1 · Introduction: Climate, people, fisheries and aquatic ecosystems

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INTRODUCTION TO THE BOOK

Evidence of human damage to natural resources and the environment is long-standing even in the sea, but some 50 years ago awareness of human degradation of natural environments around the globe grew substantially. This concern was expressed above all in the creation of protected areas, organizations and agencies focused on nature conservation. The extent to which wilderness areas everywhere were contaminated or otherwise influenced by human agency was beginning to be generally recognized, and some people predicted these impacts would only grow in future. But few predicted the extent and number of global environmental changes that are now occurring. The limits to growth of the world's economies, individually or

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collectively, were little questioned in ecological contexts. Uncertainties surrounding how economics and ecology might relate to each other were little explored, and questions such as 'At what points will economies become constrained by the decline and loss of natural ecological goods and services?' persist to this day.

Water is increasingly seen as a constraint on sustainable human development and focus of potential human conflict. Nevertheless, it has been rare for the provision of this good, and related ecological services such as fish production and waste disposal, to be viewed holistically in the context of the natural environment. Also, there have been no comprehensive reviews of status and trends encompassing all aquatic environments (Clark *et al.* 2006), from the fresh and terrestrial saline to those of the deepest seas. Certain fresh waters and saline lakes have been radically altered by humans, but the extent and nature of these impacts vary among ecosystem types and geographical locations. The seas and oceans retain a greater complement of resource-development frontiers than does the land, for example in mining and fisheries (e.g. Berkes *et al.* 2006); their wilderness value remains substantial. Clearly, the extent of human disturbance is increasing across environment types and locations, yet there is little comprehensive scientific appraisal of the magnitude and nature of this permeation.

It is important at this time to consider what is happening ecologically to the world's aquatic environments, and where possible project these forward to an appropriate time horizon at an appropriate ecological scale. The terminology surrounding ecological units is large and application can be problematic especially where, as here, freshwater and marine environments are to be bridged. Thus the term 'biome' is discerning of terrestrial environments but not with respect to those of the sea, while 'ecoregions' (e.g. Bailey 1998) omit the continental shelves. It was important in the design of this book to focus on a number of natural environments that would be comprehensive yet feasible in terms of relevant data and expertise. One aim of this chapter is to consider alternative comprehensive categorizations of aquatic environments as a basis for this book.

Natural processes and ecological services rely on notions of system functioning that have long been integral to the concept of the 'ecosystem'. Other recognized types of ecological unit such as the biotope exist, but the term 'ecosystem' is the most relevant, and most widely used and recognized, and is thus the unit of choice for this book. What was also needed in the design of this book was a time horizon sufficiently far in the future to provoke thoughtful and imaginative projections across all the ecosystems, but within a time-frame for which some detailed scenarios such as of human population growth and global ambient temperatures existed. The year 2025 was chosen as an appropriate compromise between those two constraints. This book aims to assemble the views of expert ecologists on the status of all ecosystems across the aquatic realm, review contemporary changes and their drivers, and consider likely outcomes at the 2025 time horizon. Major drivers considered are climate change and the direct impacts of human population growth and economic development.

Climate is usefully defined as the average of the weather experienced over a 10–20-year period. Temperature and rainfall changes are typical measures of change that can be expressed at local, regional, national or global scales. Global warming or cooling can be driven by any imbalance between the solar energy the Earth receives from the Sun and the energy it radiates back to space as invisible infrared light. The greenhouse effect is a warming influence caused by the presence of gases and clouds in the atmosphere, which are very efficient absorbers and radiators of this infrared light. The greenhouse effect is opposed by substances at the Earth's surface (such as snow and desert sand) and in the atmosphere (such as clouds and white aerosols) that efficiently reflect sunlight back into space (albedo) and are thus a cooling influence. Global climate changes and their possible consequences are and will remain a major area of debate within and among most nations. International negotiations in the Framework Convention on Climate Change and its Kyoto Protocol are contentious in particular because the components of the problem are many, the science is uncertain and the whole issue has a major bearing on other global problems such as poverty, inequality and economic development. Another aim of this introductory chapter is to consider uncertainties in climate predictions and review warming, sea-level rise and related trends as they might affect the world's aquatic environments.

The human population is approaching the 7 billion mark, increasing by *c.*1.2% per year. Mapping and photography of the Earth's night lights (Weier 2000) show how unevenly human beings are settled (Deichmann *et al.* 2001). Especially dense populations characterize northern South Asia, East Asia, Europe, eastern North America and south-western Africa. More than half of the world's population lives within 60 km of the coast, and this figure could reach 75% by the year 2020 (Roberts & Hawkins 1999). In addition, human economic wealth and output are often concentrated close to major rivers or estuaries, especially in the temperate regions of the northern hemisphere (Cohen 1997; Nicholls & Small 2002). Various human interactions with critical natural resources and the environment illustrate that the human population over the past several decades has reached levels that significantly modify aquatic ecosystems. While some of this change is economically and socially beneficial, some is ecologically detrimental (e.g. biodiversity loss; see below). A third aim of this chapter is to introduce a human backdrop for assessing global changes in aquatic ecosystems; this will be done in particular by reviewing some of the consequences of human population growth for water, water supply and its natural sources.

