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THE IMPACTS OF CLIMATE ON FISHERIES

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PO Box 30552
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Text written by Michael H. Glantz,
Boulder, Colorado, United States
Editing, layout and artwork: Words and Publications, Oxford, England

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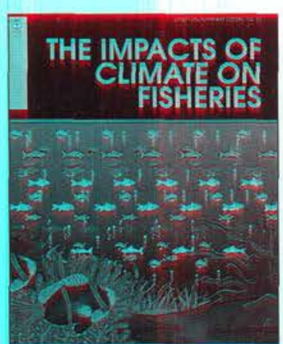

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THE IMPACTS OF CLIMATE ON FISHERIES

Contents

Foreword

Scientists and environmentalists have been warning us about the catastrophic effects of the warming of the Earth's atmosphere. But it has taken a succession of terrible droughts, devastating hurricanes and floods, and discernible changes in the climate patterns of various parts of the globe to elevate the issues of climate change and global warming to the top of most scientific and political agendas.

Although science cannot as yet state with absolute certainty that human-induced climate change has been and is occurring, and delineate its future impacts, it is certain that atmospheric composition is being inexorably altered by anthropogenic emissions of greenhouse gases. But these uncertainties must not be taken as an excuse for inaction in dealing with the problem. On the contrary, they should be regarded as reasons enough to initiate immediate measures to reduce this human impact on the atmosphere.

The global community today faces a risk of massive disruption of the Earth's natural systems, on which all its social and economic structures depend. The risks are simply too great not to start taking action immediately. There is a pressing need to identify the potential implications of climate change and variability on society, so that our ability to respond to them is suitably enhanced. Given the fact that future environmental changes and their effects are not easy to quantify, determining the appropriate response strategies is obviously difficult. One useful method to determine how society might respond to these environmental changes is through 'forecasting by analogy'. This forecasting attempts to build upon the experiences of the past, and draws lessons for the future, based on how societies have responded to such events in the past.

This volume of the UNEP Environment Library summarizes the potential implications of climate change and variability on fisheries and on the societies that depend on them. It is based on a review of several fisheries case studies and on the responses of the fisheries industry to changes in the environment and other influences on fish productivity.

After the United Nations Conference on Environment and Development at Rio, such integrated studies will be increasingly necessary to tackle the complex issue of climate change. I am sure that such integrated assessments will form the platform upon which we can formulate appropriate response strategies to reduce vulnerability to the adverse effects at the global, regional and even local scales in the future. UNEP has been advocating a precautionary approach in dealing with scientific uncertainties. It will continue to encourage and assist decision makers to identify and implement response strategies to mitigate and adapt to climate change and variability.

More than that, this small volume will, I am sure, enhance the awareness of this important—though difficult—subject among the people. Only if they are widely disseminated and known will the results of environmental assessments be effective enough to catalyse public opinion and, subsequently, public policies affecting our environment.

Elizabeth Dowdeswell
Executive Director, UNEP

Preface

Marine fisheries science has long acted as if the size of stocks depended solely on the extent they were fished. That stocks were also influenced by other species in their ecosystems and by environmental change has only recently become widely accepted. Environmental change, especially on the climate scale of years to centuries, has a particularly important influence on the yearly addition of new adults to the stock and on the changing mix of species in ecosystems.

Thus climate has always been important to the inhabitants of marine ecosystems, whether or not they are subject to commercial harvest. Because recognition of this has come so late, understanding of the mechanisms of environmental influence is still limited, and is seldom applied in stock assessment and fishery management. When fish stocks undergo sudden decline, overfishing is usually blamed, and management actions are taken that may bear little relation to the actual events under way.

The imposition of additional climate change induced by human activity, while increasing the demand for prediction of fishery consequences, gives the impression that some new kinds of stresses are being applied. In fact, some of the most useful information on possible climate effects on fish stocks, and hence on fisheries, can come from retrospective analyses, where observed changes in fish stocks are related to recorded environmental changes. The fishery record becomes dim as one goes back beyond World War II, but there are enough clues to allow some plausible hypotheses to be constructed for testing.

Discussion of the relation between changes in marine ecosystems and their causes—human or environmental—has been clouded by misinformation, misleading assertions, and misunderstanding of cause and effect. As human activity in the ocean increases, and as environmental change continues and perhaps intensifies, the need is compelling for a concerted scientific attack on finding out how the system works, and a rational approach to determining management response to the consequences.

Warren S. Wooster
Professor Emeritus
University of Washington.

Overview

Many international agencies, spanning all disciplinary boundaries, are concerned about the future productivity and health of the marine environment. Lawyers, anthropologists, oceanographers, political scientists, historians, atmospheric scientists, people concerned with food security, economists, development specialists and so on have used their expertise to improve our understanding of how the oceans might be better managed in a sustainable way.

Until recent decades, a major problem for fish populations was that they were seen as resources belonging to no one nation, available for the taking, and were considered to exist in infinite supply. Competition among fishing fleets and industries soon led to the demise of several commercially exploited stocks—the result of too many fishing boats chasing after dwindling stocks of fish. This process has been referred to as the 'tragedy of the commons'. Because no one nation could claim ownership of the fish, it was in their narrowly defined, short-term interests to heavily exploit fish populations. If they refrained from doing so, other fishermen would be likely to continue to take the catch that they refrained from taking. Ultimately, all would become losers—when the fish populations had been so decimated that they were no longer of commercial interest.

Marine fisheries supply an important proportion of the global food supply, and an even greater proportion at the many local and regional areas.

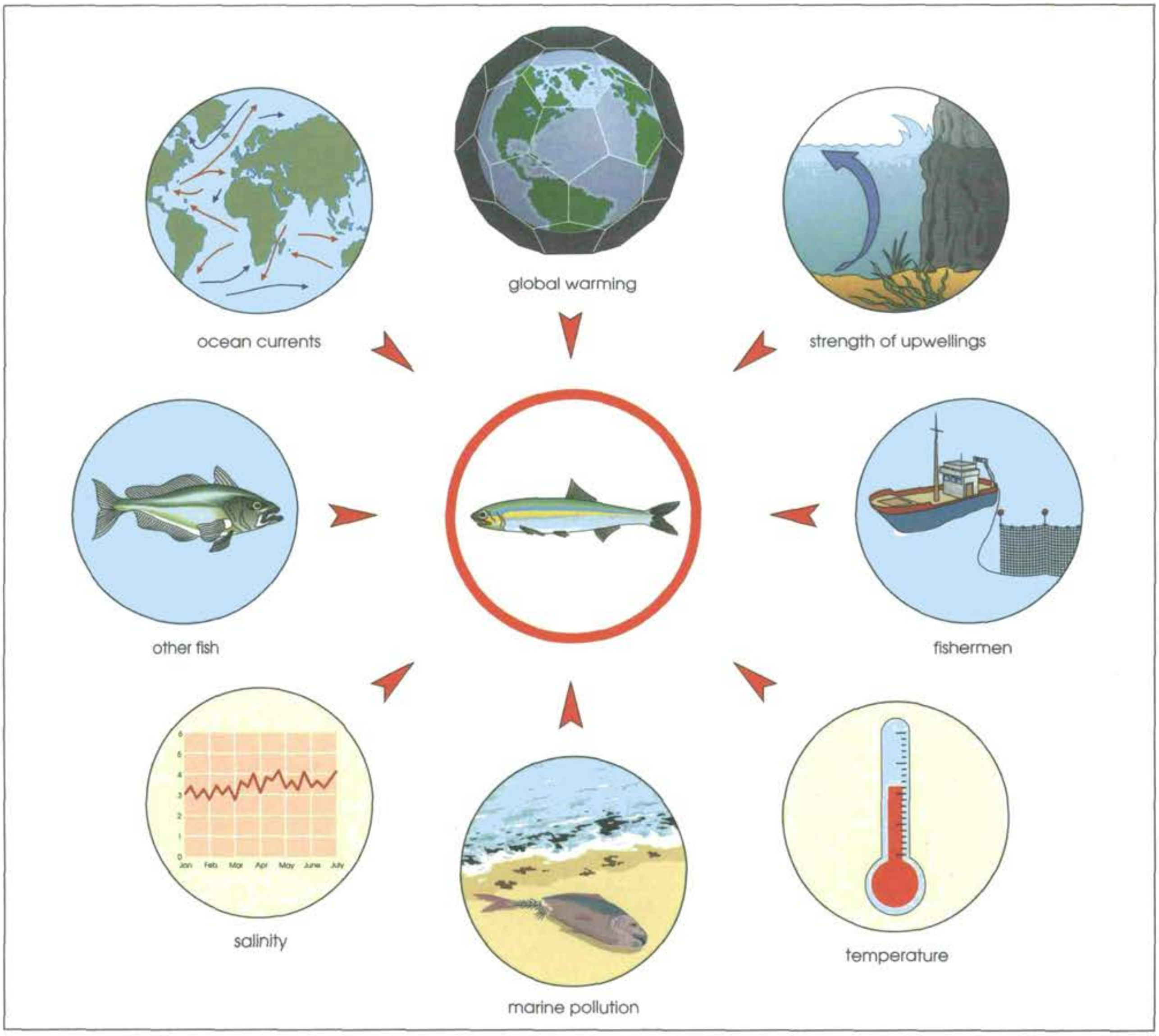
In the mid-1970s, nations agreed to abide by the concept of Exclusive Economic Zones (EEZs). This gave extended national jurisdiction over living marine resources to a boundary of 200 miles from the coast. While some countries exploited fish populations within their EEZ, others sold fishing rights to those fishing nations with a capacity to exploit their marine resources. However, national control over this region did not automatically translate into the rational control of living marine resources.

Fish populations are under tremendous pressure from year to year and season to season. Predators are manifold: other fish in the food chain; untimely changes in environmental variables (with respect to fish life cycles); and fishermen. In addition, there has appeared yet another 'predator'—global warming.

Today, there is considerable discussion and speculation about the possible warming of the global atmosphere by a few degrees Celsius. Atmospheric changes will be accompanied by oceanic changes, resulting in alterations in the marine environment. Those alterations and their potential effects on biological productivity are now capturing the attention of fish biologists, fisheries experts and policy makers.

Marine fisheries supply an important proportion of the global food supply, and an even greater proportion at the many local and regional areas. The effect of climate change on the marine environment is of major interest to governments worldwide, a concern that is likely to intensify as the global warming picture becomes clearer in future years.

Figure 1 Pressure on fish populations comes from many sources; some of these are illustrated below.



The scientific background

The 'marine environment' is a misnomer. There are, in fact, many marine environments: estuaries; the coastal ocean; the high seas; deep water; shallow shelves; bays; deltas; regional seas; and so forth. Each of these environments provides a hospitable habitat for certain types of living marine resources. These living marine resources have, over time, adjusted to the 'normal' regional or local climatic variability that occurs on different time scales—from daily to seasonal and from interannual to decadal. However, for the past few decades, an increasing number of physical scientists have contended that, because of the emissions into the atmosphere of greenhouse gases, the global climate may be changing—and that this would, in turn, affect 'normal' regional climatic conditions. In 1957,

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Three examples of marine environments: estuaries (top); the high seas (centre); and the coastal ocean (bottom).

scientists suggested that humankind had embarked on a 'large-scale geophysical experiment' by pursuing human activities—such as the burning of fossil fuels (coal, oil and gas)—that were changing the chemistry of the atmosphere and that would ultimately alter the global climate in unknown ways.

Not only has there been considerable speculation about the prospects of a human-induced global warming of the atmosphere, but even more speculation has focused on the ecological and socio-economic consequences of that warming. Concern has reached the highest levels of national governments worldwide. National and international research and policy-making activities are now geared to identify more clearly the possible impacts and risks of global warming on managed and unmanaged ecosystems—and on the societies directly or indirectly dependent on them.

Intergovernmental Panel on Climate Change (IPCC)

In 1988, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), at the direction of the United Nations General Assembly, established the Intergovernmental Panel on Climate Change (IPCC). The IPCC initiated a review of the climate change issue through the establishment of three international working groups, each with a specific focus: scientific assessment (Working Group I); impacts of climate change (Working Group II); and policy responses to climate change (Working Group III). Although the working groups have since been reorganized, they

It is likely that global warming will produce collapses of some fisheries and expansion of others.

Still Pictures/Argus

Coal-fired power stations, such as this one in former East Germany, may be changing the chemistry of the atmosphere and, as a result, the global climate.

continue to focus on the basic issues of science, impacts and policy. The objective of the IPCC has been the provision to national governments of scientific information, to enable their representatives to discuss issues related to human-induced global climate change, and to negotiate ways to prevent, mitigate or adapt to its regional and local consequences. The IPCC provides periodic updates on global warming—its causes and impacts, and possible ways in which societies might respond. The first comprehensive IPCC assessment was prepared in 1990 and updated in 1992. The next update will appear in 1995.

