to get worse. Higher real prices for fish will probably continue to create financial incentives for further investment in industrial-scale fishing effort on already depleted stocks. In many developing countries, population pressure and the shortage of alternative employment will perpetuate the status of fishing as an employment of last resort. If no effective action is taken, annual production from marine capture fisheries for direct human consumption could fall from around 50 million tonnes at present to about 40 million tonnes in 2010.[61]

Box 2. Aquaculture and the Use of Fish Feeds

In 1995, about 31 million tonnes of the global fish harvest was processed into fish meal and oils, for use in animal and fish feeds. The fish destined for non-food uses are mainly low-value pelagics, some caught as by-catch, the majority deliberately harvested to supply the animal and fish feed market. The reduction process takes about 5 tonnes of fish (wet basis) to make 1 tonne of fish meal (dry basis). In 1995, therefore, 31 million tonnes of fish ended up as about 6 million tonnes of fish meal and oil.

This fish meal and oil found its way into some 560 million tonnes of prepared feeds for livestock and farmed fish. Fish feeds represent only a very small part of all animal and feed production. Global production data for fish feeds are not collected by FAO and total production volumes are uncertain. Estimates of fish feed production for 1996 range from 6 to 18 million tonnes (1-3 percent), with more than half of production concentrated in Asia.

This relatively small volume of fish feed contains a disproportionately high quantity of fish meal and oils; the other main protein constituents being animal products, grains and soybeans. This is because carnivorous farmed fish are high on the food chain and require a high-quality, high-protein feed. The proportion of fish feed accounted for by fish meal ranges from 25 to 50 percent in shrimp feeds to 50 to 75 percent in compound feeds fed to other species.

Assuming that, on average, half of fish food is fish meal, it follows that at least half of all fish meal is fed to fish, rather than to animals.

Much aquaculture is not dependent on fish feeds. Most fish farms in fact raise species groups feeding low in the food chain and needing no supplements. Fish ponds in much of Asia utilize animal waste or run-off from fields to promote algal growth to nourish the fish. Farm-made or commercial fish feeds are used primarily in the production of carnivorous species; one estimate is that just over half of all fish feed is fed to salmonids and shrimp, and the remainder to catfish, eel, and a variety of non-carniverous species such as carp, tilapia and milkfish. The use of compound feeds appears to be increasing in previously extensive fish ponds, for example, in China.

It has been estimated that 3 million tonnes of farmed finfish and crustaceans produced in 1995 (representing about 14 percent of total aquaculture fishery production) would have required over 1.5 million tonnes of fish meal and fish oil in feeds, equivalent to more than 5 million tonnes of pelagic fish.

Salmonids and shrimp are relatively efficient food converters, requiring 2-3 units of fish input to produce 1 unit of fish output. These species are net consumers rather than producers of protein. The conversion of pelagic fish to fish meal used for aquafeeds leads to some double counting of fish production, once as capture fishery landings and again as aquaculture production.

Source: Based on Tacon, A.G.J. “Aquafeeds and Feeding Strategies,” *Review of The State of World Aquaculture*, FAO Fisheries Circular No. 886 (FAO, Rome, 1997).

Capture trends clearly indicate that continued increased fishing effort will barely increase the global catch but will lead to further declines in catch per unit of effort.[62] Conflicts for fishing rights will escalate, both between large-scale industrial fleets and small artisanal fishers, and among the industrial fleets of rival fishing nations. In both cases, the likely losers will be small-scale fishers who lack the political organization and sophisticated equipment of their larger rivals. Higher prices will also encourage more fish to be traded, tilting further the distribution of the global harvest from developing to developed countries. These trends together have serious implications for food security among low-income coastal countries, and for employment. For example, the fishing sector directly or indirectly employs some 8 million people in sub-Saharan Africa and fish provide 18 percent of total protein intake in the region’s diet. Most of the demersal fish catch is already exported, and per capita fish consumption declined by over 20 percent between 1990 and 1994. Yet harvests will have to increase 50 percent by 2010, just to maintain current consumption levels.[63]