Fisheries have been recognized as a major driver of change in the aquatic realm. They constitute a major impact at the interfaces among human population growth, economic development and environmental changes, both anthropogenic and natural. Modern industrial fisheries resulted from the economic and technological development of Europe, North America and Japan over a century ago. Frontiers in the development of global fishery resources persist in the use of Southern Ocean and deep-sea or reef resources. What are the current trends in global fisheries, and how do these relate to what is happening in the aquatic ecosystems involved? The intention in this chapter is also to introduce marine fisheries as an important example of human intrusion into the oceans and seas; this is followed by an overview of global trends in aquatic biodiversity and specific extinctions.

COMPLEXITIES OF CLIMATE CHANGE AND ITS CONSEQUENCES

Global climate has remained relatively stable (temperature changes of $<1\,^{\circ}$C over a century) during the last 10 000 years. However, society now faces potentially rapid changes because human activities have altered the atmosphere's composition and changed the Earth's radiation balance (IPCC [Intergovernmental Panel on Climate Change] 1996).

The most important greenhouse gas is water vapour, which typically remains for a week or so in the atmosphere. Concerns about global warming, however, revolve around much longer-lived greenhouse gases, especially carbon dioxide but also other long-lived gases (methane, nitrous oxide, chlorofluorocarbons), concentrations of which have increased substantially since *c*.1750. Carbon dioxide (CO_2) has risen by about 30%, methane (CH_4) by more than 100% and nitrous oxide (N_2O) by about 15%. These gases are now at higher concentrations than at any time in the past 160 000 years (IPCC 1996). The combustion of fossil fuels and, to a lesser extent, changes in land use account for anthropogenic CO_2 emissions. Agriculture is responsible for nearly 50% of human-generated CH_4 emissions and about 70% of anthropogenic N_2O emissions.

When the concentration of a particular greenhouse gas increases, it tends to lower the flow of infrared energy to space and increases the flow of infrared energy down toward the surface. The Earth is then receiving more energy than it radiates to space. This 'radiative forcing' warms the surface and the lower atmosphere; however, the rate of surface warming is slowed by uptake of heat by the world's oceans. The greenhouse effect as quantified by this radiative forcing is real and the physics relatively well understood. What is more uncertain, and the cause of much of the scientific debate, is the response of the global system that determines climate to this radiative forcing. Feedbacks in the system can either amplify or dampen the response in ways that are still only partially understood.

The IPCC was jointly established by the World Meteorological Organization and the United Nations Environment Programme (UNEP) in 1988, in order to (1) assess available scientific information on climate change, (2) assess the environmental and socioeconomic impacts of climate change, and (3) formulate response strategies. The Integrated Global System Model (IGSM) is one means that the IPCC has at its disposal to analyse carefully the scientific and economic implications of proposed mitigation policies (Fig. 1.1). The IGSM consists of a set of coupled sub-models of economic development and associated emissions, natural biogeochemical cycles, climate and natural ecosystems (Prinn *et al*. 1999; MIT [Massachusetts Institute of Technology] 2003). It attempts to include each of the major areas in the natural and social sciences that are amenable to quantitative analysis and are relevant to the issue of climate change (Schneider 1992; Prinn & Hartley 1992; IPCC 2001*a*, *b*, *c*). A major challenge inherent in global climate modelling is to decide what is important and what is unimportant. In the IGSM, the coupled atmospheric chemistry and climate model (Fig. 1.1) is driven by a combination of anthropogenic and natural emissions. The essential components of this model are chemistry, atmospheric circulation and ocean circulation, each of which, by itself, can require enormous computer resources. The atmospheric chemistry is modelled in sufficient detail to capture its sensitivity to climate and different mixes of emissions, and to address the

