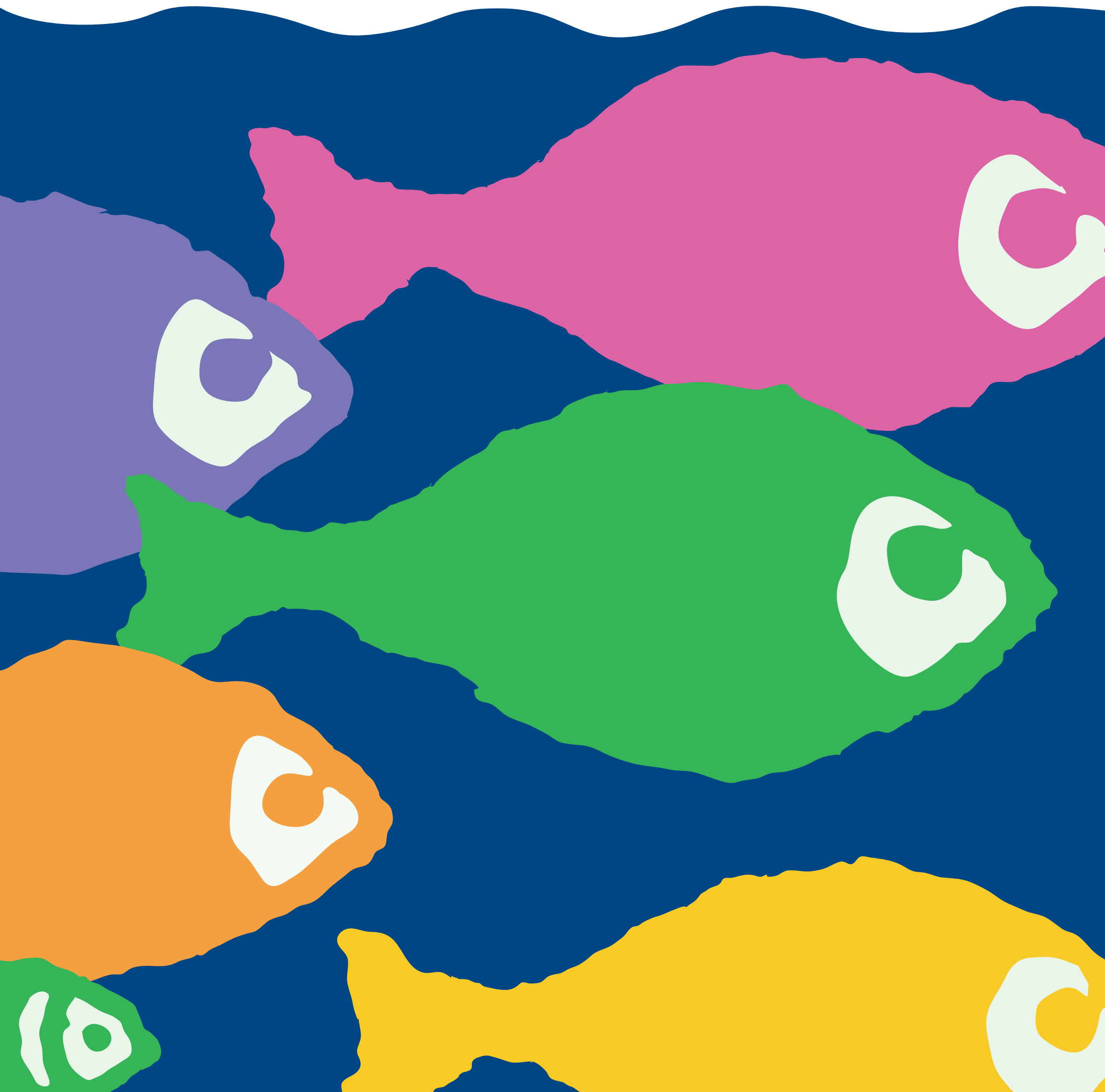
FISH TO 2020

Supply and Demand in Changing Global Markets

Christopher L. Delgado, Nikolas Wada, Mark W. Rosegrant, Siet Meijer, and Mahfuzuddin Ahmed



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IFPRI was founded in 1975 to develop policy solutions for sustainably meeting the food needs of the developing world. Research, capacity strengthening, and policy communications at IFPRI concentrate on achieving economic growth and poverty reduction in low-income countries, improving food and nutrition security of poor people, and managing the natural resource base that supports agriculture. IFPRI researchers work closely with national counterparts and collaborate to strengthen research capacity in developing countries. IFPRI also strengthens the link between research and policymaking through its regional networks. It communicates the results of its research to influence policymaking and raise public awareness about food security, poverty, and natural resource issues.

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IFPRI's 2020 Vision Initiative seeks to develop a shared vision and consensus for action on how to meet future world food needs while reducing poverty and protecting the environment. The 2020 Vision Initiative gratefully acknowledges support from the following donors: Canadian International Development Agency (CIDA), Danish International Development Agency (Danida), and Swedish International Development Cooperation Agency (Sida).

THE WORLDFISH CENTER

We are committed to improving the lives of poor people in developing countries. We do this through scientific developments, as we believe this is critical in truly making a difference. Our area of specialization is in fish and we assist with developing solutions to fisheries management and aquaculture development in developing countries. These are scientifically based, environmentally, economically and socially sensitive, and undertaken in partnership.

WorldFish Center is an autonomous, nonprofit organization, established as an international center in 1977. WorldFish has offices in 10 countries in Asia, Africa, the Pacific and Caribbean, and has research projects with collaborators from 50 countries and 39 regional/international organizations.

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IFPRI and the WorldFish Center are two of 16 food and environmental research centers supported by the Consultative Group on International Agricultural Research. They receive their principal funding from governments, private foundations, and international and regional organizations, most of which are members of the CGIAR.

The seemingly inexhaustible oceans have proved to be finite after all. Capture of wild fish have leveled off since the mid-1980s, and many stocks of fish are fished so heavily that their future is threatened. And yet the world's appetite for fish has continued to increase, particularly as urban populations and incomes grow in developing countries. Aquaculture—fish farming—has arrived to meet this increased demand. Production of fish from aquaculture has exploded in the past 20 years and continues to expand around the world. But will aquaculture be sufficient to provide affordable fish to the world over the next 20 years? And what environmental and poverty problems will aquaculture face as it expands?