In its executive summary, the first IPCC scientific assessment—officially issued in November 1990 at the Second World Climate Conference in Geneva, Switzerland—suggested how climate change might affect marine ecosystems and living marine resources:

'Climate change is one of the most important factors affecting fisheries. The level of impact varies widely and depends on attributes of the species as well as on their regional specificity ... Changes in ocean circulation may lead to the loss of certain populations or the establishment of new ones ... Warming impacts on the abundance of commercially important species can be either positive or negative, even for the same species, depending on the region ... It is likely that global warming will produce collapses of some fisheries and expansion of others.'

This paragraph reveals the uncertainties that still pervade the issue of climate change impacts on fisheries. It stresses the importance of improving our understanding of the consequences of

Dr Inigo Everson/Bruce Coleman Ltd

There is still uncertainty about the potential impact of climate change on fisheries; global warming may cause some fisheries to collapse and others to flourish.

> **fish′er•y** *n., pl.* **-ies** **1.** the act, process, occupation, or season of taking fish or other sea products: FISHING *[the golden age of the whale fishing]*; also: the catch of a specified fish or sea product *[the menhaden fishery for the year]* **2.** a place for catching fish or taking other sea products *[an oyster fishery][a salmon fishery]* **3.** a fishing establishment; also: its group of fishermen **4.** the legal right to take fish at a certain place or in particular waters esp. by drawing a seine or net [see COMMON FISHERY, FREE FISHERY, SEVERAL FISHERY] **5.** the technology of fishery: a branch of knowledge concerned with the methods and economics of fishery and the utilization and preservation of fish resources—usually used in place *[a number of schools of fisheries have been established]*.
>
> *From **Webster's Third New International Dictionary**, Merriam Company, Springfield, Massachusetts, 1966.*

global climate change for regional marine environments.

After the IPCC issued its first report, the next step was the preparation of a climate convention by the Intergovernmental Negotiating Committee on Climate Change for a Framework Convention on Climate Change (INC/FCCC). The United Nations Framework Convention on Climate Change (UN/FCCC) was adopted in June 1992 at the United Nations Conference on Environment and Development (UNCED), popularly referred to as the 'Earth Summit', in Rio de Janeiro. Having achieved the required 50 ratifications by nations, the treaty came into force on 21 March 1994. Parties to the convention must seek ways to reduce their national greenhouse gas emissions over the next several decades. More specific obligations upon parties can be required through the addition of regulatory Protocols to the framework convention.

Agenda 21

Agenda 21—an agenda for the 21st century—was, in essence, the Earth Summit's action plan. According to its preamble, 'Agenda 21 addresses the pressing problems of today and also aims at preparing the world for the challenges of the next century'. It stresses that the integration of environmental and development concerns will 'lead to the fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems, and a safer, more prosperous future'.

The conceptual basis for Agenda 21 is sustainable development. The World Commission on Environment and Development (WCED) noted in its 1987 report, *Our Common Future*, that: 'humanity

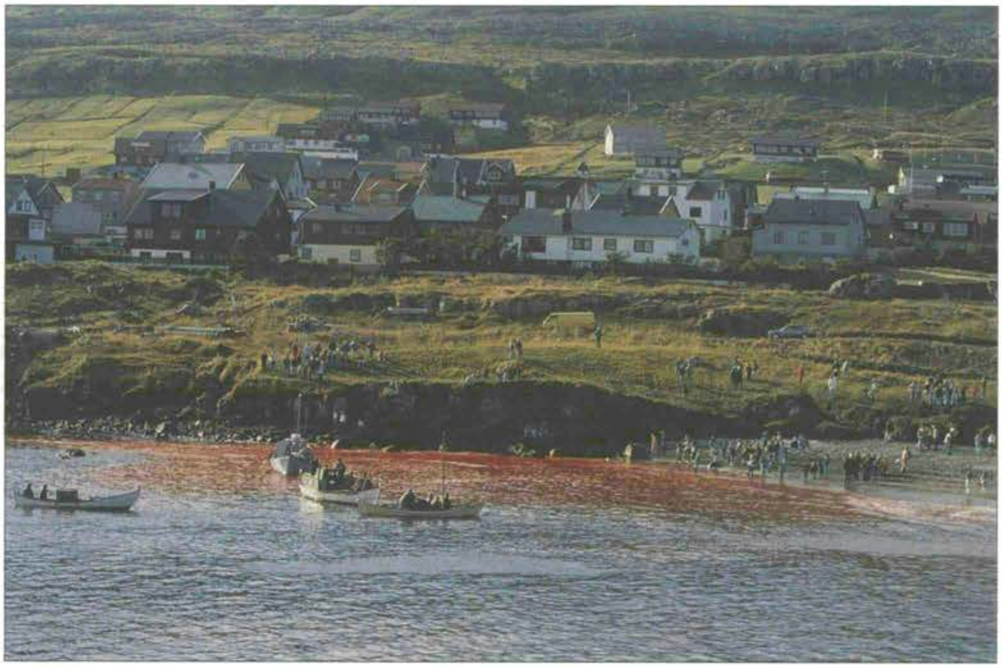
Coastal population in Egypt: more than 60 percent of the world's population lives within 60 kilometres of a coastline, and this figure is expected to increase.

has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs'.

Several sections of Agenda 21 relate directly to the oceans, the marine environment and fisheries, and discuss sustainability with regard to the protection, rational use and development of living marine resources. Agenda 21 also addresses the critical uncertainties regarding the management of the marine environment and climate change. And it warns that, although at one time—not long ago—oceans were regarded as a source of limitless amounts of fish, the world's oceans are now in trouble.

More than 60 percent of the Earth's population lives within 60 kilometres of a coastline, and this percentage is likely to increase in the next few decades. Agenda 21 notes the important responsibility of coastal states to protect their living marine resources. As a result of the Law of the Sea negotiations, coastal states control marine resources to a boundary 200 miles from their coastlines—known as the Exclusive Economic Zone (EEZ). More than 80 percent of the commercial harvest comes from the coastal and continental shelf seas that are within national jurisdictions. High-seas fisheries represent only about five percent of total world landings.

To many local communities and indigenous people, living marine resources provide an important source of employment, as well as a source of protein. Decision makers at these levels of society are most concerned about changes in the regions for which they have direct political responsibilities. Clearly, living marine



Fishing on the Faroe Islands: Agenda 21 stresses the responsibility of coastal states to protect their living marine resources.

resources can make a substantial contribution to national food security and, as the world's population increases, it will be necessary to continue to increase food production from all sources.

Notwithstanding the extensive activities of the IPCC, INC/FCCC and Agenda 21, there remain—and probably will remain throughout the rest of this decade—many scientific uncertainties surrounding the exact mechanisms associated with global environmental changes, such as increases in greenhouse gases (carbon dioxide, methane, nitrous oxide and chlorofluorocarbons).

One major source of uncertainty in the greenhouse gases-global warming equation is its effect on the oceans. How will the chemistry of the ocean be altered by continued greenhouse gas emissions? If the atmosphere heats up, what effect might this have on oceanic circulation patterns? How will such changes in the ocean environment alter the biological productivity of the oceans? More specifically, how might the coastal ocean—the land-side of which has become the location of numerous human settlements around the world—be affected by global warming and its impacts? Finally, what might be the regional and local consequences in the marine environment (that is, on 'seacosystems') of global warming?

The marine environment remains a mystery, in large measure because data gathering across the world's oceans has been difficult. Recall that the oceans cover more than 70 percent of the Earth's surface. Nevertheless, regional monitoring has been relatively successful and, as a result, we do have evidence of regional variations and changes in different marine locales

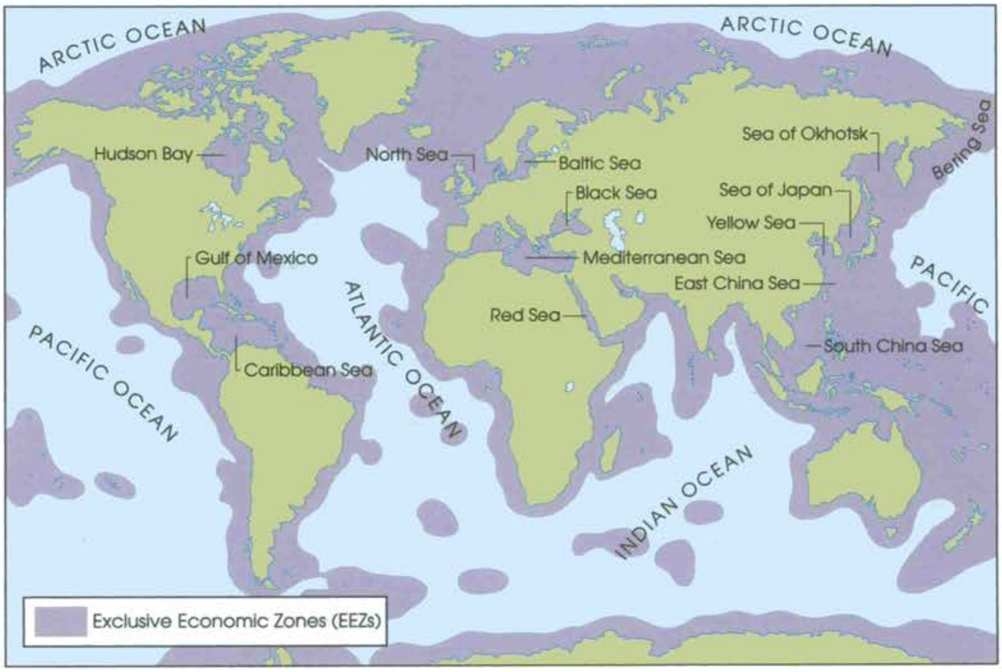


Figure 2 Although the oceans cover more than 70 percent of the Earth's surface, our understanding of them is still limited.

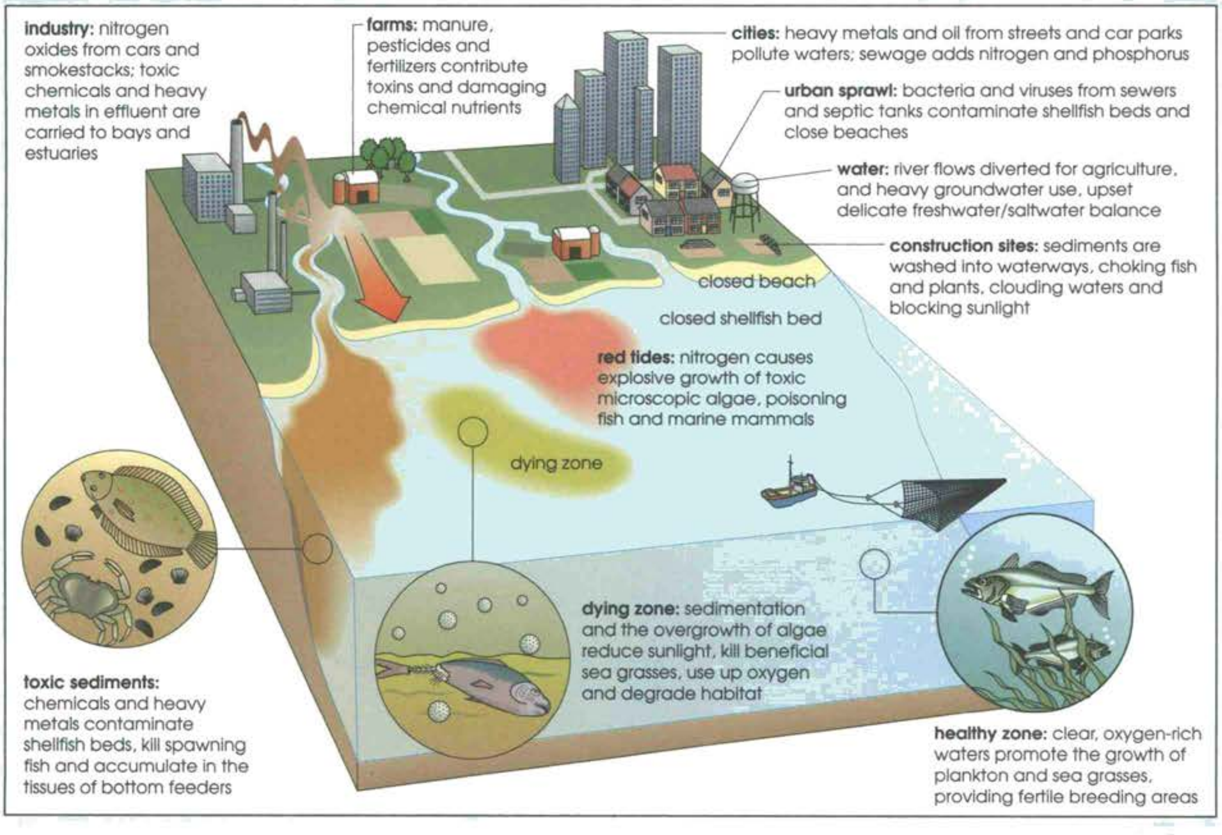
around the world. Perhaps improved satellite capabilities and increased international support for monitoring the marine environment will enable societies to gain a better understanding of and respect for the oceans.