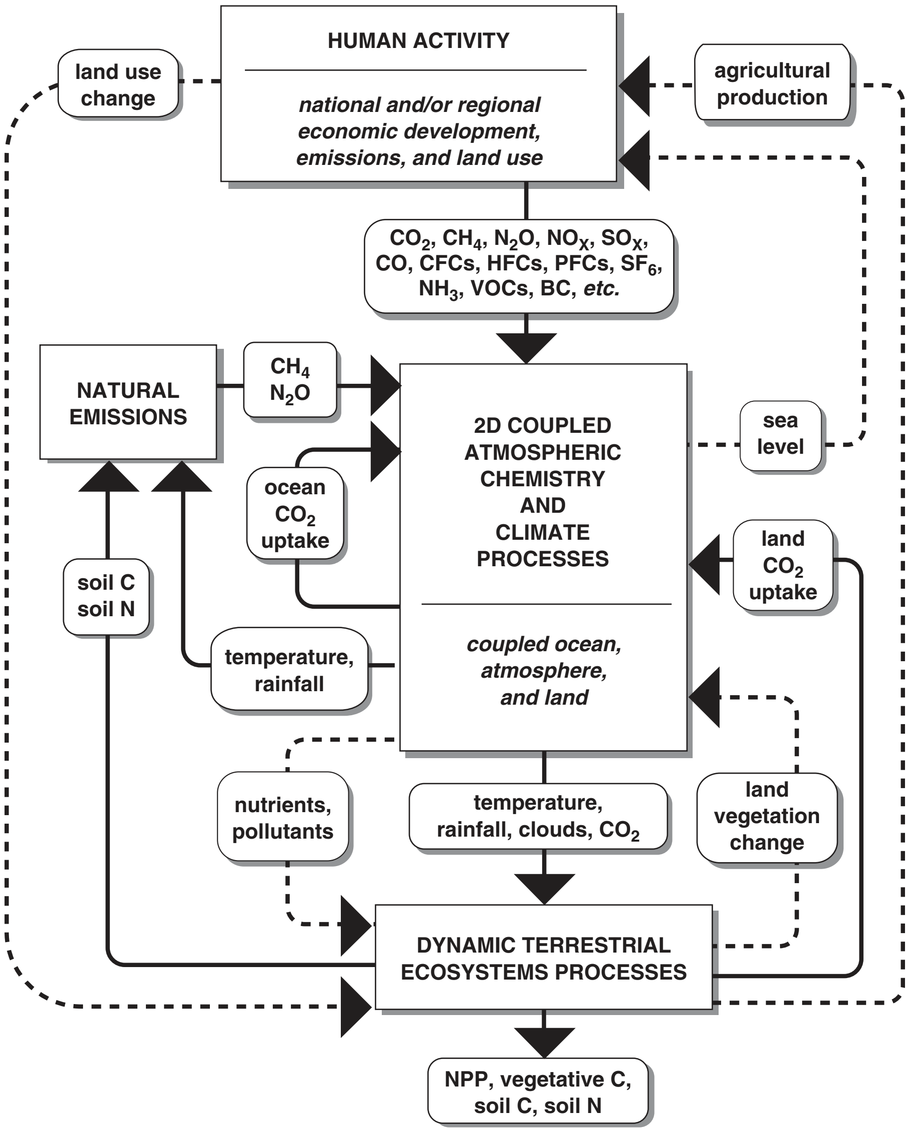

Fig. 1.1. Schematic illustration of the framework and processes of the MIT Integrated Global System Model (IGSM). Feedbacks between the component models that are currently included or proposed for inclusion in the next generation are shown as solid and dashed lines respectively (Prinn *et al.* 1999; MIT 2003).

relationship among policies proposed for control of emissions related to air pollution, aerosols and greenhouse gases (Wang *et al.* 1998). But linking complex models together leads to many challenges, illustrated by the failure of coupled ocean–atmosphere models (including IGSM) to accurately simulate current climate without arbitrary adjustments. The IGSM coupled chemistry–climate model outputs drive a terrestrial ecosystems model that predicts vegetation changes, land CO_2 fluxes and soil composition (Xiao *et al.* 1998), and these feed back to the climate model, chemistry model and natural emissions model. The effects of changes in land cover and surface albedo on climate, and the effects of changes in climate and ecosystems on agriculture and anthropogenic emissions are also included.

Hundreds of runs of the IGSM have been used to quantitatively assess uncertainty in climate projections (Webster *et al*. 2002, 2003). One study shows a global median surface temperature rise from 1990 to 2100 of 2.4 °C, with a 95% confidence interval of 1.0–4.9 °C (Webster *et al*. 2003). For comparison, IPCC (2001*a*) reported a range for the global mean surface temperature rise by 2100 of 1.4–5.8 °C, but did not provide likelihood estimates for this key finding although it did do so for others. The implications of the projected level of climate warming for the aquatic realm are unclear, but will vary with type of ecosystem. For example, small surface freshwater bodies will typically vary readily with climate, while in the open ocean, ambient temperature will lag that of the atmosphere by decades or more.