Using a state-of-the-art computer model of global supply and demand for food and feed commodities, this book projects the likely changes in the fisheries sector over the next two decades. As prices for most food commodities fall, fish prices are expected to rise, reflecting demand for fish that outpaces the ability of the world to supply it. The model shows that developing countries will consume and produce a much greater share of the world's fish in the future, and trade in fisheries commodities will also increase. The authors show the causes and implications of these and other changes, and argue for specific actions and policies that can improve outcomes for the poor and for the environment.

"This analysis of world fish markets to 2020 is the first of its kind that is firmly rooted in modeling of supply and demand based on economic theory, taking into account economic and technological as well as biological variables, and also analyzing implications for equity as well as international trade under alternative scenarios. This book is bound to become a seminal contribution in this field."

—Trond Bjorndal, professor of Fisheries Economics, Centre for Fisheries Economics, Bergen and University of Portsmouth

"We have all heard about the crisis in fisheries: dwindling catches, swordfishermen out of work, and the environmental questions that are dimming hopes for aquaculture. Here, five experts apply thoughtful scenario-building and solid economic analysis to construct a plausible picture of what this vital industry will look like in 2020. Their work should command the serious attention of policymakers—in the developing world as in the North."

—Donald Kennedy, editor-in-chief, *Science*

"Previous IFPRI reports have been uniquely important in helping decisionmakers understand global agriculture. *Fish to 2020* adds to this tradition by providing a comprehensive, quantitative, and readable account of both wild-caught and farmed fish. With its careful assessment of supply, demand, prices, and policy, this volume is must reading for anyone serious about the future of fish, fishing, and the environment."

—Roz Naylor, senior fellow, Center for Environmental Science and Policy, Stanford University

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2020 VISION

Fish *for* All

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Foreword

While fishing must surely be one of the oldest recorded sources of livelihood, it is only comparatively recently that fish have become important components of the diets of the majority of the world's people—especially those living in developing countries. Consumption of fish and seafood products reached 14 kilograms per capita in developing countries in 2001, nearly twice the level recorded in the early 1970s, while population in those countries doubled over the same period. Fish are an important component of the rapid growth of the consumption of animal products in developing countries over the past two decades and into the foreseeable future.

Most of the net growth in fish production over the past 20 years has come from the development of fish farming, especially in the developing countries of Asia. At 11 percent per year, aquaculture has in fact been the fastest growing source of food and agricultural income worldwide for the past 20 years. The composition and direction of fish trade between developed and developing countries have also shifted tremendously in recent years. Net fish exports of US$15 billion per year from developing to developed countries now surpass the monetary value of many other traditional developing-country agricultural exports. Yet wild fisheries are in a state of crisis. Total catches of fish from the wild reached a plateau in the early 1990s. And even though the production of both low- and high-value aquaculture (grass carps for food and shrimp for export, for example) has continued to grow, concerns have been raised about environmental risks associated with the ongoing intensification and spread of fish production, as well as competition between poor traditional fishers and large-scale operations. Choices for both technology and policy development are at a critical crossroads. The stakes concern how small-scale fishers will retain their access rights to future fisheries resources in the face of the demands from large-scale operators, how to rebuild depleted fisheries resources and then maintain their exploitation at sustainable levels, and how the benefits from fisheries will serve the interests of poor people and low-income countries in the face of increases in both fish consumption and trade.

This is the first comprehensive quantitative study ever undertaken to inject global food and agriculture debates with clear and concise fisheries policy issues, including questions of food security, equity, trade, environment, and food safety. The authors provide a detailed assessment of policy research issues in world fisheries arising from trends over the past 20 years. They then employ IFPRI's IMPACT model to forecast scenarios for the next 20. They explore the market linkages intrinsic to the future of aquaculture and capture fisheries, the changing consumer and producer roles of different parts of the world under globalization, and the emerging tradeoffs between environmentally sound policies and equity-oriented goals. They show that viable solutions will require an understanding of what the separate incentives are for producers and consumers of fish, and how improved policies and new technologies interact to affect wealth creation, poverty reduction, and environmental sustainability. They conclude with a list of 20 specific entry points for developed- and developing-country policies intended to influence poverty and environmental outcomes in developing countries.

The book grew out of broader collaboration between IFPRI and the WorldFish Center that started with a consultative conference held in Hirtshals, Denmark, in the summer of 1997. Attended by prominent fisheries policy analysts from developing countries, the purpose of the conference was to define the key policy research issues confronting fisheries in developing countries, and to help recommend a common agenda for policy research in fisheries between IFPRI, a food policy research institute, and the WorldFish Center, a specialist fisheries research agency. Participants identified the need for a study such as this one to illustrate the complex tradeoffs within the fisheries sector, the interactions with events outside the sector, and the impact of fisheries on food issues more broadly.

In approaching this difficult assignment, the team benefited greatly from the partnership of IFPRI's expertise in global modeling and food policy analysis and WorldFish's specific knowledge of the fisheries sector and related policy and technology issues. Several intermediate and spin-off products involving a number of additional authors have resulted from the partnership over the past five years. The plan is to continue this fruitful collaboration, focusing on areas identified in the study as priorities for future research.

Joachim von Braun
Director General
International Food Policy Research Institute

Meryl Williams
Director General
WorldFish Center

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We would like to particularly acknowledge the support, patience, and foresight of four managers and colleagues at our institutes who recognized the value and importance of a comprehensive, forward-looking approach to global fish supply and demand. These individuals were also—importantly—willing to risk promoting a research venture without the certainty of a worthwhile product. Per Pinstrup-Andersen, Director General of IFPRI at the time this work began and currently H. E. Babcock Professor of Food, Nutrition, and Public Policy at Cornell University, was instrumental in this regard, as was Rajul Pandya-Lorch, head of IFPRI's 2020 Vision Initiative. Their moral and financial support were fundamental to getting this work off the ground. They also provided lengthy written comments on the first draft that were a valuable contribution. We would also like to acknowledge the ongoing significant support for fisheries policy research at IFPRI from Joachim von Braun, IFPRI's current Director General. Meryl Williams, Director General of the WorldFish Center (formerly known as ICLARM), consistently provided moral support to the team, facilitated collaboration from her staff, and placed the moral authority of her center behind fundraising efforts for what—in the end—was a lengthy effort.