Over time, scholars in a variety of disciplines have assessed just about every facet of fish populations, fishing communities and fishing industries. Anthropologists, for example, have focused on the investigation of the social dynamics of coastal communities dependent on fishing activities. Economists have assessed the benefits and costs of a variety of fishery-related activities, from landing and processing to marketing and trade. Economic assessments have been used to determine whether, as well as when, to exploit different fish populations, and how those populations might best be exploited. Political scientists have researched conflicts related to fish stocks, such as the Anglo-Icelandic Cod Wars that ended in the mid-1970s, the Franco-Brazilian lobster war, the controversy over the Bering Sea Doughnut Hole, and many others. Fisheries scientists have also evaluated institutional needs for optimal fisheries management. Thus, while uncertainties do remain, we nonetheless know a great deal about specific fish populations, how they respond to some types of environmental changes and how they have been exploited by society at various levels of economic development.

Marine pollution

The Brundtland Commission report, *Our common future*, pointed out that the oceans are the ultimate sinks for the by-products of human activities, receiving water from cities, farms and industries via sewage outfalls, dumping from barges and ships, coastal runoff, river discharge and even atmospheric transport. Pollution from the land ultimately reaches the oceans, either directly, as a result of streamflow and run-off, or indirectly, through atmospheric processes. In addition, the continual destruction of coastal habitats, such as estuaries, lagoons, wetlands and mangroves, from pollution and land conversion adversely affects the ability of certain fish populations dependent on those habitats.

Pollution of the coastal zone can be viewed as yet another 'predator-like' environmental change, as far as living marine resources are concerned. Clearly, as human populations increasingly inhabit coastal areas, we will be likely to hear more about the adverse impacts on fish populations resulting from human-induced environmental change.



A historical perspective

Fishing in history

Fish have been an important source of protein to human societies since humans first settled along water courses and seashores, and along the edges of wetlands, ponds and lakes. Fishing is probably as old as human society. Civilizations have developed ways to use fish and fish products to their benefit. Evidence in the form of prehistoric mounds of mollusk shells, as well as fishing equipment such as netting and hooks, has been discovered at archaeological sites around the globe.

There are many kinds of fishermen, and their methods of capturing fish span a continuum from simple to complex. Some live in coastal villages and fish along the coast in dug-out wooden boats; others wade chest-high into the water, casting their nets by hand; still others have put motors on their boats, enabling them to cover more area in less time. At the other extreme are highly efficient trawlers with hundreds of thousands of dollars' worth of specialized equipment, and even larger factory ships that can stay at sea for long periods of time, processing and freezing fish for later delivery.

Some authors have noted that the methods for catching fish today are quite similar to methods used by fishermen hundreds of years ago. Figure 3 illustrates four of these present-day methods: lines, gill nets, seines and trawls.

Hooks are attached to lines to catch fish. There are several types of line: hand lines; demersal long lines, which are a few kilometres in length; and pelagic lines, up to 80 kilometres in length.

Gill nets are long curtains of netting into which the fish swim and become caught by the gills. A drift net, perhaps 2.5 kilometres in length, is suspended from the surface or floated up from a heavy rope attached to the vessel—the whole system drifts or drives with the tide. Set nets are anchored to the sea bed.

A purse seine is an enclosing net shot around a shoal, which is closed or pursed below by ropes from the vessel that are laced through rings at the bottom of the net. With a Danish seine, a circle of net laid on the sea bed is hauled from the vessel and herds the fish into the net.

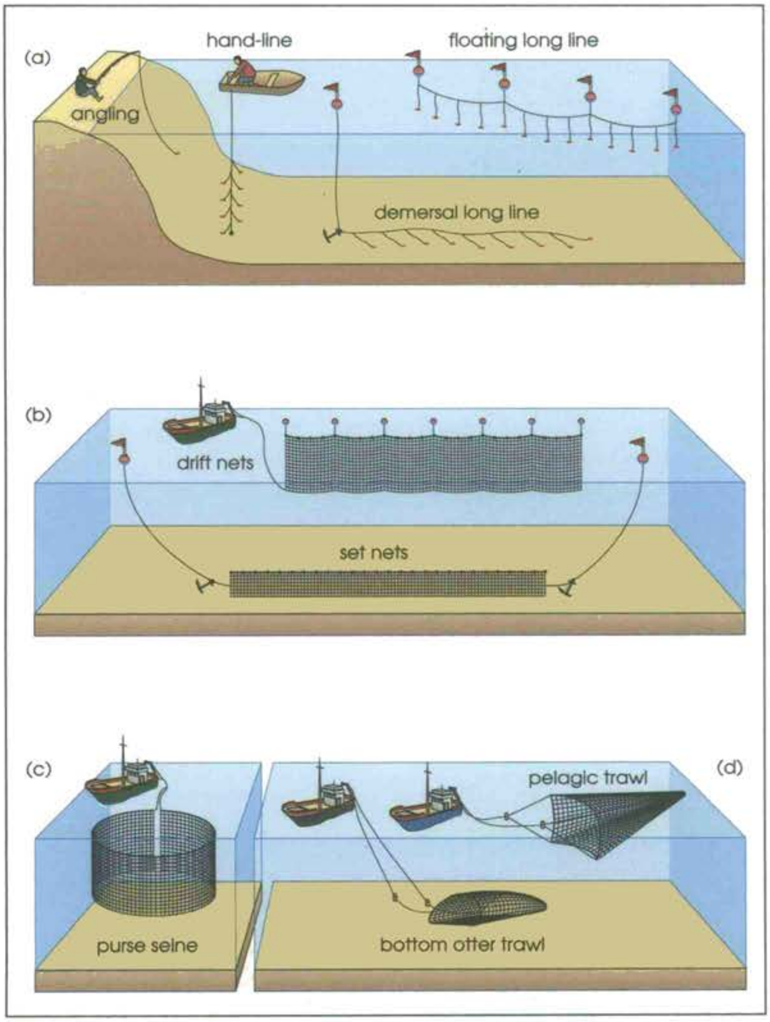


Figure 3 The main types of fishing gear: (a) lines; (b) gill nets; (c) seines; and (d) trawls (from Cushing, 1988).

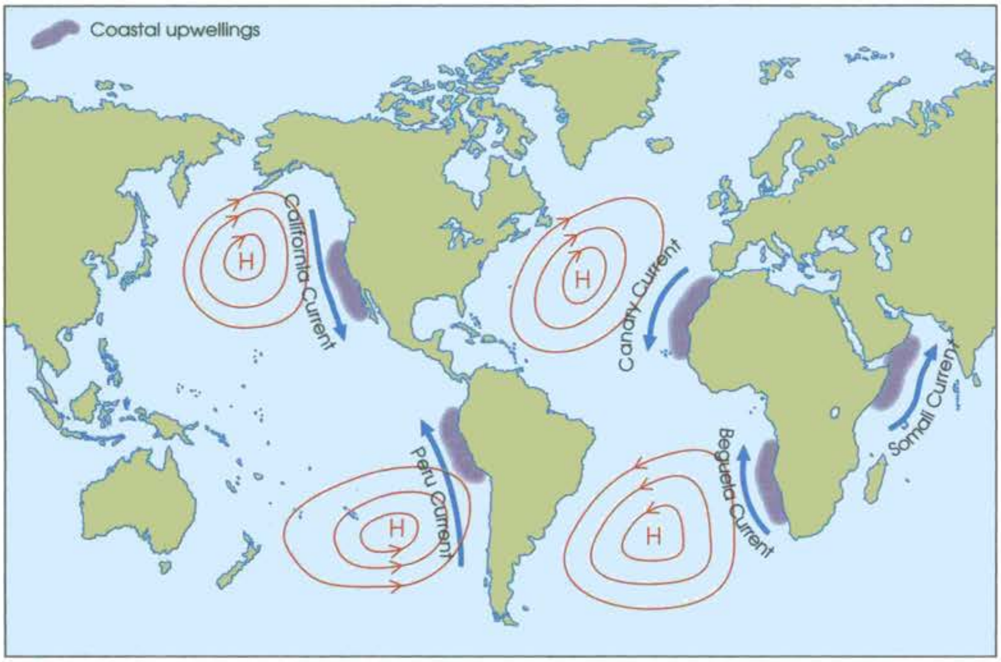


Figure 4 Idealized schematic diagram of the major coastal upwelling regions of the world and the summertime sea-level atmospheric pressure systems (anticyclones) that influence them.

Trawls are conical nets with a broad, low mouth, dragged along the sea bed. The otter trawl is kept spread with doors or otter boards, and the headline is lifted with spherical floats. In a beam trawl, the same functions are carried out by a beam fastened to iron trawl heads. A pelagic trawl is a large net with a roughly square mouth, towed in midwater.

Almost half the commercial fish landings are taken from coastal upwelling ecosystems, which represent only a small fraction (about 0.1 percent) of the world's ocean area. The rich biological productivity of coastal upwelling regions results from a set of natural conditions: winds blowing offshore; the Earth's rotation; and cold, nutrient-rich, deep water welling up to the sunlit zone near the ocean's surface, where photosynthesis takes place. These systems are generally found along the western coasts of continents, situated in what are called eastern boundary currents. There are at least five major upwelling regions: along the western coast of Ecuador, Peru and Chile; the Mauritanian coast; the Namibian coast; the Californian coast; and the Somali coast, which is an anomaly, in that the coastal upwelling is found on the eastern side of a continent (see Figure 4).

Aside from their obvious value to societies as a source of protein, fish are used by industry in a variety of ways: for fertilizer, medicine and livestock feed supplement, in the production of varnish and so on. The demand for fish products is growing at a time when fish populations are being heavily exploited.

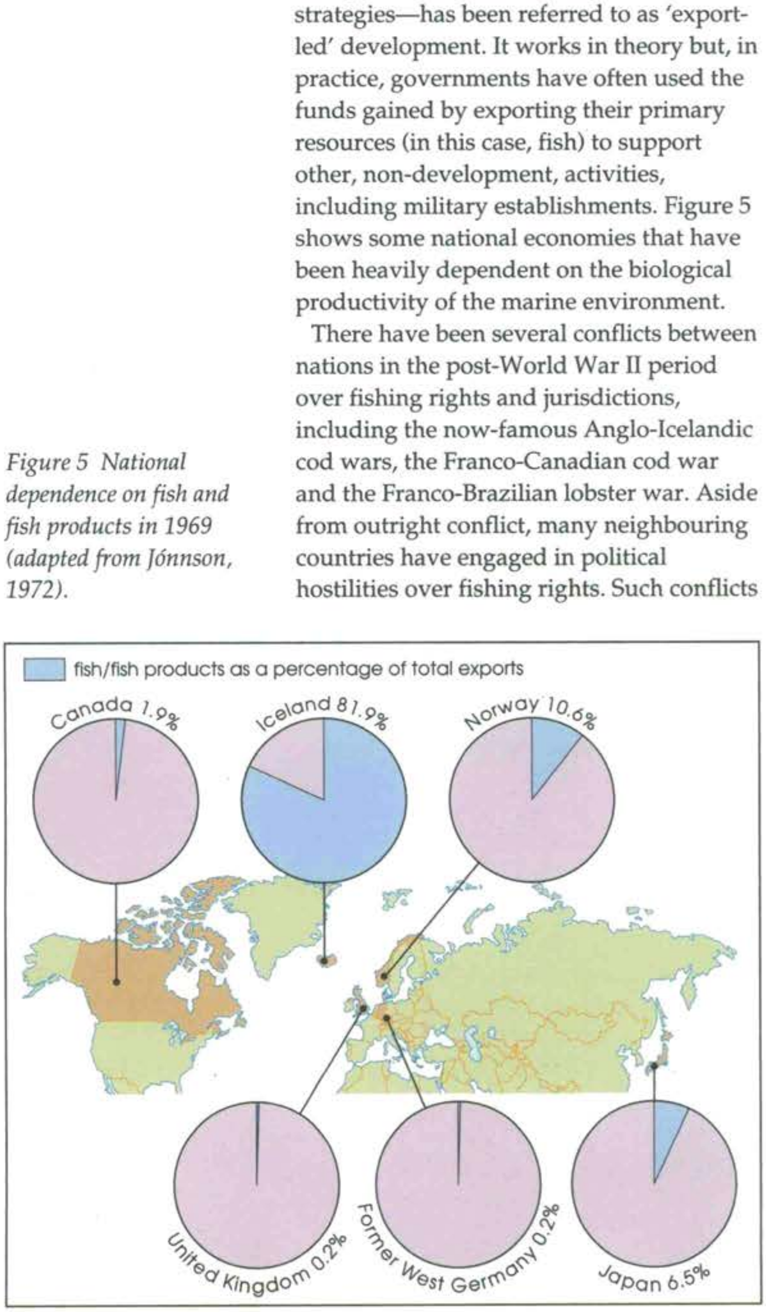
Some coastal countries earn foreign currency by selling fishing rights to other countries with well-established fishing industries. In the absence of a national fishing sector developed enough to enable coastal countries to effectively exploit their living marine resources, these countries permit countries with more advanced fishing fleets to operate in their EEZs. Other coastal countries use their fishing fleets, often operating at a financial loss, to lay continuing claim to and to protect their coastal marine resources by flying their flags in waters whose ownership is subject to political controversy.