When the probability distribution functions for the mean global surface temperature and sea-level increases between 1990 and 2100 are compared between no-policy and applied-policy scenarios (designed to simulate strict regulations leading to stabilization of atmospheric CO_2 concentrations at about twice pre-industrial levels), a median of only 1.6 °C and 95% range of only 0.8–3.2 °C is forecast (Fig. 1.2). There is a 50% chance of warming exceeding 2.4 °C in the no-policy case and a 1-in-7 chance in the policy case. Implementing the policy therefore lowers the probability of large amounts of warming to a substantial degree.

To better appreciate the risks of the no-policy scenario, it is important to examine the latitudinal distribution of the projected warming. In common with other climate models, the computed temperature increases in polar regions are much greater than those in equatorial regions (no-policy case: Fig. 1.3). Polar regions contain vulnerable ecosystems with large carbon storage (e.g. Chapter 8), and the Greenland and Antarctic ice sheets with large water storage (e.g. Chapter 21). Release of some of this stored carbon and water is of significant concern. A 1-in-40 chance of warming by 8–12 °C or greater in polar regions for the no-policy case (Fig. 1.3) is particularly worrisome. The policy scenario lowers the polar warming in the 1-in-40 calculation to 5–7 °C (Webster *et al*. 2003).

Similar significant reductions in the probability of large and risky amounts of sea-level rise due to the hypothetical policy are also evident (Fig. 1.2). Emissions reductions are predicted to lower the chance of exceeding an extreme climate outcome but not to eliminate the risk entirely, and analysis of the reduction in probability is an important policy consideration. Future climate assessments would better serve the policy process by including formal analysis of uncertainty for key projections, with an explicit description of the methods used (Allen *et al*. 2001; Reilly *et al*. 2001).

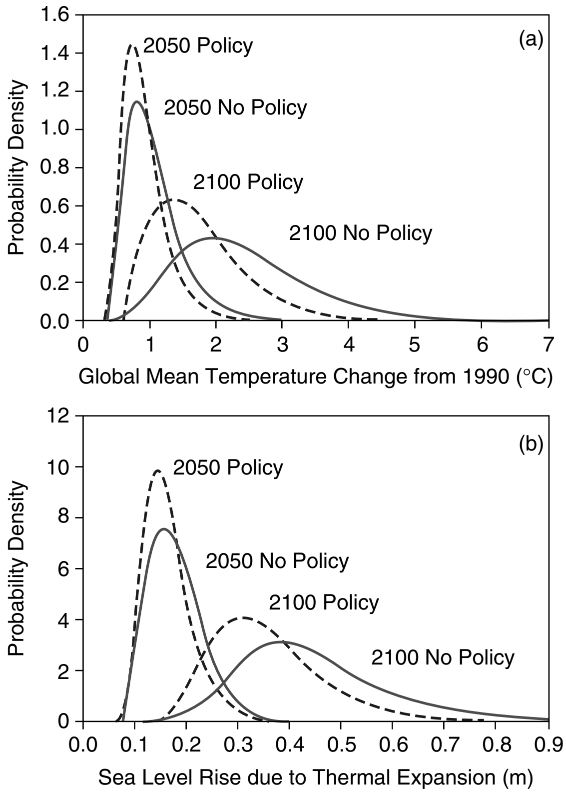

Fig. 1.2. Probability density function (PDF) for the change in global mean: (a) surface temperature and (b) sea-level rise from 1990 to 2100 estimated as a best fit to 250 simulations using latin hypercube sampling from input PDFs for uncertain variables. The solid line shows the PDF resulting from no explicit emissions restrictions and the dashed line is the PDF under hypothetical emissions policy leading to steady levels of atmospheric CO_2 of about twice pre-industrial values (Webster *et al*. 2003). The IPCC (2001*a*, *b*, *c*) upper estimate is beyond the 95% confidence limit. Based on this distribution there is a 12% chance that the temperature change in 2100 would be less than the IPCC lower estimate.

Sea-level rise

Global mean sea level has risen by 10–25 cm over the last 100 years, and although there has been no detectable change in the rate of sea-level rise over the course of the century, it would appear that this has been significantly higher than the rate averaged over the last several thousand years (IPCC

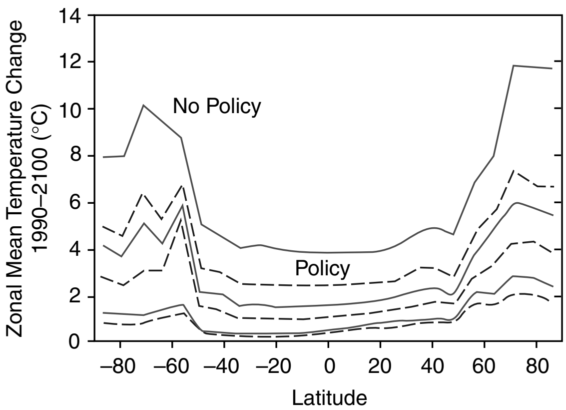

Fig. 1.3. Zonal mean temperature change in surface warming by latitude band between 1990 and 2100 in the case assuming no explicit policy in Fig. 1.2. There is a 1-in-40 chance of being above or below the upper and lower curves and a 1-in-2 chance of being above or below the middle curve respectively (Webster *et al*. 2003).