The origins of this study lie in a consultation of eminent fisheries experts from developing countries, universities in Europe and the United States, donor agencies, and the Food and Agriculture Organization of the United Nations (FAO) through a meeting on research priorities for fisheries policy in developing countries that was held in Hirtshals, Denmark, in 1997. The meeting was made possible by the financial support of Danish International Development Assistance (Danida) and the Overseas Fishery Cooperation Foundation of Japan; it was co-sponsored by IFPRI, the WorldFish Center, and the Institute of Fisheries Management and Coastal Community Development, Denmark; and it was held in cooperation with the FAO and the Royal Veterinary and Agricultural University, Copenhagen. Undertaking a study of this kind was identified as a top priority at that meeting.

We would also like to acknowledge help on specific issues provided by colleagues within and beyond our two institutes. The team particularly wishes to acknowledge the invaluable research assistance of Claude Courbois, an IFPRI staff member in the early stages of the project when data re-aggregation seemed so daunting. Cheng Fang, then of IFPRI and now of FAO, provided helpful comments for revisions, particularly on the presentation of modeling issues and on questions relating to China. We also thank Madan Dey of the WorldFish Center for his assistance on trade issues. Also providing assistance from Worldfish were Bing Santos, Mohammed Rab, and Rosalina Kamaruddin. Externally, Albert Tacon provided invaluable consulting advice on the nature of fishmeal markets and fish feeding technology issues, greatly broadening our economic perspective, and Ulf Wijkstrom and his colleagues at FAO were generous with their time in providing comments on the study's direction.

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Chapter 1

INTRODUCTION

Fisheries are in the news. A flurry of media activity has centered around fisheries issues in the past year prompted by the release of several studies and reports that point to growing crises and controversy in both wild fisheries and aquaculture. A recent report from a panel of fishermen, scientists, business leaders, and government officials pointed to overfished and depleted stocks in U.S. waters, along with severe habitat degradation (Pew Oceans Commission 2003). The report argued that the restoration of U.S. fisheries requires a major overhaul of policy, including the introduction of ecosystem-based management and stronger regulations. A much-publicized study in *Nature* reported that the population of large predatory marine fish has been reduced by 90 percent since preindustrial times (Myers and Worm 2003). Another recent study argued that correcting reported Chinese fisheries statistics to levels that better fit estimates of biophysical potential renders global catch trends far less favorable (Watson and Pauly 2001). The Food and Agriculture Organization of the United Nations (FAO), particularly in its State of World Fisheries and Aquaculture publications, has consistently sounded the alarm over threatened stocks of wild fish (FAO 1995, 1998, and 2000a).

The rapidly growing field of aquaculture, which now accounts for 30 percent of the world's food fish, has also pushed its way into the media spotlight. For some years now, aquaculture has been seen as a possible savior for the overburdened wild fisheries sector, and an important new source of food fish for the poor (FAO 1995; Williams 1996). However, there are some problems with the industry. A recent report from the World Wildlife Fund argued that some forms of aquaculture place pressure on wild fisheries through demand for wild-caught fish as feed (Tuominen and Esmark 2003). Another Pew report warned of the lack of effective regulatory mechanisms for dealing with genetically modified fish, some varieties of which are already in development (Pew Initiative on Food and Biotechnology 2003). Numerous studies have warned of potentially negative effects of escaped farmed fish on wild populations. A 2000 study in *Nature* argued that while aquaculture has the potential to contribute considerably to the world's supply of fish, significant environmental tradeoffs have occurred with many forms of aquaculture (Naylor et al. 2000). In response, many industry advocates and policymakers have strongly defended aquaculture as an environmentally sustainable means of contributing to the world's fish supplies.

In this context, what does this study contribute to the growing dialogue on world fisheries? Why would economists attempt to address issues of fisheries that typically have been dealt with by biologists, ecologists, and policymakers? The answer: a key missing component to the puzzle thus far has been a broad economic analysis of the rapid changes in fisheries over the past two decades. Economic factors have been a crucial driver of these changes in fisheries, and economic factors will drive further changes to the year 2020. It is imperative that audiences beyond the fisheries sector—especially policymakers—have a better understanding of fisheries issues, and how they interact with other critical policy issues in world food and agriculture.

Most critical among the issues addressed in this study are those of poverty reduction and environmental sustainability in developing countries. The intention is to address the issues in a consistent economic framework that focuses on the dynamic and interacting decisions of producers, consumers, and traders all over the world, at the same time permitting sufficient data disaggregation by commodity and location to support useful conclusions on the likely future of fisheries.

A better understanding of these market interactions is not a substitute for other aspects of forecasting fisheries outcomes, such as stock assessment, fish population dynamics, and biophysical modeling; however, better information on price-mediated inter-relationships with supply and demand for other foods and feeds is essential for reasoned policymaking. We trust that this study addresses this need to some degree.

OBJECTIVES OF THE STUDY

The overall purpose of the study is to analyze the changing—and now critical—place of fisheries in global food policy issues. The term "fisheries" is applied equally to the capture of wild fish and to aquaculture. The focus is developing countries, although the analysis includes the developed world.[1] In a sector as globalized as fisheries has become over the past two decades, events in one part of the world impinge quickly on outcomes in another. The study starts from a series of premises that are documented and supported as the book unfolds. Attention is paid to

[1]See Appendix A for definitions of developing-country, developed-country, and regional categories.

critical changes in the fisheries sector and their impacts on a broader set of policy objectives for growth, poverty reduction, and environmental sustainability in developing countries. Many past and future developments in the fisheries sector can best be understood by considering fish as a series of commodities within a changing world supply and demand system for different food and feed items. The study concludes with a delineation of key domains for policy action within the fisheries sector that can improve outcomes for broader food and agricultural development policy objectives in developing countries. Thoughts on priorities for further food policy research in the fisheries area are also provided.

The study investigates the following key premises:

- Fish production has developed from a primarily local and relatively minor specialized activity into an important part of a rapidly evolving global high-value food activity.
- Limits to wild capture fisheries mean that the time for fish farming has come—but how and with what perils remains to be seen.
- Capture fisheries affect aquaculture both as a competitor and as a supplier of feed, leading to a complicated price-mediated relationship that is generally not well understood.
- Poor rural people in developing countries are major stakeholders in the future of fisheries—and this is true, furthermore, for an expanding inland rural population.
- Tremendous uncertainties inherent in capture fisheries affect aquaculture in key ways, particularly through markets for inputs and outputs.
- Policies and technology development in both developing and developed countries will be crucial to improving global outcomes.

We investigate these premises first by focusing on what is changing and then by devising a way to project how these trends might play out under different scenarios. Historical consumption, production, price, and trade trends are assessed for a wide variety of regions and for a number of fisheries products. The study then attempts to illustrate the economic component that cuts across these important multidisciplinary issues and cannot be ignored. The analysis aims to link modeled outcomes to issues for environmental sustainability, technology generation, trade policy, poverty alleviation, and human nutrition in poor countries.