Although fishing activities play a relatively minor role in most national economies, for some nations, such as Peru, Chile and Iceland, the fishing industry remains an important source of economic activity. These countries catch fish either for domestic consumption or for export. Exports generate foreign currency, which is badly needed for the purchase in the international market-place of goods required for economic development. This approach—generating capital from exports to support economic development strategies—has been referred to as 'export-led' development. It works in theory but, in practice, governments have often used the funds gained by exporting their primary resources (in this case, fish) to support other, non-development, activities, including military establishments. Figure 5 shows some national economies that have been heavily dependent on the biological productivity of the marine environment.

There have been several conflicts between nations in the post-World War II period over fishing rights and jurisdictions, including the now-famous Anglo-Icelandic cod wars, the Franco-Canadian cod war and the Franco-Brazilian lobster war. Aside from outright conflict, many neighbouring countries have engaged in political hostilities over fishing rights. Such conflicts have broken out between developing and developed countries (Namibia and Spain), between developing countries (Peru and Chile) and between industrialized countries (United States and Canada). There is no sign of abatement in the occurrence of such fishing-related conflicts. As the demand and need for protein increase, along with growing human populations, the number of such conflicts is likely to increase. Recent international laws (such as the Law of the Sea) have sought to reduce conflict over marine resources by giving coastal states control over resources in their coastal waters. Most conflict, however, seems to occur over regional resources between adjacent states and states within a particular region—largely because migrating fish populations do not respect international boundaries.

Some governments and corporations have encouraged their fishing fleets to exploit abundant fish populations in distant parts of the globe. Historically, for example, British fishermen exploited the biologically rich coastal waters surrounding Iceland—from the 1300s well into the 20th century. Poland, with a short coastline along the Baltic Sea, developed one of the world's major long-distance fishing industries, capturing fish around the globe. The former Soviet long-distance fleet was well-known for its large catches and its ability to traverse the world's oceans, capturing and processing living marine resources.

Figure 5 National dependence on fish and fish products in 1969 (adapted from Jónnson, 1972).



Ghost acres and fish acres

A few decades ago, the geographer Georg Borgstrom developed a method to compare the biological productivity of the land with that of the sea. He converted the amount of protein taken from the sea into the amount of land that would be required to produce the same amount of protein. He discussed two concepts: ghost acres and fish acres. These concepts are thought-provoking, and underscore the direct, as well as indirect, importance of living marine resources to a nation's ability to feed its people.

Each country is capable of producing a certain portion of its food supply on its own arable land. In order to make up the differences between what it grows and what it needs, it imports food. Imports represent ghost acres. The amount of land that would be required in order to grow the amount of imported foodstuffs can be calculated.

However, many countries do not have the large expanses of arable land that would be needed to meet their growing food needs. Japan, for example, would require at least three times the area of the entire country in order to grow the equivalent amount of food that its citizens consume.

The concept of fish acreage suggests that living marine resources provide a country with a considerable amount of protein that would otherwise require large expanses of arable land to produce. The notion of fish acreage shows how important marine resources are to resolving problems related to national food needs. The following chart (Figure 6) was composed by Borgstrom to make his point. These concepts can be used to remind governments about the importance of sustainable exploitation of the living marine resources available to them.

'The sea is to those who fish what land is to those who farm.'

Richard Caskin, Task Force on Income and Adjustment in the Atlantic Fishery, March 1994

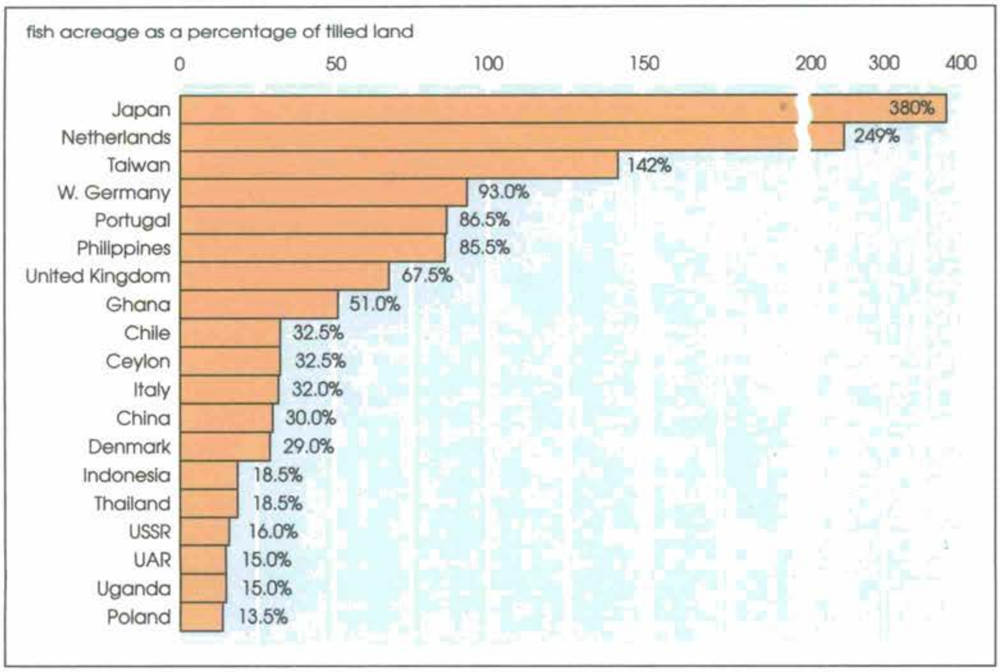


Figure 6 The acreage required in respective countries to produce through agriculture an amount of animal protein (in most cases, milk protein) equivalent to that provided by fish as food and fodder (Borgstrom, 1972).

Post-World War II development of fisheries

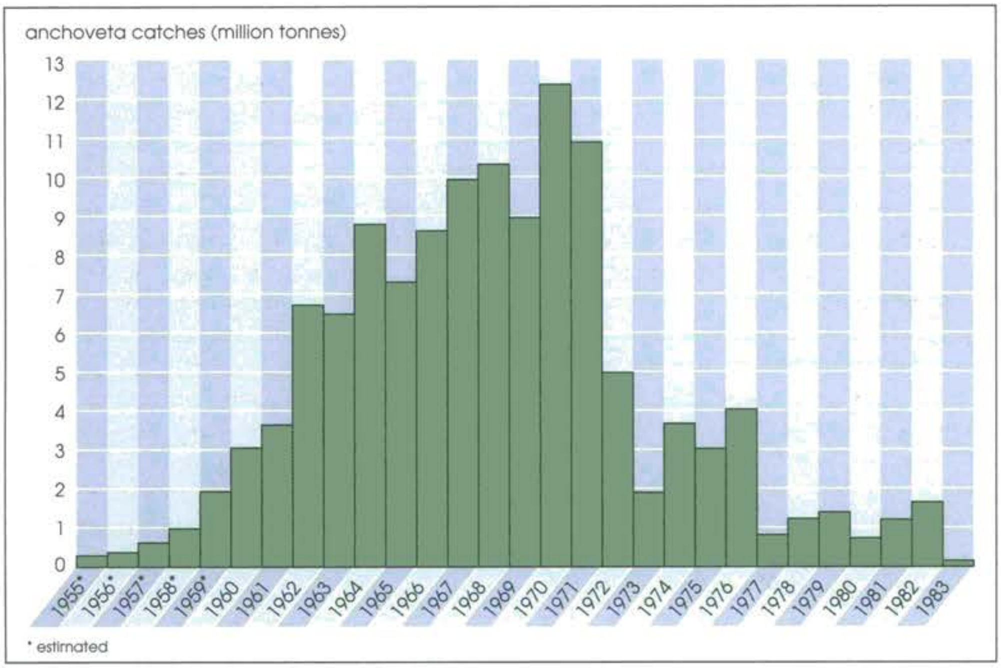
With the end of World War II, fishing fleets were able to sail the high seas and to resume the exploitation of traditional fishing grounds that had become inaccessible during the war years. Restrictions on fishing activities during World War II allowed heavily exploited fish stocks to recover. As a result, fish stocks in many parts of the world were in relatively good condition at the end of the war. This was the setting for the 25-year fishing bonanza that was to follow.

Newly regained accessibility to these commercially favoured fish populations was not the only source of pressure on the long-term viability of living marine resources. Market pressures were also rising. Increasing human populations, as well as improved standards of living, led to additional demand, and thus to additional pressures on fish populations. With an increase in affluence following World War II, the eating habits of those in the industrialized countries shifted from grains to fish, poultry and red meat. Fish were not only caught for direct consumption, but ever-larger amounts were reduced to fishmeal—a dried, flaky fish flesh, which served as a high-value feed supplement for the rapidly growing poultry and feedlot industries. In the early 1950s, American naturalist Robert Cushman Murphy observed that, with regard to fish, man was the only insatiable predator. While other predators would catch only the amount of fish they could consume at a given time, fishing fleets were not controlled by any such limitations and were able to capture as many fish as they could find.

In response to these demands in the international market-place, fish landings rose markedly each year compared to

Mark Edwards/Still Pictures

*Modern fishing techniques and equipment allow humans to over-exploit fish populations. Almost all of the 200 fisheries monitored by the FAO are fully exploited; one in three is depleted or heavily over-exploited—almost all in the developed countries (*The Economist*, 1994).*



those of the preceding year. The catches of Peruvian anchoveta, used primarily for fish meal export, provide a good regional example. Peruvian anchoveta landings doubled each year during the 1950s, as shown in Figure 7. Such increases were the result of a variety of physical, biological, technological, socio-economic and political reasons.

By the end of the 1960s, scientific studies were suggesting that there were limits to the amount of fish that could be taken from the world's oceans. John Ryther of the Woods Hole Oceanographic Institute wrote an influential article in *Science* magazine in 1969, arguing that large expanses of the oceans could be categorized as biological deserts. At that time, about 44 percent of commercial fish landings came from coastal upwelling areas, areas that comprise only 0.1 percent of the ocean's surface.

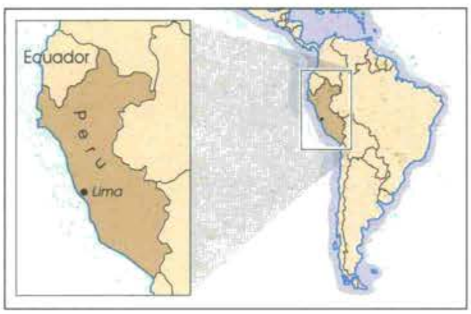


Figure 7 (top) shows anchoveta catches off the coast of Peru in 1955–83. In 1972, the Peruvian anchoveta fishery started to collapse, coinciding with a major El Niño event off the coasts of Ecuador and Peru (left).

It was difficult for policy makers to accept such a view, because fish catches worldwide had increased considerably, with little sign of any potential decline. Although the landings of various specific species in different regions rose or declined, the total commercial biomass taken from the ocean was still on the rise.

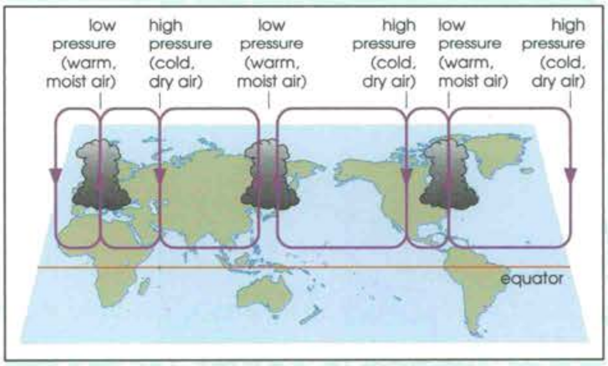
In 1972, one of the largest fisheries in the world began to collapse. The Peruvian

El Niño and teleconnections

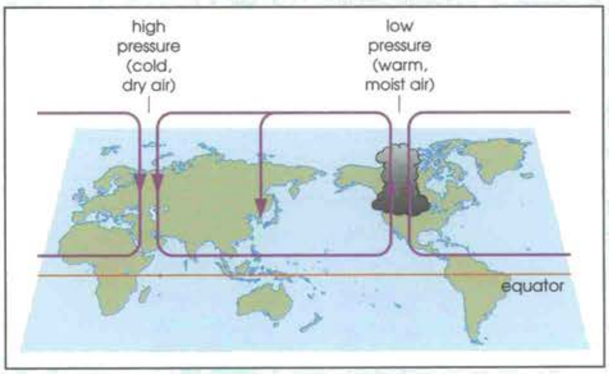
El Niño is the name given to an invasion of nutrient-poor warm water into the eastern equatorial Pacific, more specifically along the western coast of South America. El Niño, the name given to this event by local fishermen, refers to the 'Christ Child', because these events generally begin around Christmas. Under ordinary circumstances, this region is one of upwelling, that is, the welling up to the sunlit zone of the ocean's surface of cold, nutrient-rich deep water that serves as a breeding ground for marine life. When El Niño events take place and the nutrient-poor warm water enters this region, biological productivity is sharply reduced, and the fish populations disappear, either dispersing or going to lower depths beyond the reach of the fishing vessels. No two El Niño events are exactly alike in their geographic magnitude, their intensity (degree of elevation of sea surface temperatures), and duration.