2001*a*, *b*). It is likely that the rise in sea level has been largely due to the increase in global temperature over the last 100 years. The possible factors include thermal expansion of the oceans and melting of glaciers, ice caps and ice sheets. Changes in surface water and groundwater storage (related to changes in human activities and changes to drainage basins) may also have affected sea level.

Model simulations have predicted 2–7 cm of the reported sea-level rise over the last 100 years (10–25 cm) and attributed it to thermal expansion of the oceans, yet many of the world's mountain glaciers have retreated substantially over this time period and may have accounted for 2–5 cm of the observed rise. However, most of the non-oceanic water on Earth resides in great ice sheets, namely those of Antarctica and Greenland, and most of their volume lies on land above sea level. Loss of only a small fraction of this volume could have a significant effect on sea level (Warrick *et al*. 1996). In Antarctica, discharges of enormous icebergs and recent break-ups of Antarctic Peninsula ice shelves have focused public attention on the possibility of 'collapse' of this ice reservoir within the next century, with major potential impacts on sea level.

According to the IPCC (2001*a*, *b*) 'best estimate' climate change scenario, global sea level is projected to rise by 20 cm by the year 2050 (within a range of uncertainty of 7–39 cm) and by 49 cm by 2100 (within a range of uncertainty of 20–86 cm); more than half of this is attributed to oceanic thermal expansion.

Lakes, streams and wetlands

Inland aquatic ecosystems are expected to be greatly influenced by climate change through altered water temperatures, flow regimes and water levels (e.g. Kaczmarek *et al*. 1996; Öquist *et al*. 1996). Water-level declines may be severe in lakes and streams in dry evaporative drainages and in basins with small catchments, whilst the distribution of wetlands is likely to shift with changes in temperature and precipitation (IPCC 2001*a*; Chapters 2–10). Wetlands temporarily store runoff water, thereby reducing floodwater peaks and protecting downstream areas, consequently a reduction of wetland area due to climate change could severely hamper flood-control efforts in some regions (e.g. Kaczmarek *et al*. 1996; Öquist *et al*. 1996; Chapters 9 and 10).

Coastal systems and small islands

Coastal systems are economically and ecologically important. Climate warming, sea-level rise and increases in storms and storm-surge frequencies may result in erosion of shores and associated habitats, altered tidal ranges in rivers and bays, changes in sediment and nutrient transport, and increased coastal flooding (see Bijlsma *et al*. 1996). Some coastal ecosystems are particularly at risk, namely saltmarshes, mangroves, coral reefs and atolls, and river deltas (Chapters 11–13 and 16). Changes in these ecosystems are likely to negatively affect tourism, fisheries and biodiversity (IPCC 2001*b*). Many small island countries could lose a significant part of their land area with a sea-level rise of 0.5–1 m, the Maldives for instance having average altitudes of only 1–1.5 m (Bijlsma *et al*. 1996).

Oceans

Climate change could lead to altered ocean circulation (e.g. weakening of the Atlantic thermohaline circulation) and wave climates, and reductions in sea-ice cover (IPCC 2001*a*, *b*, *c*; ACIA [Arctic Climate Impact Assessment] 2004). As a result, nutrient availability, biological productivity, the structure and functions of marine ecosystems, and heat and carbon storage capacity may be affected with important feedbacks to the global climate system (see Ittekkot *et al*. 1996). These changes would have implications for coastal regions, fisheries, tourism and recreation, transport and offshore structures.

Most CO_2 released into the atmosphere as a result of burning fossil fuels will eventually be absorbed by the ocean. As the amount of CO_2 in the atmosphere rises, more of the gas reacts with seawater to produce bicarbonate and hydrogen ions that increase the acidity of the surface layer. Ocean pH was around 8.3 after the last ice age and 8.2 before CO_2 emissions took off in the industrial era. Ocean pH is now 8.1 and if atmospheric CO_2 exceeds 1900 ppm by the year 2300, pH at the ocean surface could fall to 7.4 (Caldeira & Wickett 2003). There is limited understanding of the effect increased acidity might have on marine biota, but coral reefs, calcareous plankton and other organisms, skeletons or shells of which contain calcium carbonate, may be substantially affected.