6. Possible Solutions

Demand for food fish will rise by between 34 and 46 percent by 2010. It is possible that this demand can be met, but only if significant changes are made in fisheries management. Over-exploited fish stocks must be given time to recover; a reduction in fishing pressure today will yield bigger and long-term harvests tomorrow. Other commercially important fisheries must be managed in a way that better protects the structure, productivity, function, and diversity of entire aquatic ecosystems (including both fish habitats and ecologically related species). The productivity of aquaculture must be maximized through diversification, less polluting production methods and – in many countries – more sympathetic integration with its local social and economic environment.

Fisheries management is immensely complex, involving disputed allocation rights over a global resource, issues of national sovereignty, private and public sector interests, economic development, employment, and basic food security. Everything is complicated by scientific uncertainties over the number and distribution of fish in the sea. Despite the difficulties, the past few years have seen a flurry of activity, at international and national level, aimed at shifting fisheries management onto a less self-destructive course. This section outlines some of the institutional, economic and technological reforms which might help the global fishing industry to remain viable over the coming decades.

Conserving the Global Resource

The problem of overfishing encouraged by open access (whereby anyone has the right to harvest a common resource) is, in principle, addressed by the United Nations Conventions on Fishing and Conservation of the Living Resources of the High Seas (UNCLOS I, II and III).[64] These agreements established national control over fishing rights within 200-nautical-mile Exclusive Economic Zones (EEZs) and curbed the fishing free-for-all within national waters. The 1995 Agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks advocates use of the precautionary principle to protect fish which move between EEZs and the High Seas and are therefore vulnerable to being fished twice over. A further important achievement is the FAO's Code of Conduct on Responsible Fisheries (1995) which sets out principles and policies for more sustainable management of the world's marine resources. UNCLOS III also contains provisions for more responsible fisheries management, such as requirements for environmental impact assessments and monitoring, pollution controls, and conservation of threatened ecosystems or species.

A major weakness in all such international agreements to date has been unwillingness on the part of important fishing nations to commit themselves. Scientific uncertainty regarding the size of fish stocks and "sustainable maximum yields" has often been exploited by powerful fishing industry lobbies, and made the pretext for delaying or ignoring implementation requirements. UNCLOS III waited 12 years to come into force and, as of February 1999, only 3 of the top 10 fishing countries have signed and ratified the Straddling Fish Stocks Agreement.[65] Only one of the next ten (Iceland) has done so. Even when in force, monitoring and enforcement of agreements remains an immense challenge, especially for developing countries lacking the financial and sophisticated technological resources required.

A number of fisheries experts are now suggesting that the way forward lies in sidestepping the whole question of "how many fish are in the sea?" and focusing on reduced catch *effort*, rather than reduced catch. In late 1998, the FAO convened negotiations aimed at reaching a non-binding agreement on global fishing overcapacity. Monitoring the number of boats, and when and where they are at sea, is a simpler matter than seeking to control fish landings from each individual boat. A number of countries, both developed and developing, have introduced conservation and management measures aimed at restricting entry into the fishing industry and reducing catch size. Policy instruments include Individual Transferable Quotas (ITQs) allocated among fishers and tradeable on the market, government buy-back schemes for fishing vessels combined with moratoria on entry of new vessels into the fishery, and "no-take" zones where fishing for one or more species is temporarily banned.[66]

These schemes have led to some decreases in local fleet capacity, and improved efficiency among the fishers that remain.[67] The administrative costs, and equity issues involved in forcing out less efficient fishers, are daunting obstacles to implementation of such measures in many developing countries. The dilemma could be eased if commercial fishers were charged for access to the fisheries resource (most governments currently do not charge national vessels for use of EEZs) and if the prices paid by major fish importing countries (predominantly the industrialized countries) were to reflect better the value and scarcity of the fish they are importing. Economic issues are discussed below. Priorities for future international negotiations should include more explicit allocation of resource rights to individual users, and the development of concrete mechanisms, including transnational agreements, to compensate those who will inevitably lose out as fishing effort is reduced.