Major El Niño events are accompanied by heavy, often devastating, rains along the normally arid coastal areas of Peru and Chile. Such rains often cause costly and widespread destruction of roads, rail lines, communication networks and human settlements.

The major El Niño events can also have devastating consequences for many other countries around the globe. Certainly, the relationship between El Niño events and climatic variations in the equatorial Pacific regions is extremely strong and well-documented. However, it is less easy to prove that weather disturbances far from the Pacific are related to El Niño. Nonetheless, weather anomalies occur all over the world every year, and some do tend to recur with most or all El Niño events; these are referred to as 'teleconnections'. Once the validity of teleconnections is established, scientists will be able to use more successfully knowledge about El Niño for the purpose of reliable long-range climate-related forecasting for other parts of the world.



The equatorial atmospheric system is the basis of global atmospheric circulation. The system comprises three major convection cells of rising warm, moist air and descending dry, cold air located over the Indian, Pacific and Atlantic Oceans.



During an El Niño, changes in atmospheric pressure result in warm, moist air moving eastwards from Indonesia to the South American coast, and cold, dry air, formerly over the oceans, moving east over the major land masses.

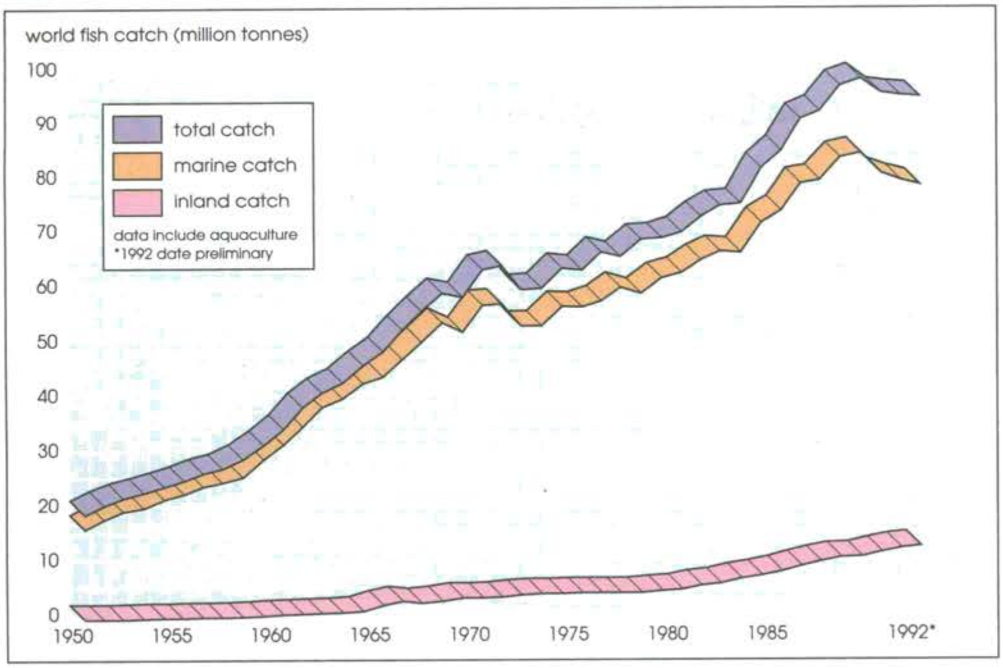


Figure 8 World fish catch 1950–92 (from the United Nations Food and Agriculture Organization).

anchoveta fishery, which had been heavily overfished, was simultaneously hit with a major El Niño event off the coast of Ecuador and Peru. With the collapse in 1972–73 of the Peruvian anchoveta fishery, the worldwide catch of commercial fish registered a major decline for the first time since 1945. This gave credence to scientific suggestions about the limited productivity of the ocean.

Beginning in the mid-1970s, global fish landings once again began to increase, reaching levels almost 50 percent above those that Ryther had suggested were possible. There was a cautious resurgence in the belief that the oceans could provide considerably more protein for the purpose of feeding future generations. That belief was again challenged in the mid-1990s, because major fishing areas showed signs of severe stock depletion.

The anchoveta story: an alternative view

It is often recounted that the collapse of the Peruvian anchoveta fishery in the early 1970s was a direct consequence of the El Niño of 1972–73. Comparison of time series of upper-ocean thermal data, fishery catch records, and ichthyoplankton samples from the Peruvian and northern Chilean coasts suggest that the anchoveta collapse started as early as 1968—as part of long-term ocean and atmosphere processes. These resulted in a general coastal ocean warming, due to decreased upwelling of cold water along the eastern Pacific coast, and consequent ecological changes.

Although intense fishing pressure remains a major reason for which many fisheries ultimately become unproductive and uneconomical, fishing is usually neither the sole, nor necessarily even the primary, force behind the greater fluctuations of this region's pelagic resource populations.

(Excerpt from Sharp, G. D. and McLain, D. R., Fisheries, El Niño-Southern Oscillation and Upper-Ocean Temperature Records: an Eastern Pacific Example, in: *Oceanography*, Vol. 6, No. 1, 1993, p. 13.)

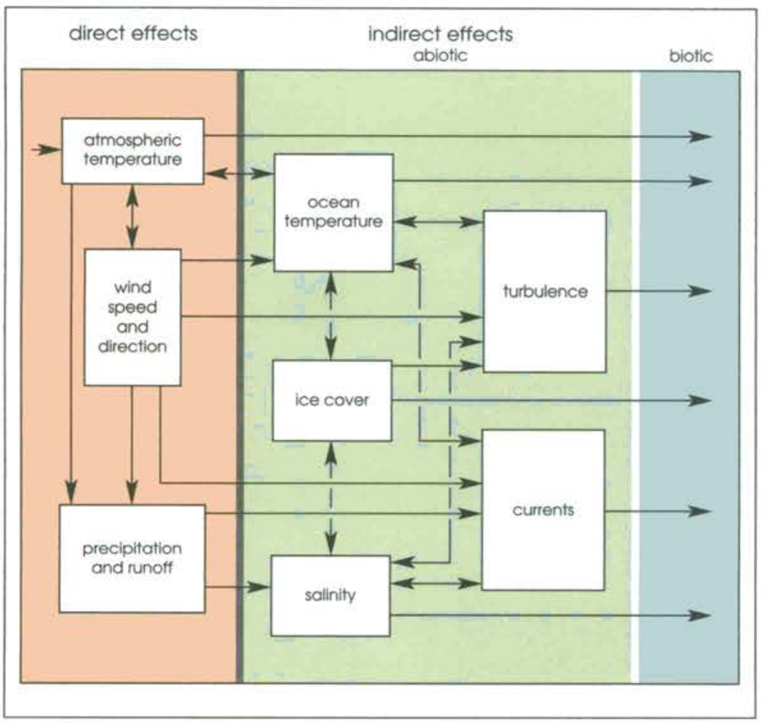
Climate change and fisheries

It is uncertain how global climate change (for example, global warming) might affect the productivity of the upwelling regions or even the location or strength of the upwelling phenomenon itself. Fish populations are influenced by many elements of their natural environments during each phase of their life cycles. Subtle changes in key environmental variables such as temperature, salinity, wind speed and direction, ocean currents, strength of upwelling, as well as the number of predators, can sharply alter the abundance, distribution, and availability of fish populations. Human activities also affect the sustainability of these populations through, for example, the application of a variety of fishing management schemes such as maximum sustainable yield, optimal yield and changes in technologies (for example, nylon nets and echo sounders), each of which would have a different—either beneficial or adverse—impact on the state of the fishery.

Figures 9 and 10 depict the environmental vulnerabilities of fish populations. At any point along the pathway of the fish life cycle, climate-related changes in the environment could enhance or reduce biological productivity. Figure 9 illustrates the major climatic pathways affecting the abiotic environment of fish: increased atmospheric carbon dioxide (CO_2) directly affects climate and dissolved CO_2, and CO_2 indirectly affects seawater temperature, salinity, ice cover, turbulence and currents. All these abiotic effects have biotic sequences (US DOE, 1985). Figure 10 illustrates the main biotic processes affecting fish production, and the abiotic factors that modify these processes. The four major hypotheses concerning control of fishery abundance are related to the major processes controlling production and mortality of early life history stages: reproductive output; starvation; predatory (including cannibalistic) losses; and transport losses. To represent an actual fishery environment, several such interlocking diagrams would be needed to depict multiple species (US DOE, 1985).

The marine environment is extremely complex. Unlike assessments of crop production on land, it is very difficult to monitor changes in the ocean on a systematic, sustained basis. Fish populations are mobile and less easy to monitor. Even subtle, seemingly small, environmental changes can send ripples that cascade through the entire life cycle of a fish population. For example, the lack of winds during spawning can thwart the

Figure 9 Major climatic pathways affecting the abiotic environment of fish.



necessary drift of larvae to the nutrients that they need to survive, thereby destroying a year class. The lack of development of a year class of a particular fish population, especially one that is already heavily exploited, can lead to the decimation of that population. Normal fishing pressures, following an undetected failure of fish recruitment (when relatively few fish survive to become old enough to be legally captured by a fishing operation), can lead to the collapse of a fishery.

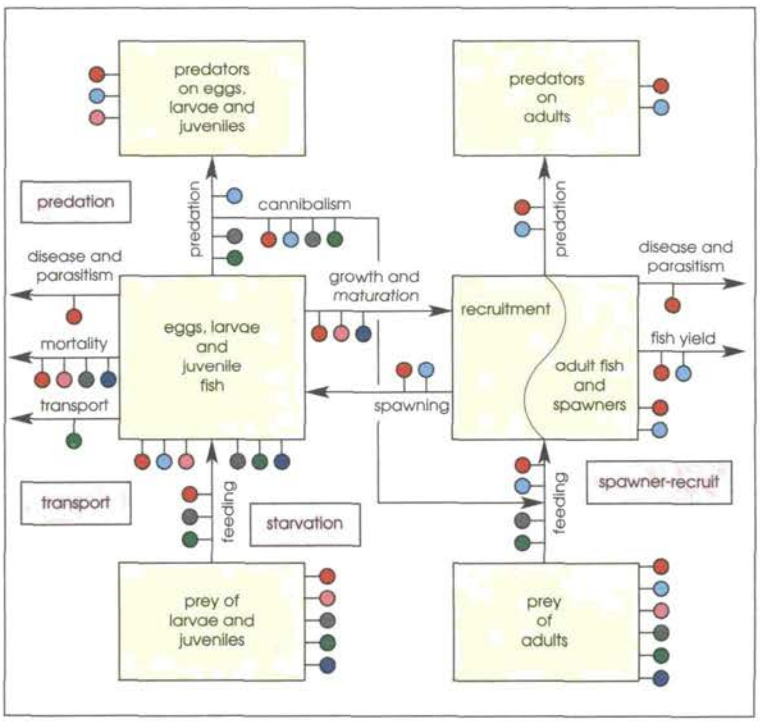
There have been several climate-related fluctuations in fish populations throughout the 20th century. For example, in the 1920s and 1930s, warmer atmospheric and sea-surface temperatures in the North Atlantic led to changes in the abundance and productivity of different commercial fisheries. The pressures of environmental changes on living marine resources have been augmented by pressures resulting from fishing activities. Climate fluctuations, however, are not always bad for fish populations. For example, there was a sharp increase in Atlanto-Scandian herring catches in the 1920s and 1930s, as a result of a warming in the North Atlantic at that time. As another example, the Chilean sardine fisheries eventually expanded following the 1972–73 El Niño event that contributed to the collapse of the Peruvian anchovy fisheries mentioned earlier.

Many studies already exist about the effects of human and environmental factors on the specific aspects or characteristics of living marine resources under contemporary climatic conditions. The implications of changing climatic trends over decades have been felt in different parts of the globe throughout this century. Classic cases of the collapse of major commercial fisheries include the Hokkaido herring in the northwest Pacific in the early part of this century, the California sardine in the late 1940s and early 1950s, and the Peruvian anchoveta in the early 1970s.