A key objective is to put the consideration of fisheries issues into the broader context of evolving world markets for food. Looking at fish as a series of market commodities with different market profiles draws explicit attention to the role of prices in affecting both consumer and producer behavior toward different subcategories of fish. It also permits examination of market tradeoffs within fisheries and between fish and other foods. Fish is both a food market competitor and an input to meat production, with nearly one-third of all wild-caught fish being used as a feed input. Even within fisheries, competition exists among different kinds of fish, and some kinds of fish provide critical inputs to the production of others. Events affecting prevailing prices for different kinds of fish and meat affect other commodities in the animal protein group. Furthermore, fish feed prices also potentially interact with prices for vegetable protein sources, such as soy.

A CHANGING WORLD FOR FISHERIES AND FISHERS

Three main sets of fisheries issues attracted policy and research attention in the late 1980s and 1990s: the decline of traditional marine capture fisheries, mainly in developed countries; the growing roles of developing countries and aquaculture, which have been inextricably linked; and the rising role of China. Salient facts from each of these sets of issues are briefly outlined below.

Traditional Fisheries Under Threat in Developed Countries

Fisheries in developed countries have traditionally been considered—at least in popular culture—as the northern fishing grounds off the coasts of the United States, Canada, Norway, Russia, and Japan. The fisherman of lore is a dogged sailor setting off into stormy seas in oilskins, to bring home a hold of fish like cod and halibut. Such fishermen were not thought of as farmers, much as range cowboys of the American southwest would also reject that label. Fishermen were not thought of as rich, and their life was indisputably hard. Their product was traditionally the "poor man's meat" (Kurlansky 1997), a view that has some statistical basis across countries (Kent 1998).

Fishermen of the Northern countries were great travelers, sailing long distances in search of rich schools of fish. They were also pioneers of the food processing industry, dealing with problems of conservation and disposal of a perishable, seasonally harvested commodity hundreds of years ago. Dried cod (stockfish) became one of the early trade goods, transported great distances and to tropical climes along with European expansion in the 17th century (Kurlansky 1997).

In recent decades, capture fisheries in developed countries have entered a crisis. Global capture fisheries production for human consumption grew through the late 1980s, largely driven by technological improvements that increased capacity; but it has stalled since then. In fact, food fish production from capture fisheries is lower in developed countries than it was 30 years ago, and has declined steadily since the late 1980s. Although some of this decline is attributable to the establishment of 200-mile exclusive economic zones (EEZs) and the resulting reduced fishing access for some developed countries like Japan, overfished and declining stocks are also responsible.

Fisheries policy issues in developed countries have always been oriented toward issues of access to fishing grounds claimed by others, and protecting the grounds of one's own country. As stocks began to dwindle, disputes over fishing rights became more exclusionary and even violent, as in the "Cod War" between Iceland and Great Britain during the 1970s. The other main fisheries policy issue in developed countries revolves around saving the livelihoods of people (and regions), typically among the poorest in the nation, whose incomes are threatened by declining catches. Fisheries subsidies have become even larger relative to output than other agricultural subsidies. Milazzo (World Bank 1998), drawing on work from FAO (1993), reports that fisheries subsidies in developed countries have played a large role in excessive investment in boats and gear. Overcapacity, abetted by the lack of appropriate resource rent charges and the scaling up of fleet and vessel sizes and port infrastructure, has led to the over-exploitation of marine fisheries resources.

To make matters worse for the traditional fisherman in the North, average per capita consumption of fish actually declined in developed countries from 24.3 kilograms (kg) per year in 1985 to 21.7 kg per year in 1997, as saturation levels have been reached in the diets of rich consumers. Since human population growth in developed countries was also low, aggregate consumption stagnated in the North. Yet even here, per capita consumption of certain high-value items, such as shrimp and salmon, has substantially increased. These commodities shifted in the 1990s from being primarily wild-caught to being primarily aquaculture-produced, and their shelf prices decreased. At the same time in developed countries, per capita consumption of many low-value items, like canned sardines, fell.

It is an open question as to whether supply or demand factors best explain these events. On the supply side, some fish have become scarcer with decreased supply, and salmon and shrimp have become much cheaper with increased aquaculture production. Evolving distribution systems, including the expansion of cold chains, also changed the product mix available to consumers. On the demand side, most people in developed countries experienced real income growth over the 1990s, which presumably led to substitution toward preferred (higher priced) fish-based calories and away from less preferred (cheaper) fish-based calories.

One trend that undoubtedly helped make once-expensive items like shrimp and salmon more abundant and much cheaper in developed countries is the globalization of the fish trade to include developing-country production. Institutional developments applicable to more than the fisheries sector alone have had tremendous implications for fish trade. Examples are tariff reduction under the

World Trade Organization (WTO), inaugurated late in 1994; a more rules-based trading system for perishables under the Sanitary and Phyto-Sanitary Agreement (SPS) associated with WTO in early 1995; and improved airfreight facilities. Another factor was the move from costly and lengthy inspection-based systems for assuring food safety implemented by importing countries to process-based procedures implemented by exporting countries; the Hazard Analysis and Critical Control Points (HACCP) system is the dominant example. Finally, globally integrated supermarket chains that procure in one country and retail in another have proliferated in recent years. Many local fishermen no longer have naturally protected markets for chilled and frozen products. The removal of protected markets has also led in some cases to trade disputes that hinder aquaculture exports (Anderson and Fong 1997).

Dietary Diversification and Aquaculture in Developing Countries

Despite the stagnation of fish production and consumption in developed countries, global fish consumption has doubled since the early 1970s. The developing world is responsible for the vast majority of this increased aggregate consumption, much of which has come in the form of low-value freshwater fish in East Asia. In developing countries, per capita consumption of all fisheries commodities has grown modestly since the 1960s, with consumption of the relatively expensive crustaceans and mollusks rising fastest. Population growth, however, has been robust in developing countries, and its overall impact on aggregate fish consumption has been high. At the same time, aquaculture grew at an explosive rate in developing countries. Aquaculture production from developing countries rose from under 2 million metric tons (mmt) in 1973 to over 25 mmt in 1997, and developing countries now represent nearly 90 percent of total aquaculture production. Globally, aquaculture production has been the only engine of growth in food fish production, and hopes have risen that aquaculture may ease pressure on threatened wild fish stocks.