PEOPLE AND WATER

Perhaps the best-documented human interaction with aquatic ecosystems involves the use of fresh water (Engelman & LeRoy 1993; Engelman *et al*. 2000). Precious little of the world's water is salt-free, and only a small proportion of this fresh water is accessible to human beings. Water use has increased for many centuries, but in many major watersheds (the key geographic unit of interest for freshwater use), only in the past few centuries has the scale reached the point where natural variations in water supply have begun to collide with growing human use. This is most evident in western Asia and eastern and southern Africa, but to varying degrees such problems of availability are also present elsewhere. Humans already use more than half of the renewable fresh water that is readily accessible (Postel *et al*. 1996), and human population growth is currently the dominant factor in the increase of water withdrawals worldwide.

The world's urban population is currently growing at four times the rate of the rural population. Between 1990 and 2025, the number of people living in urban areas is projected to double to more than 5 billion out of a total 8 billion (Table 1.1). An estimated 90% of the increase will occur in developing countries and at the current pace, over 60 million people are added to urban populations each year, placing great strain on local governments to provide even the most basic services. Of all urban inhabitants in developing countries, 25–50% live in impoverished slums and squatter settlements, with little or no access to adequate water, sanitation or refuse collection (UN [United Nations] 1997).

Human water demand for agricultural irrigation (an increasing proportion of food production comes from irrigated cropland), industrial and household uses almost invariably takes precedence over environmental needs. In all but the most remote and best-protected areas, there is constant pressure on water resources. By hydrological benchmarks of water stress (*c*.1000–1700 m^3 per person per year) and scarcity (<1000 m^3 per person per year) (Falkenmark & Widstrand 1992; Engelman & LeRoy 1993), the numbers of human beings living in these two high-risk categories is growing much faster than population growth generally. One-third of humanity lives in countries experiencing moderate to high water stress (WRI [World Resources Institute] 1998), and a billion people could face severe water shortages by 2025 (Potts 2000).

Table 1.1. *World population by year and UN projection variant*

Year	Low-variant projection	Medium-variant projection	High-variant projection
2010	6 843 645 000	6 906 558 000	6 967 407 000
2025	7 568 539 000	8 010 509 000	8 450 822 000
2050	7 791 545 000	9 191 287 000	10 756 366 000

Source: UNPD (2006).

Apart from fisheries, which are considered below, several other interactions between human population and the environment are especially salient for aquatic ecosystems. In terms of food security, much is made of agricultural intensification as the antidote to forest loss. When more food can be produced on the same land, there is less need to convert relatively wild land to farmland. This can, of course, benefit wetlands, which historically have been lost to farmland more frequently than to settlement, although this ratio is changing as coasts and river valleys become more densely populated (Chapters 9–13).

Water is the greatest transportation network for chemical wastes of all types. Humanity now exceeds nature as a fixer and producer of nitrogen compounds (Smil 1997), and studies of rivers have shown that nitrogen loads are highly correlated with human population density along river banks (Cole *et al*. 1993). Intensive farming can also exacerbate soil erosion if farmers do not have the resources to manage their soil properly, and the world's rivers offload much of the resulting silt onto the continental shelves and beyond. Conversion of forest to farmland is another source of soil erosion, also closely correlated with population density and growth.

Introduction of alien species is an indirect result of human population growth and economic and technological development, because human beings uniquely face few barriers to their movement over the Earth's surface. From Nile perch to zebra mussels, the list of introduced aquatic species altering aquatic ecosystems is lengthening. In addition, marine life is at growing risk from a range of diseases, the spread of which is being hastened by global warming, global transport and pollution (Harvell *et al.* 1999, 2002). Well-documented cases include crab-eater seals in Antarctica infected with distemper by sled-dogs, sardines in Australia infected with herpes virus caught from imported frozen pilchards, and sea-fans in the Caribbean killed by a soil-borne fungus.

The further interaction between human populations and economics offers an additional obstacle to the conservation or restoration of aquatic ecosystems. When ecosystems are degraded, a common action of last resort is to attempt some sort of protection, where human use and access are restricted. But the process of setting land and/or fishing space aside becomes more difficult as population density increases. People may bid up the price of land to the point where conservation efforts become financially impossible (Cincotta & Engelman 2000). Land conservation organizations have increasingly focused on wetlands, coasts and other aquatic ecosystems, knowing they are in a race with time to buy key parcels of land or convince governments to protect them. Too rarely, however, do conservationists acknowledge that continued population growth limits their prospects for long-term success, simply because land will become too valuable to serve environmental rather than economic interests.

Market forces and global economics can also greatly influence the need for and development of port and shipping facilities. Historically, estuaries and saltmarshes have provided cheap sources of land for development. As commodities continue to be traded on global markets and ships become ever bigger, the demand for coastal land for development will increase and much of it will become degraded (Pinnegar *et al.* 2006).