The rise and collapse of fisheries to date have been occurring under what has been considered to be a 'normal' global climate regime. The average conditions of such a global-scale regime do not really represent reality, because temperature variations occur constantly on the global, regional and local space and time scales. We know from direct experience how much the climate in a given region can vary from one year, or one decade, to the next. For example, the 1920s and 1930s was a warm period with regard to global atmospheric temperatures, whereas the 1940s, 1950s and 1960s were considered to be cool, followed by the

Figure 10 Main biotic processes affecting fish production, and the abiotic factors that modify these processes.

key
temperature
ice
pH
turbulence
current
salinity



warmer decades of the 1970s and 1980s. In fact, the global atmospheric temperature record of the 1980s, which included six of the hottest years on record, has been cited by some scientists as evidence of a human-induced enhancement of the naturally occurring greenhouse effect.

Climate modellers have suggested that the increase in emissions of greenhouse gases will be likely to lead to an increase in the global average temperature of the atmosphere of 2.5–4.5 °C by the end of the 21st century. Given that most societies have adjusted to their 'normal' regional climates of the past several decades, any changes would disrupt human patterns of interaction. Even seemingly beneficial changes, such as additional precipitation in a relatively dry region, may not prove to be beneficial, depending on when and where that additional precipitation falls. And, as the philosopher Eric Hoffer observed, 'people fear change'.

How might an increase of global atmospheric temperature of a few degrees Celsius affect the biological productivity of the marine environment? Speculation on such impacts is on the increase but, at present, speculation is all we have to go on to gain a glimpse of global warming consequences for terrestrial and marine ecosystems. Yet a good information base already exists with which to develop a first approximation of the possible regional and local implications of a global atmospheric warming.

In 1988, a Conference on the Changing Atmosphere was convened in Toronto, Canada, by the Canadian government, supported by UNEP. Conference organizers brought together, among other scientists, a group of fisheries experts to discuss their views about the consequences of climate change. Their findings were, briefly stated, as follows:

'A small global warming of the ocean would modify moderately, and possibly positively, the overall world fish production, which contributes one-fifth of societies' animal protein consumption, excluding milk and eggs. In particular, the regional patterns of production and variability in naturally fluctuating stocks, such as sardines and anchovies, could change markedly. Moreover, the spatial distributions of such stocks could be displaced, thus affecting national, as well as local, economies, should the warming be of sufficient magnitude to alter significantly the general ocean circulation patterns.

'In coastal areas, the productivity of highly valued species, such as shrimps and anadromous species, and the yields from extensive aquaculture, will often be negatively affected by the reduction of the nursery and growing areas associated with the expected rise of sea level. Depending on changes in rainfall, river runoff will either augment or reduce the above yields.

'Atmospheric transported pollutants, such as nitrates, polychlorinated biphenyls (PCBs) and peroxyacetyl nitrates (PANs), are having harmful effects on freshwater and marine living resources. Such effects will change in relation to the rates of emissions.'

Since the Toronto conference, many national and international studies have been launched, in order to identify and quantify sources and sinks of greenhouse gases. It is an obligation for parties to the Framework Convention on Climate Change to undertake such inventories. Once inventories have been completed, nations and international organizations can better determine how to lower those emissions in order to reduce the likelihood of major changes in the global and, therefore, regional climate regimes. Scientists who model the ocean and atmosphere can produce at this time only plausible scenarios about what the climate of the future might look like. The reliability of these scenarios for policy making is easily challenged, as far as the making of specific policy responses to a specific expected global warming impact on a specific fish population. The scientific uncertainties that surround the regional aspects of a potential global warming of the lower atmosphere make such decisions very risky propositions.

There are several ways that researchers can try to gain a glimpse of how potential climate changes in the future might affect fish populations and fisheries. One way would be to use computer models. For example, general circulation models of the atmosphere, coupled with ocean models, are being used to generate scenarios of global climate change. Those scenarios are being used by some to generate possible impacts of climate change on ocean currents, winds and so on, and in turn to assess the biological impacts of those changes. Societal responses to changes in the availability or abundance of fish populations on which certain societies have become dependent are then identified. Yet, such scenarios of climate change, while plausible, are highly speculative and, as guides to policy making at the local and regional levels, they are inadequate and possibly misleading. Such a research process sets off a cascade of projected impacts, with each successive stage exhibiting larger error bars and lower credibility.

Another approach might be to look at earlier warm and cold periods with regard to global atmospheric temperatures. For example, the 1920s and 1930s have been identified as an above-average warm period. How did fish populations adjust to those changes induced by warmer atmospheric temperature? How did fishing industries adjust to the change in availability or abundance of fish populations? Of course, in the intervening decades, new technologies and information communication systems have changed the way that many fishing companies and fishermen operate. Nevertheless, some insights might be gained from such an approach.

While scientists are perfecting the methods designed to improve our understanding of how the atmosphere, ocean, human activities and fish populations interact in time and space, what can we do to understand better this nexus? One approach is to start an assessment of such potential impacts from the societal end of the equation. Instead of looking at the atmospheric changes impacting oceanic processes which, in turn, impact biological processes in the marine environment, which then affect fishing activities, one could obtain a first glimpse at how society might cope with these impacts by looking at how societies have responded to previous changes in the abundance and availability of fish. This approach is referred to as 'forecasting by analogy'.

The 20th-century history of fisheries provides scores of examples of global and regional changes in the productivity of fisheries. Scores of fisheries around the world have been either growing or collapsing because of natural and

Large marine ecosystems

Scientific research efforts have often focused on understanding the behaviour of a particular fish population such as sardines, anchovies or tuna. Others have focused closely on multi-species fisheries in which several species can be found within a given ecosystem. A different approach to looking at fisheries emerged in the early 1980s, for the purpose of identifying large marine ecosystems (LMEs).

Using this approach, 23 LMEs were delimited around the globe, and the major—but not necessarily the only—perturbations to biological productivity in these LMEs were attributed to large-scale environmental changes, excessive fishing mortality or pollution effects, or a combination of these factors. Recent studies on the biological yields of these 23 LMEs suggested the following:

- six ecosystems (Kuroshio Current, Oyashio Current, Humboldt Current, California Current, Iberian Coastal and Benguela Current) were affected primarily by large-scale natural environmental changes;
- three ecosystems (Gulf of Thailand, Yellow Sea and northeast United States continental shelf) were primarily affected by excessive fishing pressures;
- in one ecosystem (Australia's Great Barrier Reef), predation by starfish was seen as the cause of reduced productivity; and
- in another ecosystem (Baltic Sea) a primary cause was identified as excessive pollution.

(From Sherman *et al.*, 1990)

Forecasting by analogy: understanding how societies have already responded to regional climatic variability will help to forecast possible future responses to global climate change.

anthropogenic factors. These examples can be used to identify or approximate society's ability to cope with unanticipated environmental changes, regardless of cause. This approach can identify existing strengths and weaknesses in societal responses to changes in the marine environment. This would help to reduce the mounting political pressure on climate and ocean modellers, who are constantly being asked to provide reliable scenarios of regional climate change and its implications for biological productivity. It would allow them more time to perfect their research tools and to understand air-sea interaction and its impacts on fish populations and on fisheries.

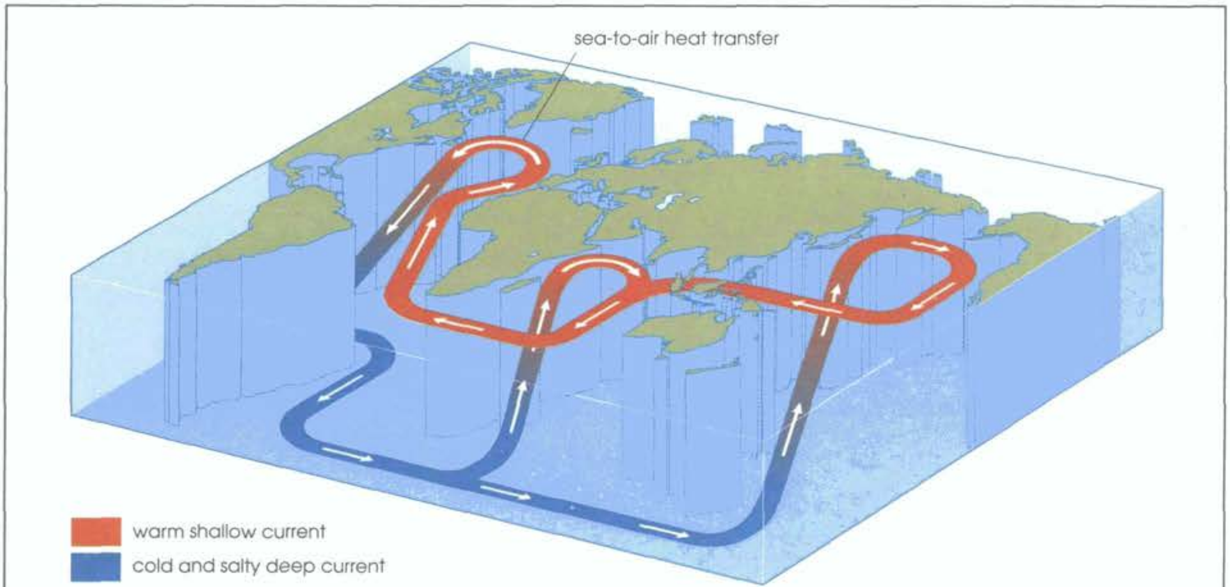
Forecasting by analogy enables us to focus on a set of cases in which fisheries have had to cope with changes in the availability, abundance or location of living marine resources. This approach represents a no-lose situation. Whether or not the climate changes at the scale, magnitude and rate proposed by some global warming proponents, assessments of successes and failures in fisheries can provide information for improving societies' operations in the face of an uncertain future climate. Although some scientists have suggested that past changes in the environment will not necessarily recur in the future, society can benefit from forecasting the ability to cope with fluctuations in fish landings and from attempts to better identify ways to cope with these fluctuations, whether or not they are associated with changes in the global climate.

The Earth's changing climate and the oceans

Climate change could affect primary production in ocean ecosystems through effects on phytoplankton. Predictions are difficult, but it seems likely that in many areas, warmer waters could result in a decrease in phytoplankton, although we do not know enough to make an overall assessment. Many fish species may move towards higher latitudes, with possibly some problems for colder water species being squeezed from their traditional habitats. Some species increase in warmer waters, while others decrease. These changes, in turn, have impacts on sea birds and marine mammals. [1]

The thermohaline circulation, driven by density differentials in the ocean, acts as a giant conveyor belt transporting heat and salt for great distances and, it is thought, modulating global climate. In the Atlantic, the thermohaline circulation is manifested as warm saline water transported by the Gulf Stream and North Atlantic current systems to high latitudes in the North Atlantic in the surface layers. There, the saline water cools, becomes denser, sinks and returns southward at depth, to form a large-scale meridional cell in the ocean. If surface forcing is altered, for example by inherent variability in the atmosphere, or by warming and freshening of the surface ocean layer from increased CO_2 in the atmosphere (that is, the atmosphere is warm and there is more precipitation, especially in winter), the water at high latitudes is no longer cold or saline enough to sink, and the entire thermohaline circulation can be weakened or can even break down entirely. Consequently, there is some evidence that the coupled climate system may be able to exist in more than one stable state (that is, there may be multiple equilibria), and the thermohaline circulation is an essential component of this phenomenon. This has major implications on long time scales in the climate system, and may be a factor in the changes from glacial to interglacial climates. The implication of this model experiment is that the coupled system can exist in a stable manner both with and without the thermohaline circulation, with significantly altered atmospheric and oceanic characteristics in the two states. Additional studies of the consequences of changes of the thermohaline circulation in coupled models are just beginning.[2]

The great ocean conveyor logo, depicting global thermohaline circulation. Colder water in the north Atlantic sinks to the deep ocean, to resurface and be rewarmed in the Indian and north Pacific oceans. Surface currents carry the warmer stream back again through the Pacific and south Atlantic. This circuit takes almost 1000 years (from Broecker, 1987).



[1] Excerpt from the Executive Summary of *Some like it hot: climate change, biodiversity and the survival of species*, Markham, A., Dudley, N. and Stolton, S. (eds.), World Wildlife Foundation International, Gland, Switzerland.

[2] Taken from Meehl, G. A., 1992, Global Coupled Models: Atmosphere, Ocean, Sea Ice, in Trenberth, K. E. (ed.), *Climate system modelling*, Cambridge University Press, Cambridge, United Kingdom, pp. 579–80.

Impacts on society

The following section presents a summary of findings based on a forecasting by analogy study of 15 fisheries around the globe. Six fisheries have been selected as examples of societal responses to changes in the availability or abundance of fish populations. They are the California sardine fishery, the Far Eastern sardine fishery, the North Sea herring fishery, the Alaska king crab fishery, the Indian Ocean tuna fishery and the Polish distant-water fisheries.