Since both fish consumption and aquaculture production have soared in developing countries, the question arises as to which is the primary driver of trends in the fisheries sector. Chapter 3 examines this question in the context of rising incomes, urbanization, and population in developing countries. At the same time, institutional development and improved infrastructure for trade in perishable food items was an element of great opportunity for the fish farmer in developing countries. Global fish trade in the mid-1990s totaled well over US$50 billion (FAO 2002a), and has grown far more rapidly than food and agricultural trade as a whole. Meanwhile, developing countries have increased their value share in world fish exports to 50 percent.

Aquaculture represented only 6 percent of food fish production in 1970, and now represents over 30 percent. As this share has grown, so has its demand for fishmeal and fish oil, both of which are derived from wild fisheries. Further, as farmed production of organisms such as shrimp and salmon—which have relatively strong requirements for these feed ingredients—grows, aquaculture's share will continue to grow. This possibility has caused some concern among those who fear that higher fishmeal and fish oil demand will lead to greater fishing pressure on stocks of fish used for feed—otherwise known as "reduction" fish (Naylor et al. 2000).

There are also other environmental issues associated with aquaculture. Aquaculture operations, especially in developed countries, have received attention for pollution in the form of effluent, chemicals, and escaped farmed fish (Goldburg and Triplett 1997). These issues are also of concern in developing countries, where aquaculture operations are expanding rapidly. Already, hundreds of thousands of hectares of mangrove habitat have been converted to coastal aquaculture. As both high-value and low-value aquaculture expand during the next two decades, pressure on the environment will intensify in both developed and developing countries.

The rapid expansion of operations and large amounts of money associated with the rise in export aquaculture in developing countries raises the issue of its impact on equity, and particularly on the welfare of the poor. Cutting down mangroves for shrimp farms, it has been claimed, displaces traditional fishers who rely on mangrove fishing habitat for their livelihoods (Naylor et al. 2000). If land suitable for aquaculture expansion becomes scarcer in Asia, it can be anticipated that issues associated with the governance of natural resource use will become more acute. Another issue for the poor is the rising relative price of fish (Bouis 2000). It has been shown that the poor in developing countries get a higher share of their much smaller animal protein consumption from fish than do better-off people in the same countries (Kent 1998). The question arises as to the net effects of aquaculture growth in developing countries on the access of the poor to better nutrition, and specifically to animal protein.

The Rapid Rise in the Relative Importance of China

Surprisingly, China's dominant role in world fisheries is often overlooked in overviews of the industry. Chinese production totals for both aquaculture and capture fisheries have soared during the past 20 years, turning China into the single largest producer in both categories. China is particularly important as an aquaculture producer, now accounting for more than two-thirds of total production of farmed fish. As a consequence of this rapid growth, per capita consumption totals in China have more than tripled in the past 15 years, and total consumption has consistently grown at a rate of over 10 percent per year, according to official figures.

It has been suggested, however, that China significantly over-estimated its production totals in the 1990s (Lu 1998a; Watson and Pauly 2001). Irrespective of their accuracy, it is worth putting such assertions into a conceptual framework for examination because their significance is not straightforward, the magnitudes involved are sizable, and the claims have received widespread publicity.

POLICY RESEARCH QUESTIONS

Seven sets of key policy research questions can be inferred from the above trends. These are briefly developed below and are addressed in full as the study unfolds.

Will Growth Patterns Continue for Fish Demand in the North and South?

This is clearly a critical issue, especially given the suspected role of demand changes in developing countries in shaping structural changes in the fisheries sector. The question involves finding a consistent way to first assess what the trends are. Achieving consistency in terminology and product flows (so that production plus net trade matches consumption) is not a small matter when trying to attain balance across a large number of commodities and countries. Next, the forces driving these trends must be assessed, so as to understand both how existing trends came about and how new trends may emerge in the future. Projections based on straight-line extrapolation of past trends are rarely accurate. A number of structural driving forces are external to the fisheries sector, such as population growth, urbanization, and income growth. But events in other food sectors and within fisheries (the impact of salmon consumption on fishmeal use, for example) also need to be accounted for, typically through the mutual interaction of prices.

Where Will Supply Come From?

This is a counterpart to the demand issue, and it has several aspects: What sorts of production systems (both in aquaculture and capture fisheries) are likely to be needed? What sorts of products will be in demand (high-value like shrimp or low-value like grass carp) and from what part of the world? What does this tell us about technology needs? What are the implications for reduction fish? What does this imply for livestock products and vice versa? Most of all, these questions have implications for trade and prices.

What Will Happen to Trade and Fish Prices?

Will the developing-country export boom in high-value seafood items continue? What will be the impact on food fisheries in developing countries, and what will be the impact on the price of the low-value food fish that the poor rely on? How is the world trading system for fish likely to evolve? Will food safety or ecological concerns in importing developed countries create insurmountable barriers for developing-country exporters? Will barriers lead to economies of scale in developing-country fish production and marketing that effectively exclude small-scale producers and the poor?

What are the Implications for Sustainable Use of the Oceans and Coastal Areas?

Given all of the above, will pressure on capture fisheries continue to increase? Where will this happen? Will pressure increase faster on low- or high-value items and in the North or in the South? To what extent are answers to these questions dependent on a pessimistic or optimistic view of either capture fisheries or aquaculture? What are the implications of different assumptions on demand for reduction fish? Will reduction fish emerge as a constraint to aquaculture production?

Can Aquaculture Alleviate the Pressure on Capture Fisheries?

How important is aquaculture production in easing pressure (through substitution relationships) on capture fisheries? How sensitive is capture fisheries production to alternative assumptions about growth in aquaculture? Is it necessarily the case that increased demand for aquaculture products will raise the relative price of fishmeal and fish oil, and thus provoke a number of important changes? Among these, possibilities include a decline of reduction fish stocks resulting from overfishing, decreased profitability of carnivorous aquaculture, and de-linking of fishmeal prices from soy prices as the value of fishmeal in fish feeding begins to substantially exceed its value in other uses.

What are the Implications for the Poor?

Will the poor who currently fish get crowded out by larger-scale operators? Will landless agricultural workers who currently work in rice paddies lose their jobs as land-holdings are converted to less labor-intensive pond aquaculture? What will happen to the nutritional security of those poor rural people who previously relied on cheap fish and now have only more expensive fish? What would happen to the incomes and livelihoods of the rural poor in the absence of aquaculture development?

What are the Entry Points for Making the "Blue Revolution" More Favorable to the Poor?