The need for more comprehensive protection of ocean ecosystems, habitats and species has been addressed in a number of recent global agreements relating to conserving biodiversity and combating environmental degradation of coastal areas.[68] A key test in their successful implementation will be the willingness of countries to strengthen the existing system of Marine Protected Areas (MPAs), which lags far behind the equivalent terrestrial protected area system. Currently there are over 1,300 MPAs located in 18 different regions around the world but most are relatively small and there is little information regarding their effectiveness. A recent report suggests that, to provide adequate protection for the species within them, MPAs will probably need to be much larger than their current size, or should be linked in a network to protect smaller critical areas.[69] Monitoring to ensure that they are genuinely "off limits" will also need to be improved.

Improving Fisheries Management

Economic Efficiency: In common with other natural resource-based industries, fishing is often characterized by distorted economic incentives, which encourage overcapacity, inefficiency and wasteful consumption patterns. The total costs of the global fishing fleet exceed revenues by at least $US50 billion annually.[70] The losses are borne by governments, in the form of tax breaks and low-interest loans, payments for fishing rights in foreign waters, and direct subsidies. One recent estimate is that global fishing subsidies account for a minimum of 20 to 25 percent of current fishing revenues, and probably closer to 40 percent.[71] Analysts at the FAO have calculated that, for the world's fishing fleets to break even, fleet capacity would have to be reduced by about 50 percent, or costs reduced by over 40 percent, or ex-vessel fish prices raised by more than 70 percent, or some combination of the three.[72] Subsidies which encourage fishers to remain in, or enter, an already overcapitalized industry worsen the pressures on fish stocks and increase the number of individuals who will suffer when resource or economic scarcity eventually forces them out of the business. A few countries have already begun to reassess the relative costs and benefits of supporting capture fisheries or aquaculture compared with other uses of marine resources.

Production Efficiency: There is much scope for improving the efficiency with which fish are caught and utilized. The problem of growing volumes of bycatch and discard mortality is now the subject of intensive study and experimentation in many countries. Vessels are often pressured into fishing fast and indiscriminately by extremely limited fishing seasons (the U.S. Pacific halibut fishery "season" is one or two days). Reduced fishing effort would allow more time to fish with care and selectivity. Pending improved management regimes, technology regulation can help. High Seas driftnets have already been banned, many fisheries specify minimum mesh sizes to allow smaller fish to escape and inventions such as the Turtle Excluder Device have proved successful in reducing mortality rates among non-target marine animals. Utilization of these and other techniques, and enforcement, varies widely. Norway, for example, has made a major effort to use various gear technologies to reduce bycatch mortality and has enacted a ban on discards. Some African countries are taking an alternative route which concentrates on developing markets for bycatch species, so that they are no longer wasted.[73] World-wide, however, the sheer volume of fish harvests so far continues to offset the benefits of technology-induced bycatch reductions.

Research: Information regarding key biological and economic parameters of marine ecosystems, and related fisheries markets, is still lacking or inadequate. Fisheries science lags far behind agronomic science and there is an urgent need for it to catch up. To take just two examples: improved knowledge of predator-prey interactions among species would enable selective fishing to maximize yields of the desired species.[74] Greater understanding of the environmental factors affecting fish larvae survival and mortality rates would enable more accurate prediction of future population size. (Because larvae exist in their billions, even small percentage changes in their survival rate can have very large effects on the mature stock.)[75] Major opportunities also exist, especially in developing country fisheries, in finding new methods for reducing post-harvest losses and adding value to the fish catch. National governments, investors and donor agencies should consider making more development investments in post-harvest operations, including processing, and fewer in fishing vessels and gear.[76]