California sardine fishery

The California sardine fishery began in the last decades of the 1800s, peaked in the 1930s and began to collapse after World War II. It is a classic case of the rise and fall of a fishery which is dependent on a pelagic species, of over-capitalization of an industry and of too many fishing boats using new technologies to harvest a fragile, if not dwindling, resource.

Its collapse spawned the rapid development of similar fisheries in Peru, Chile and South Africa, each of which then underwent essentially the same kind of growth and decline as the California sardine fishery. This fishery can be used as an analogy of potential changes that might accompany the regional impacts of a global warming of the atmosphere, and which could provide lessons for proactive, as well as reactive, responses to changes in abundance of a pelagic industrial fishery.

Lessons

- Development-oriented government agencies can contribute toward delayed and ineffective fisheries management responses to changing environmental conditions.

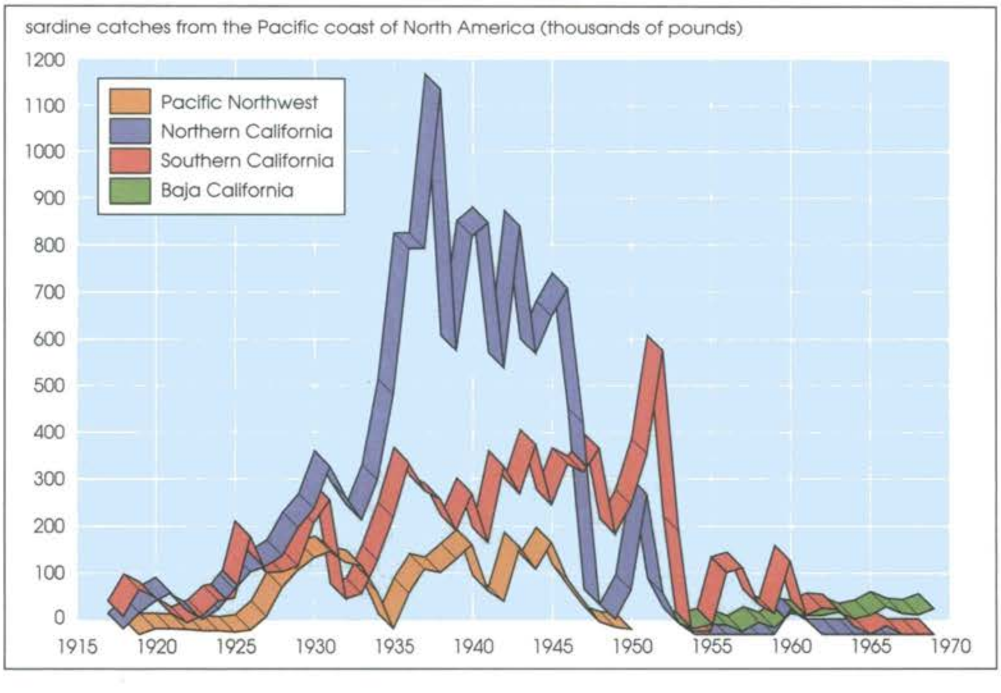


Figure 11 Sardine catches from the Pacific coast of North America, 1915–70. Pacific Northwest includes British Columbia, Washington and Oregon. Northern California includes reduction ships, San Francisco and Monterey. (Data from Murphy, 1966.)

- A substitute fishery will develop more rapidly than a newly developed independent fishery, because existing capital, labour, technology and markets can readily be transferred to the substitute fishery.
- The instant availability of technology and expertise eliminates the 'learning curve', and a rapid transfer of expertise, technology and processing capacity will exacerbate inherent instability in the fishery.
- The political process of establishing management institutions and the scientific process of developing predictive fishery models are much slower than the processes associated with the industrial development of substitute fisheries.
- Internationally, governments and their fishery management agencies should be prepared to adopt politically difficult (and industry resisted) management policies of deliberately constrained fishery development, and should avoid politically popular, but economically destabilizing, subsidies.

Far Eastern sardine fishery

The Far Eastern sardine fishery extends back to the early part of the 17th century. In the earliest days of the fishery, the fortunes of the fishing villages rose and fell with the increase and decrease in the abundance of sardine populations. In the 1940s, sardine catches started to decline sharply, ebbing in 1965 at 9000 tonnes. Beginning in 1970, the sardine catch began to increase once again. Substantial catches have been obtained off the coasts of South Korea since 1976, and off the former Soviet Union since 1978. If sardine landings decline again, Japanese society—as well as the fisheries—will be seriously affected.

Lessons

- The Japanese fishing industry has become dependent on large-quantity fisheries and is, therefore, vulnerable to both environmental and societal changes.
- An improved understanding of the interaction between fish populations and global and regional environmental factors needs to be fostered to protect the fisheries—and society—from dislocations caused by a sudden decline in sardine landings. This will enable scientists to make better forecasts of biological productivity on which fishing communities have become dependent.
- Ports and industries that are dependent on sardine landings should develop measures to anticipate and cope with problems that might accompany sharp changes in sardine availability or abundance. For example, changes in the abundance of sardines could adversely affect the availability of low-value feed, generating economic problems in the production of *hamachi*, an important source of protein for the Japanese, which is only economically accessible because of the abundance, and the low-cost and high-volume, catches of sardine.

North Sea herring fishery

The North Sea herring is one of the world's most important marine fish resources. It has supported major fisheries in many countries of northwest Europe for hundreds of years. Yet, in 1977, the fisheries were closed, following a collapse of the stocks to a small fraction of their earlier levels.

If climatic change were to result in more persistent changes in the ecosystem, then changes in herring and other stocks are likely to persist over much longer periods.

In particular, this case addresses the relevance of environmental changes to the North Sea herring collapse, and whether action could have been taken to prevent—or mitigate—the stock's collapse. The role of perceptions of management bodies and of the fishing industry are important concerns, and an evaluation is given of what might be expected in similar instances in the future. While the scenario presented here does not directly address this eventuality, it is relevant to situations in which anomalous events recur with a greater frequency.

Lessons

- As a fishery collapses in one area, the fleet will move to other areas, adding additional pressures to the existing commercially exploited fish stocks.
- General consensus on concepts of conservation and of environmental change does not necessarily lead to agreement on particular policies, as long as there is a high level of uncertainty.
- If the worst effects of a stock collapse are to be mitigated in the future, fishery managers have to react to strong inference as opposed to scientific proof. This is likely to be contentious because there is more than one way to respond to uncertainty.

Alaska king crab fishery

This study focuses on the red king crab stock in the eastern Bering Sea and the Gulf of Alaska. King crab abundance has fluctuated tenfold in the past 25 years. From the late 1960s, king crab was the second most valuable marine resource in Alaska, surpassing all salmon stocks combined. In 1981, stock abundance fell

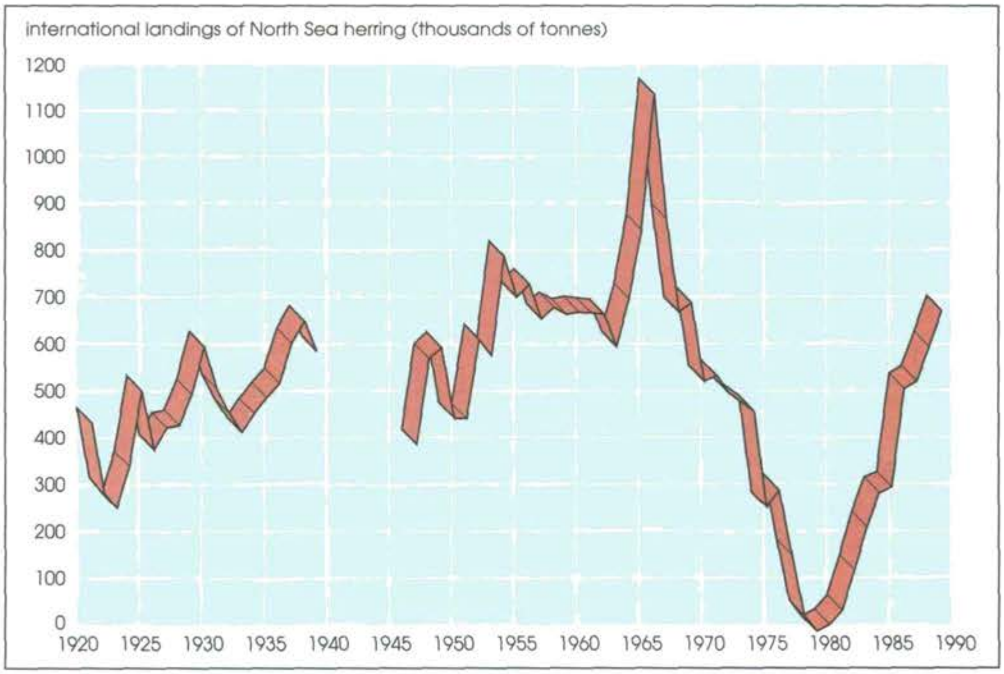


Figure 12 Total international landings of herring from the North Sea, 1920–88.

sharply and has recovered only very slightly since then.

Many reasons have been offered for the collapse: overfishing, predation, disease and environmental change. The collapse of the fishery was devastating, because the fleet was too large, boats carried big loans and fishermen were unable to pay their debts. The eventual solution to this dilemma for the industry was to transfer effort and investment to other resources. Given the growing concern about climate change and speculation about potential impacts on living marine resources, studying management responses to the changes in the abundance of red king crab might provide some lessons to fishery managers about problems that could arise from global warming.

Lessons

- The fate of any specific fishery under changed environmental conditions is difficult to predict, but large changes in the abundance and distribution of many fishery resources are likely to continue.
- The fishing industry's traditional response to collapse is to diversify, to target other stocks and to develop new fisheries. Success requires that transition costs be kept tolerable.
- Present methods for fishery management in the United States are clearly ineffective in matching catching capacity to fluctuating resource potentials.
- An underlying concern is whether there will continue to be alternative fishery resources available as the climate changes.

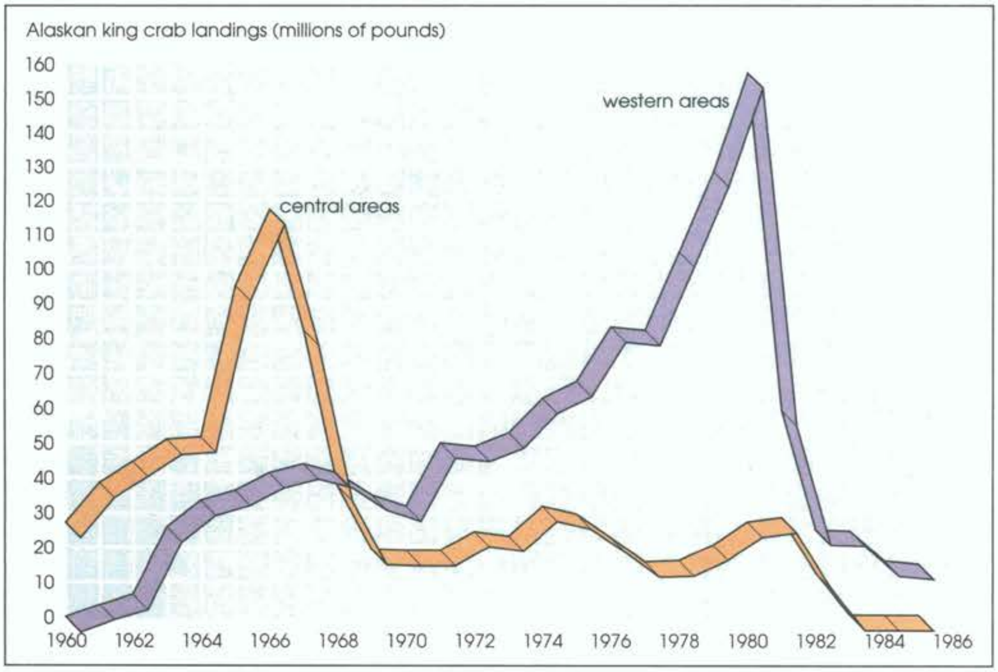


Figure 13 Alaskan king crab landings from central and western areas. Central areas include Prince William Sound, Lower Cook Inlet, Kodiak Island and South Peninsula. Western areas include Bristol Bay, Dutch Harbour, Adak, and eastern Bering Sea. (Data from Hanson, 1987.)

Indian Ocean tuna fishery

The development of the western Indian Ocean tuna fishery, particularly around the Seychelles plateau, is recent and unique. This fishery is thriving, whereas similar developments in other oceans over recent decades have either been marginally successful or have failed. During the past few decades, there have been several national efforts to develop near-shore fisheries for tuna. These have been successful in locating resources, but have not been very effective in transferring the technology needed in order to extend local fishing grounds into the open ocean. Most recently, tuna development projects began in the Maldives and the Seychelles, both of which have been successful, but for different reasons. After several decades of failed tuna ventures, poor planning and investments, and overly optimistic or misleading resource assessments, the success of several of these Indian Ocean development efforts merits careful study before initiating any other fishery development efforts.