The major events and changes portrayed above for fisheries closely resemble even more widespread changes taking place in the meat and milk sectors of developing countries, which has been called the "Livestock Revolution" (Delgado et al.

1999).[2] If that is the case, it also seems likely that what some have termed the "Blue Revolution" in fisheries is also confronted by the dilemma that the changes in question are market-driven by millions if not billions of participants. They will be very hard to stop but can perhaps be slightly steered at the margin to improve outcomes for important policy goals such as poverty reduction and improved environmental sustainability in developing countries.

If so, a key for policy research is to find the effective entry points for harnessing the power of the market to effect desired changes. Do trade restrictions on aquaculture-produced imports affect the price of low-value food fish? Can a small increase in feed efficiency have a much bigger impact? What factors are likely to exclude the poor from the export bonanza, and which are policy-changeable? To what factors are production and demand trends sensitive? Where are food fish prices likely to go, and should policymakers be worried? Where are consumer and producer substitutions likely to occur if the price is right? Research on market-driven relationships cannot answer all these questions completely, nor can it provide solutions to all important fisheries policy issues. It can, however, help sharpen the focus on entry points for policy intervention that can better harness the energies of market forces.

[2]Except that in the case of the Livestock Revolution, export growth from developing to developed countries has not occurred on any large scale because of sanitary barriers.

Chapter 2

HISTORICAL TRENDS AND CURRENT PATTERNS OF FISHERIES PRODUCTION

Global production of aquatic food products totaled approximately 93.2 million metric tons (mmt) in 1997,[3] of which capture fisheries supplied 64.5 mmt and aquaculture 28.6 mmt. Total global production has more than doubled since 1970, with most of the increase since the mid-1980s coming from aquaculture. From 1985 to 1997, aquaculture was responsible for 71 percent of the total growth in food fish production by weight. Table 2.1 and Figure 2.1 show trends in total capture food fish and aquaculture production for 1973–97 and 1970–98, respectively.

Aquaculture's rapid growth has resulted in a steadily larger share in total food fish production, rising from only 7 percent in 1973 to 12 percent in 1985, and to more than 30 percent by 1997. Although capture fisheries production exhibited considerable growth through the late 1980s, its growth has slowed considerably, if not stalled entirely, since then. Total global capture food fish production has hovered near 60 mmt since 1986, marking an end to decades of steady growth.[4] The FAO's *State of World Fisheries and Aquaculture* (FAO 2000a) reports that the majority of world capture fisheries stocks are fully or over-exploited.

China has become an increasingly dominant figure in the production of fisheries products. According to official statistics, nearly 75 percent of the growth in production during 1985–97 came from China, with both capture food fish and aquaculture production growing at rates near 10 percent per year. In 1985, China

[3]Production data presented in this chapter for 1973, 1985, and 1997 are three-year averages centered on the specified years.

[4]Grainger and Garcia (1996) provide a useful analysis of trends in marine fisheries for the period 1950–94.

Table 2.1 Total production of food fish, 1973–97

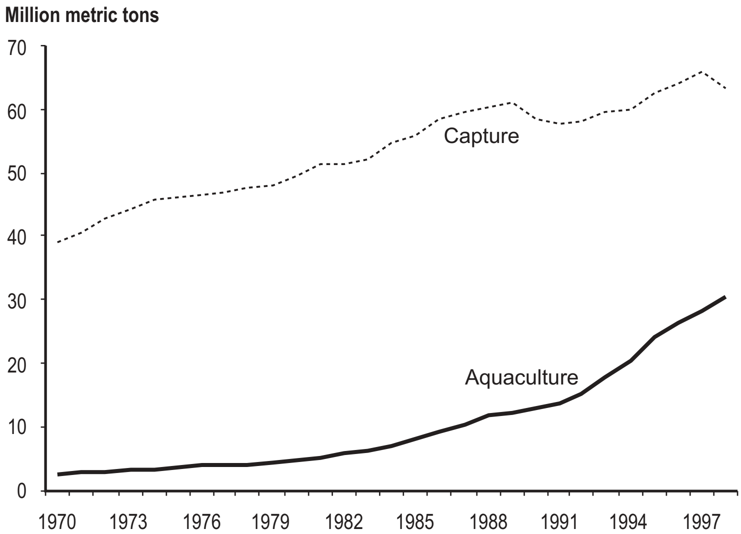
	Total production per capita (million metric tons)			Annual growth rate (percent)
Region	1973	1985	1997	1985–97
China	4.9	8.4	33.3	12.2
Southeast Asia	5.4	7.8	12.6	4.1
India	1.9	2.7	4.8	4.8
Other South Asia	1.2	1.2	2.1	4.3
Latin America	2.3	4.1	6.4	3.7
West Asia and North Africa	0.7	1.5	2.2	3.7
Sub-Saharan Africa	2.1	2.6	3.7	3.2
United States	1.8	3.8	4.4	1.2
Japan	8.2	9.0	5.2	–4.5
European Union 15	6.1	5.8	5.9	0.2
Eastern Europe and former Soviet Union	7.9	9.2	4.9	–5.1
Other developed countries	2.9	3.8	4.8	1.9
Developing world	20.7	32.6	68.0	6.3
Developing world excluding China	15.9	24.2	34.6	3.0
Developed world	26.9	31.7	25.2	–1.9
World	47.6	64.3	93.2	3.1

Source: Calculated by authors from FAO 2002a.
Notes: Data are three-year averages centered on 1973, 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

represented 43 percent of aquaculture production by weight, and 9 percent of capture food fish production. By 1997, China's shares had grown to 68 percent and 21 percent, respectively (Tables 2.2 and 2.3), becoming by far the single largest producer in both categories. As mentioned in Chapter 1, the reliability of China's production numbers has been called into question by recent studies (Lu 1998a; Watson and Pauly 2001) suggesting that production has been systematically overestimated at least since the early 1990s. The implications of this possibility are discussed later in this chapter.

Even without China's contribution, another important trend has manifested itself in the past three decades. The composition of overall fisheries production has steadily shifted away from developed countries and toward developing countries (Table 2.1). Excluding China, developing countries have more than doubled total food fish production since 1973, while production from developed countries has remained virtually unchanged, even declining somewhat. This shift in capture fisheries (as in countries like Morocco and Mauritania) and aquaculture (as in Thailand and Malaysia) has created a major source of export revenue. Developing

Figure 2.1 Global capture fisheries and aquaculture production, 1970–98



Source: Calculated by authors from FAO 2002a.

countries have gone from being net importers of fisheries products to large net exporters over the past 30 years. Fisheries products represent a major source of export revenue for developing countries, totaling over US$20 billion per year in the late 1990s (FAO 2002a). The value of fisheries exports from developing countries exceeded that from meat, dairy, cereals, vegetables, fruit, sugar, coffee, tobacco, and oilseeds in 1997 (International Trade Centre 2002).