While these interactions between human population and aquatic ecosystems paint a bleak picture, there are also reasons for hope. One of the most positive trends is that the human population is seen by most demographers as unlikely to double again. One way to explain this is that women all over the world are having fewer children than ever before, and seemingly want to have even fewer in the future. Average family size has shrunk from five children per woman in the early 1960s to a bit more than 2.5 children per woman today. In more than two-fifths of the world's countries, couples are only just replacing themselves in the population, or they are having fewer than the *c*.2.1 children needed for net replacement (UNPD [United Nations Population Division] 2002). Contrary to public impressions, this does not mean that these populations are now stable or declining. The large proportion of people of childbearing age in populations that up until recently were growing fairly rapidly guarantees that more births than deaths will occur for essentially an average human lifetime after replacement fertility is reached. Also, high levels of migration mean that most nations experiencing low fertility rates will continue to grow (International Organization for Migration 2000; UNPD 2002).

GLOBAL TRENDS: THE CASE OF GLOBAL MARINE FISHERIES

Given the means and opportunity, fishers like hunters before them ultimately deplete the resources that they target (e.g. Clovis of North America: Alroy 2001). Understanding this analogy is important, as it provides a framework for understanding the severe depletion of smaller and mid-size mammals in Africa ('bushmeat': Bowen-Jones 1998) and large fishes in the world's oceans. The recent marine fish biomass declines (e.g. Christensen *et al.* 2003 for the North Atlantic) are primarily attributable, not to scientific incompetence in monitoring (Malakoff 2002), nor shifts in distribution (Bigot 2002), nor regime shifts (Steele 1998), but to overfishing (Jackson *et al.* 2001).

When fishing starts in a new area, the large fishes go first, as they are relatively easier to catch than small fishes (e.g. with harpoons or lines) and tend to provide a better return on investment (Pauly *et al.* 2002). Large fish, with their low natural mortalities and relatively high age at first maturity (Pauly 1980; Froese & Binohlan 2000), cannot sustain substantial fishing pressure and rapidly decline (Denney *et al.* 2002), forcing the fishers either to move on to smaller fishes, and/or to other, previously unexploited areas. As larger fish tend to have higher trophic levels than smaller fish – indeed, the latter are usually the prey of the former – this process, now called 'fishing down marine food webs', leads to declining trends in the mean trophic level of fisheries landings (Pauly *et al.* 1998; though see Caddy *et al.* 1998).

The 'fishing down' process has occurred around the world (Table 1.2) and the broad pattern is that fishing targets a succession of species until the residual species mix ceases to support a fishing economy. This implies a

Table 1.2. *Occurrence of 'fishing down' using local/detailed data sets, following the original presentation of this phenomenon by Pauly* et al. *(1998), based on the global FAO catch dataset*

Country/area[a]	Years	Decline	Source and remarks
Iceland	1900–1999	1918–1999	Valtsson and Pauly (2003), based on comprehensive catch database of Valtsson (2001)
Celtic Sea	1945–1998	1946–2000	Pinnegar *et al.* (2002), based on trophic levels estimated from stable isotopes of nitrogen
Gulf of Thailand	1963–1982; 1963–1997	1965–1982; 1965–1997	Christensen (1998); Pauly and Chuenpagdee (2003)
Eastern Canada	1950–1997	1957–1997	Pauly *et al.* (2001), based on data submitted to FAO by the Canadian Department of Fisheries and Oceans
Western Canada	1873–1996	1910–1996	Pauly *et al.* (2001), based on comprehensive dataset assembled by S. Wallace
Cuban EEZ	1960–1995	1960–1995	Pauly *et al.* (1998) and Baisre (2000)
East Coast, USA	1950–2000	all	R. Chuenpagdee *et al.* unpublished data; emphasis on Chesapeake Bay
Chinese EEZ	1950–1998	1970–1998	Pang and Pauly (2001)
West Central Atlantic	1950–2000; 1950–2000	1950–2000; 1950–2000	D. Pauly and M. L. Palomares unpublished data, based on FAO data (Area 41), disaggregated into USA (North) and other countries (South)
World, tuna and billfishes	1950–2000	1950–2000	D. Pauly and M. L. Palomares unpublished data, based on FAO data (ISSCAAP [International Standard Statistical Classification of Aquatic Animals and Plants] group 36 only)
World, all fishes	1950–2000	1950–2000	Pauly and Watson (2003), based on spatially disaggregated data

[a] EEZ, Exclusive Economic Zone.

transition from fisheries targeting large fish (e.g. northern cod) to those targeting smaller fishes (e.g. capelin) or invertebrates (e.g. northern shrimp and snow crab). In the north-east Atlantic, fish species that mature later, grow more slowly and have lower rates of potential population increase, have exhibited greater long-term declines in abundance than closely related species which are smaller, grow faster and are more fecund (Jennings *et al.* 1998, 1999; Dulvy *et al.* 2000). In sharks, rays and skates, large size combined with low fecundity makes them particularly vulnerable to overexploitation; many populations have been rapidly declining (Dulvy *et al.* 2000) and are likely to be rendered extinct in the coming decades (Dulvy *et al.* 2003). In some cases, depletion of keystone species may have important indirect effects on community and habitat structure (e.g. Dulvy *et al.* 2004).