Lessons

- Fish populations rise and collapse with climate changes. The concept of stabilizing them through management is only an optimistic artifact of expectations resulting from two decades of somewhat stable climate (1947–67), when fisheries science was becoming a quantitative exercise.
- It is usually the case that while one array of populations is in decline, another array will be in transition to greater abundance. Adaptability of the fishery is imperative.
- The message from the fisheries science community, which has remained valid for decades, is that too much competitive fishing effort destroys population breeding potential, as well as the economics of fisheries.
- We know a lot more about the relationships between the ocean as habitat and the responses of various species than many researchers use in their assessments of existing and potential ocean resources.
- The challenge is to recognize the precursors of systemic change, to mount the appropriate changes in behaviour in preparation and to change behaviour once these processes have occurred. Pre-adaptation and versatility are the keys to ecological and economic survival.

Charlie Pye-Smith/Still Pictures

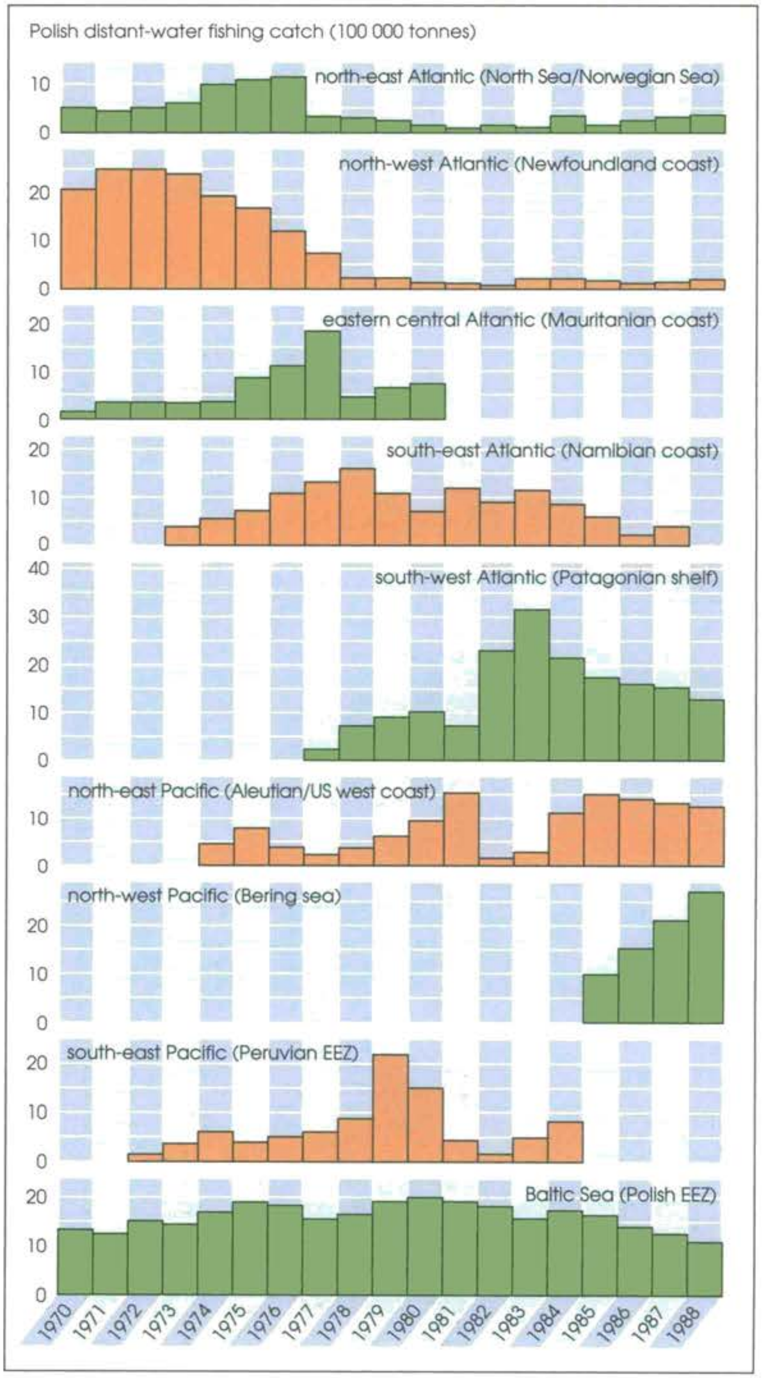
Versatility is one of the keys to survival when faced with a declining fish population; often, as one population goes into decline, a fishery will seek other species to exploit.

Polish distant-water fisheries

Because of widespread international support for the establishment of national exclusive economic zones (EEZs) in the late 1970s and early 1980s, the Polish distant-water fleet was confronted by what was essentially a lock-out from many of the fishing grounds it had been exploiting for decades.

This relatively abrupt change in the accessibility to living marine resources of Polish vessels can be viewed as analogous to the impacts of a global climate change on local fisheries, because species change in abundance and locations, and habitats change. Thus, the establishment of the EEZs, its impacts on Polish fishing activities and Poland's responses to those impacts,

Figure 14 Distribution of catches by the Polish long-distance fleet according to fishing area, 1970–88.



can provide useful insights into societal responses to the impacts of global warming.

Lessons

- Access to the appropriate level of technology required for catching and processing different species in remote areas needs to be available.
- In the event of a change in resources associated with global warming, fishery managers should consider exploiting fauna at lower trophic levels.
- One should not expect to find homogeneous views about, and actions with regard to, coping with the impacts of global warming on fishing industries and communities.
- In order to alleviate regional differences and to make social responses more effective: international cooperation should be strengthened through relevant institutional arrangements—perhaps the existing international fisheries bodies could establish a coordinating committee; and knowledge about the possible consequences of a global warming must be widely disseminated to fishery administrators and managers.

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Conclusions

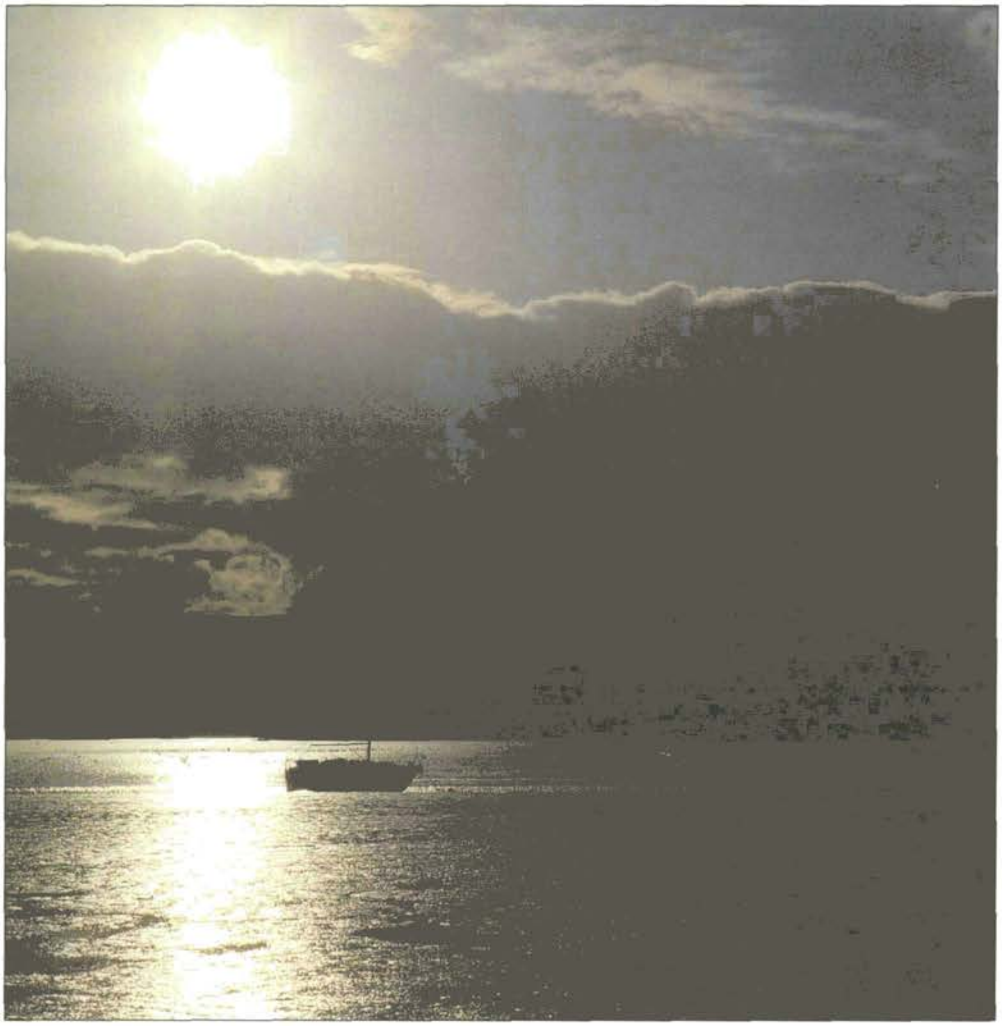
Living in harmony with the marine environment is one of the major economic, as well as environmental, challenges facing the international community in the 21st century.

The marine environment is truly complex. Innumerable factors interact to produce conditions at local and regional levels that may be conducive to changes in biological productivity. There are many natural factors, the timing and location of which determine the development of a major fishery. For example, slight changes in wind speed or wind direction at a crucial period in the life cycle of a particular fish population (for example, at spawning) can spark a successful spawning effort of a fish population or can lead to its demise. Uncertainty surrounds the life cycle of a fish and of a fish population. Add to it the pressures of human activities—bigger vessels, more efficient gear, improved technologies for locating fish, increasing demand for fish and fish products in the market-place—and all fish populations in which societies worldwide take a commercial interest become at high risk to survive. These pressures are occurring just as population growth is making it more and more imperative to maximize food production from all sources.

The latest predator to be confronted by living marine resources could be a changing climate. Global warming would have direct and indirect impacts on the marine environment. Speculation about how climate change might affect fisheries around the world has sparked new research efforts. There is a growing effort to expend a larger share of research funds on assessing physical and biological factors that affect positively, as well as adversely, the availability and abundance of living marine resources. In the meantime, social science researchers have embarked on a variety of approaches to gain a glimpse of how the future climate might affect marine resources, and how societies might best respond to the consequences of future changes in biological productivity.

The approach chosen for discussion here has been referred to as 'forecasting by analogy', which moves the emphasis from the physical science end of the puzzle to the social end. The computer modelling approach generates possible scenarios of future climatic conditions and then generates hypotheses—based on physical and biological principles—about how relationships might change within the food web, food chain and predator-prey relationships, and how seasonality in the marine environment and the spatial distribution (both vertical and horizontal) of marine resources might change. Forecasting by analogy looks at past changes in the atmosphere and ocean environments to see how living marine resources have been affected and to identify those societal responses that have been most successful. Thus, the focus is on society's ability to respond to changes in the environment, regardless of the cause.

This assumes that societal responses to past crises can provide insights to decision makers about societal strengths and weaknesses in strategic and tactical responses to future disasters. Such insights could help them to mitigate the impacts of possible future climate-related environmental crises. While it is valid to argue that, several decades into the future, society will probably not be like that of today, one could also argue that societies evolve slowly. Thus, today's institutions and institutional responses are likely to be similar to those within the next decade or so, with exceptions notwithstanding. While scientists are perfecting their forecasting tools and skills, and improving their understanding of all facets of the global



Ian Stewart Millington/Bruce Coleman Ltd

'While some fishermen realize that the age of the unbounded ocean is already over, and that fisheries must be managed, the question is how to persuade all fishermen, and all governments, of the urgency of that need.' (The Economist, *1994)*

warming issue, societies can begin to evaluate and strengthen their ability to cope with unexpected changes.

There are many case histories of fisheries that have developed quite rapidly. There are also many case histories of collapses of fishing industries. In many of these, climatic factors have taken the blame for the demise of a seemingly healthy fish population or fishing industry. For example, the El Niño event in 1972–73 took the blame for the collapse of the Peruvian anchoveta fishery. However, climatic variations and climate change are all too easy to blame. The adverse effects of other factors may be equally, if not more, important than atmospheric processes. These include: the development of new technologies that enable fishermen to concentrate on preferred fish populations with relative ease; larger, more sophisticated vessels to carry and process greater volumes of catches; increases in demands in the market-place; and marine pollution in coastal areas, especially in spawning grounds. While, in any given instance, it may be difficult to identify the 'smoking gun' and the precise cause of the sharp decline of a fish population—or, conversely, its rapid expansion—it is possible to determine whether societies have responded appropriately to changes in a fishery. Living in harmony with the marine environment is one of the major economic, as well as environmental, challenges facing the international community in the 21st century.

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