Aquaculture could also become more productive if greater research effort were applied to genetic improvement of commonly farmed species. Genetic improvement of fish is estimated to lag behind similar advances in terrestrial species by nearly 50 years and the genetic base of currently farmed stock may actually be deteriorating to the point where average growth performance is reduced.[77] Another important area is the improvement of fish feeds, both to reduce diversion of food-grade fish away from direct human consumption and to reduce nutrient pollution from unused food. Researchers are experimenting with alternative sources of protein such as soybean meal and non-food grade fishery products to replace fish meal in fish feeds. More attention should be paid to what is currently fed to herbivorous fish. Commercial fish feed for use on non-intensive fish farms, in particular, is often overformulated, and reduced protein input would minimize waste and water pollution from excess nutrients.[78] It is generally expected that strong demand from Asia for available feed resources will have a considerable impact on world commodity markets and feed prices; aquaculture will find itself facing competition for protein supplies from humans and the much larger livestock production sector. A key challenge for the feed-dependent sector of aquaculture is the need for it to become a net contributor to world fish production, rather than a net consumer of food-grade fish that would otherwise be consumed directly by humans.

Raising Consumer Awareness

Prosperous consumers in the industrialized countries and urban centres world-wide have relatively low awareness regarding the fish they eat. There are few information guides to purchasing and, while fish prices have risen, consumers have been protected to some extent by processing advances which convert low-value fish into more appealing foods such as fish fingers, fish cakes and products such as “imitation crab.” Currently, therefore, the market exerts little pressure on fishing industry practices. An important exception, which demonstrates the potential power of consumer choice, is the clear swing in the United States and Northern Europe towards tuna caught with pole and line, so-called “dolphin-friendly” tuna. More recently, swordfish have become the subject of a consumer boycott in the United States. Many environmentally preferable fishing technologies exist, but are resisted by an industry which sees additional costs, loss of competitiveness and no market incentive. This attitude has been reinforced by recent decisions of the World Trade Organization, which has not upheld the right of individual nations to discriminate against fish products caught with environmentally-damaging technology.

One attempt to counter this trend is the establishment of the Marine Stewardship Council (MSC). Founded jointly by Unilever, one of the world’s largest purchasers of frozen fish, and the World-Wide Fund for Nature (WWF), the Council aims to stimulate the market for sustainably harvested fish. In 1998, the MSC launched an accreditation scheme under which certified producers must meet agreed environmental standards.[79] Unilever, which has about 20 percent of the European and U.S. frozen fish market, has pledged that all its products will be accredited by the MSC by 2005.[80] Given the political and administrative difficulties of reforming the fishing industry at source, market pressure from the consumer is likely to prove an invaluable aid to governments.

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Notes

1. The apparent sudden jump in production over the reported 1995 figure (113 million tonnes) with which readers may be familiar is explained by a recalculation of aquaculture production in China. Previous under-reporting by China (reporting shelled weight of molluscs, rather than live weight) has now been corrected by the FAO for the time series 1950-96. The new data are incorporated in Figure 1 and Figure 3 of this report. For additional information, see FAO Fisheries Department, "China's underestimated national aquaculture production and global contribution addressed and rectified by FAO," internet reference: http://www.fao.org/WAICENT/FAOINFO/FISHERY/trends/china/chinaef.htm.

2. 1996 world production data are: pig meat: 79.3 million tonnes (mt); chicken and turkey meat: 53.7 mt; beef and veal: 53.3 mt; sheep meat: 7.3 mt. (FAOSTAT).

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8. *Ibid*.

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12. *Op. Cit.* note 9.

13. *Op. Cit.* note 5.

14. Food and Agriculture Organization of the United Nations, *The State of World Fisheries and Aquaculture 1996* (FAO, Rome, 1997), Table 3, p. 36.

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16. *Op. Cit.* note 14, p. 33.

17. *Ibid*, pp. 49, 51.

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