Exports have become a major issue in fisheries, with marine products being amongst the most heavily traded commodities (Pauly *et al.* 2002). The general trend is for developed countries to increasingly to compensate for the shortfall of products from traditional fishing grounds in their exclusive economic zones (EEZs) by fishing in developing countries (Pauly *et al.* 2005). Given the debts that most developing countries have run up with respect to international lenders, this implies that marine resources, and their underlying ecosystems, suffer from increased pressure to make up shortfalls. Examples include the countries of West Africa, whose dependence on financial support from the European Union forces them to sign fisheries agreements providing access for European fishing fleets under terms that appear unfair to these countries (Kaczynski & Fluharty 2002). In Argentina, demersal

Table 1.3. *Marine fish that are unlikely to survive, given continuation of present fisheries trends*

Major features	Representative groups
Large- to moderate-sized, predaceous, territorial reef fishes and rockfishes with late age at maturity, very low natural mortality rates and low recruitment rates versus adult stock size	Snappers, sea basses, emperors, rockfishes, sea breams
Large- to moderate-sized shelf dwelling, soft bottom predators susceptible to bottom trawling	Cods, flounders, soles, rockfishes, croakers, skates
Large- to moderate-sized schooling midwater fishes susceptible to midwater trawling	Hakes, rockfishes, armorheads, rougheyes
Large- to moderate-sized shelf dwelling, schooling, pelagic fishes	Bonitos, sierras, capelin, eulachon, salmon, sharks
Any species with exceptionally high monetary value	Bluefin tuna, red snappers, halibuts, medicinal fishes, aquarium fishes, groupers, salmon, red mullets, billfishes

Source: Adapted from Parrish (1995, 1998) and Pauly (2000).

resources which in the early 1980s were among the few that were both large and underexploited have now collapsed under the pressure of both national and international fleets, licensed for their ability to generate foreign exchange (Sánchez 2002).

Given present trends and pressures, present target species are not expected to survive and small non-palatable non-schooling species will be those that will fare best (Table 1.3). In extreme cases, finfish may be progressively replaced by consumer species such as jellyfish, which have few predators and may impede any finfish recovery (e.g. northern Benguela, Namibia: Lynam *et al.* 2006).

The fishing industry on its own is incapable of reversing the fishing down of food webs. There are other social forces, which can and will play an increasing role in the international debates on fisheries. Foremost is the community of non-governmental organizations devoted to maintaining or re-establishing 'healthy' marine ecosystems, and striving for ecosystem-based fisheries management. Public debate about fisheries was unheard of 20 years ago, and many conservation biologists feel they need to debunk those who deny the need for action (e.g. Lomborg 2001). Global catches are declining (Watson & Pauly 2001; Pauly *et al.* 2002) but catches can and usually do remain high when stocks collapse. Thus the cod off eastern Canada yielded good catches until the fishery had to be closed because there were literally no fish left (Myers *et al.* 1997).

Some suggest that aquaculture could help compensate for overfishing, and a quarter of human fish consumption now derives from aquaculture. However, as currently practised, aquaculture also causes environmental damage, raising questions about how to meet food demands and preserve environmental quality (WRI 1998). Aquaculture in fact exists in two fundamentally different forms. One is devoted to the farming of bivalves (e.g. oysters, mussels) and/or freshwater fish (e.g. carp, tilapia) and relies mainly on plant matter to generate a net addition to the fish food supply available to consumers. This is based predominantly in developing countries (mainly in China, but also in countries such as the Philippines and Bangladesh), and supplies cheap animal protein where it is needed (New 2002). By contrast, the other form of aquaculture involves the farming of carnivorous fish such as salmon or sea bass, and increasingly, the fattening of wild-caught bluefin tuna. In nature, salmon, sea bass and bluefin tuna have high trophic levels, hence it is impossible to feed them only on vegetable matter. This implies that as this form of aquaculture increases, there will be fewer cheap fish (e.g. sardine, herring, mackerel and anchovies) available for humans to buy and eat. It is thus not adding to global fish supply, and instead increases the pressure on wild fish stocks (Naylor *et al.* 2000).

This second type of aquaculture predominates, and it has led to massive imports by developed countries of meal from fishes caught and ground up in developing countries, exacerbating fishing pressures in these regions. Coastal pollution and diseases emanating from the uneaten food and faeces of these marine feed-lot operations are also seen