CAPTURE FISHERIES PRODUCTION TRENDS

Expansion of fleet capacity, technological innovation, and increases in investment all led to explosive growth in the exploitation of capture fisheries through the 1970s and 1980s. Global capture production of food fish soared from 44.5 mmt in 1973 to 64.5 mmt in 1997 (Table 2.3). The vast majority of this production (over 90 percent in 1997) has come from marine fisheries. During this period, the developed world's production as a whole actually declined by about 3.6 mmt,

Table 2.2 Production of food fish from aquaculture, 1973–97

Region	Total production (million metric tons)			Annual growth rate (percent)
	1973	1985	1997	1985–97
China	1.0	3.4	19.5	15.6
Southeast Asia	0.4	0.9	2.3	7.6
India	0.2	0.6	1.9	9.6
Other South Asia	0.1	0.1	0.5	10.5
Latin America	...	0.1	0.7	19.4
West Asia and North Africa	...	0.1	0.2	9.2
Sub-Saharan Africa	...	...	...	11.7
United States	0.2	0.3	0.4	1.9
Japan	0.4	0.7	0.8	1.6
European Union 15	0.5	0.8	1.2	3.3
Eastern Europe and former Soviet Union	0.2	0.4	0.2	–6.4
Other developed countries	...	0.1	0.6	17.8
Developing world	1.8	5.7	25.4	13.3
Developing world excluding China	0.8	2.3	5.9	8.4
Developed world	1.3	2.3	3.2	2.7
World	3.1	8.0	28.6	11.2

Source: Calculated by authors from FAO 2002a.
Notes: Data are three-year averages centered on 1973, 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints. An ellipsis (…) indicates quantities less than 0.1 million metric tons when rounded.

while production in the developing world grew at an average annual rate of 3.4 percent. This has resulted in an overall shift in production toward developing countries and away from developed countries. Part of this shift is the result of the establishment of 200-mile EEZs allowing coastal nations to claim exclusive fishing rights. In some cases, developed-country companies still own the vessels that fly the flags of developing countries.

In 1973, production in developed countries exceeded that of developing countries by 6.6 mmt. By 1997, developing-country landings of food fish were approximately double those of developed countries, at 42.5 to 22.0 mmt. The decline of developed-country production has come despite large, capacity-enhancing fisheries subsidies in developed countries. Global fisheries subsidies were estimated in one study to total US$14–20 billion per year, or 20–25 percent of revenues (World Bank 1998). While investment and fishing capacity have grown rapidly, catches have grown much more slowly as stocks have become fully exploited and even over-exploited.

Table 2.3 Production of food fish from capture, 1973–97

	Total production (million metric tons)			Annual growth rate (percent)
Region	1973	1985	1997	1985–97
China	3.8	5.0	13.9	8.9
Southeast Asia	5.0	6.9	10.4	3.5
India	1.7	2.1	2.9	2.8
Other South Asia	1.1	1.1	1.6	3.1
Latin America	2.3	4.1	5.7	2.9
West Asia and North Africa	0.7	1.4	2.1	3.3
Sub-Saharan Africa	2.1	2.6	3.7	3.1
United States	1.7	3.5	4.0	1.1
Japan	7.8	8.4	4.4	–5.2
European Union 15	5.6	4.9	4.7	–0.4
Eastern Europe and former Soviet Union	7.7	8.8	4.7	–5.1
Other developed countries	2.8	3.7	4.2	1.0
Developing world	18.9	26.9	42.5	3.9
Developing world excluding China	15.1	22.0	28.7	2.2
Developed world	25.6	29.3	22.0	–2.4
World	44.5	56.3	64.5	1.1

Source: Calculated by authors from FAO 2002a.

Notes: Data are three-year averages centered on 1973, 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Production by Region and Fishing Area

One of the most striking trends in capture food fish production is China's emergence as the largest producer, and the simultaneous decline of Japan's production. In 1973, Japan was the largest capture food fish producer, accounting for 7.8 mmt or 18 percent of global production (Table 2.3). By 1997, Japan's share had plummeted to 7 percent, and its absolute level of production had dropped by nearly half. Enforcement of the EEZ had significantly reduced the fisheries resources available to Japan, and dwindling stocks of fish such as pilchard further reduced Japanese catches. Heavy subsidies to the Japanese fishing sector likely slowed this steady decline, which has been particularly acute among small- and medium-scale producers (World Bank 1998). Meanwhile, China increased its share from 9 to 21 percent, boosting production from 3.8 mmt to 13.9 mmt.

Southeast Asia also dramatically increased its capture food fish production, more than doubling its output from 5.0 to 10.4 mmt during 1973–97. The region is led in terms of production volume by Indonesia and Thailand. More than one-quarter of the overall increase in capture fisheries production since 1985 can be attributed to the Indian Ocean, which in 1997 still represented less than 10 percent of global landings. The Indian Ocean was the sole major marine fishing area to show sustained growth in the past three decades.

Peru and Chile led Latin America's production, which also grew significantly from 2.3 mmt in 1973 to 5.7 mmt in 1997. Production from Eastern Europe and the former Soviet Union declined precipitously after the fall of the Soviet Union, as the heavily subsidized Soviet and Eastern European fleets aged quickly and investment declined. Total production in these regions was nearly cut in half from 1985 to 1997. European production declined over the same period, while India, Sub-Saharan Africa, the United States, and West Asia and North Africa exhibited overall growth. However, production in all developed countries declined during 1973–97 from 25.6 to 22.0 mmt.

Production from all Atlantic areas has stalled above 20 mmt since 1970, with the composition of production moving toward species of lower trophic levels (Pauly et al. 1998). The high-profile collapse of the significant Atlantic cod fisheries in the northwest Atlantic has become emblematic of the threats posed by heavy fishing. Production from Pacific areas grew steadily through the mid-1980s, especially landings of tuna, but has remained near 50 mmt since 1986. Despite the slowdown in growth, total Pacific production has more than doubled Atlantic production since the mid-1980s, at 52 mmt compared with 23 mmt in 1997. Overall production trends in the Pacific mask considerable variation across species, with dramatic fluctuations in the production of fish such as the Peruvian anchoveta, the Japanese pilchard, and the Alaskan pollock. Though dwarfed by marine fisheries, production from inland fisheries has grown modestly from 5 mmt in 1985 to 8 mmt in 1997, the bulk of production coming from Asia and Africa.

The Contribution of China to Global Production Totals

China's astonishing growth in the production of both wild- and aquaculture-derived fisheries commodities during the 1990s and the contrast between trends in China and neighboring countries have raised suspicions about the accuracy of reported totals. There is a significant and growing discrepancy between estimates of fish consumption based on independent household surveys and estimates of fish availability derived from production, trade, and other use data. Estimates of consumption based on household surveys result in totals far lower than those suggested by officially reported data. Moreover, in the case of wild fisheries, reported catches have risen rapidly despite the classification of major stocks as over-exploited; and vessel survey data are at odds with Chinese estimates of catch and catch per unit effort. The FAO has been concerned about Chinese fisheries and agriculture statistics for some time, and has organized several collaborative workshops on the problem (FAO 2001a). Lu (1998b) concluded that Chinese fisheries production—including aquaculture—was over-estimated by 43 percent in 1995, after taking into account possible under-estimation of fish consumption. Lu suggests that institutional incentives that reward or punish local officials based on reported productivity may be largely responsible for the increasing distortion.

Watson and Pauly (2001) used a spatial model that predicted marine catches based on oceanographic and climatological data. They reported a significant deviation between expected and reported catches in Chinese coastal waters—a deviation that only arose in the 1990s—and conclude that institutional incentives encouraged the exaggeration of capture fisheries production totals in China in that decade. The FAO has made it clear that its interpretation of Chinese statistics, and hence of global trends, had already taken into account the possibility of inaccuracies (FAO 2000b, 2002b). The most recent FAO workshop on the issue in 2001 did not result in any official adjustment of historical production statistics but did propose further investigations (FAO 2001a).

If China has indeed over-reported its fisheries production for institutional or other reasons, trends in global fisheries production would appear much less favorable than they otherwise do. In fact, Watson and Pauly argue that removing the alleged distortions in China's production statistics and the catches of the Peruvian anchoveta results in a negative trend in global capture fisheries production since 1988.

The net impact of changes of this magnitude can only be considered in a framework that balances assumptions about supply, demand, and trade. If China produced less fish than reported, this must mean that Chinese consumers ate less fish than reported, or Chinese fish imports were greater than reported, or some combination of the two. Global production, consumption, and trade numbers must be re-balanced according to a consistent set of assumptions. Chapter 4 presents this issue in terms of economic modeling concerns; however, the officially reported statistics are used for the purposes of the historical discussion.

Capture Fisheries Production by Market-Based Commodity Category

Low-Value Food Fish from Capture. In terms of production volume, the largest market-based fisheries commodity is low-value food fish from capture. (Table 2.4. See Appendix E for detailed historical production tables.) Global production totaled over 27 mmt in 1997, with the vast majority of production coming from the developing world (85 percent). Developed-country production of low-value food fish from capture has remained relatively static over the past several decades, while developing countries have expanded their production significantly. China has expanded its share of production to nearly one-quarter of the global total,

Box 2.1 Re-aggregation of commodities according to market criteria

The food policy issues considered in this report require that aggregated commodity data follow market lines rather than biological classifications. For modeling purposes, commodities within a group should have similar supply- and demand-response parameters. This usually implies the need for fairly homogeneous product categories in terms of value and function; modeling further dictates a small, manageable number of commodity categories. It is also important to create categories that are meaningful and identifiable to audiences lacking specialized fisheries knowledge.

Country-level data on production are available from FAO at a finer resolution than data for consumption. Consequently, production data map more easily into the desired categories (see Appendix B for details). Four basic commodity aggregates for human fisheries consumption were chosen so as to keep data and parameter requirements manageable, with each category split by origin of production (aquaculture or capture). The term “food fish” in this report refers to the sum of these categories. Fishmeal and fish oil—derived products from capture fisheries that are used as feed inputs—are considered as separate commodities.

“Low-value food fish” are fish destined for human consumption that are of relatively low value, including freshwater species like carp, and marine species like herring and mackerel. Similarly, “high-value finfish” include higher-cost species like tuna, cod, salmon, and trout. The category “crustaceans” comprises mainly shrimp, prawns, crabs, and lobsters. “Mollusks” include shellfish such as oysters, clams, and scallops; and also cephalopods, like squid.[†] Table 2.4 shows historical production totals for each market-based fisheries category.

[†]Production totals are live weight and include shell weight. This results in an overstatement of the amount of product available for human consumption, especially in the case of mollusks.

while Southeast Asia nearly doubled its production from 3.6 mmt in 1973 to 6.3 mmt in 1997.

Japanese production of low-value food fish has declined over the past two decades, and Russia's production also declined after the fall of the Soviet Union. Low-value food fish from capture constitutes Sub-Saharan Africa's largest source of fisheries production, and is the only commodity category in which Sub-Saharan Africa represents a significant share of the global total (11 percent in 1997). Inland fisheries have maintained a fairly constant share of low-value food fish production, at about 25 percent during 1973–97. Anchovies, herring, mackerel, and miscellaneous marine and freshwater fish are the largest species categories within this commodity grouping.

High-Value Finfish from Capture. The second-largest capture fisheries commodity group is high-value finfish, with a global total in 1997 of 25 mmt. Production has grown only modestly in the past 30 years, although the composition of production has changed somewhat. China has emerged as a large producer, and the developing world in general has taken up a larger share of production. Developed countries accounted for 57 percent of production in 1997, down from 82 percent in 1973. Russia has remained the top producer of high-value finfish since taking over the lead from Japan in the mid-1970s; however, its production has declined almost

Table 2.4 Global production of food fish by IMPACT category, 1973–97

	Global production of food fish (million metric tons)			Annual growth rate (percent)
Commodity	**1973**	**1985**	**1997**	**1985–97**
Aquaculture	3.1	8.0	28.6	11.2
Low-value finfish	1.7	4.9	17.2	10.9
High-value finfish	0.1	0.3	1.4	13.4
Crustaceans	...	0.3	1.3	13.3
Mollusks	1.3	2.5	8.8	11.1
Capture	44.5	56.3	64.5	1.1
Low-value finfish	18.6	24.7	27.1	0.8
High-value finfish	20.8	23.8	24.9	0.4
Crustaceans	2.3	3.1	5.7	5.2
Mollusks	2.7	4.6	6.8	3.3

Source: Calculated by authors from FAO 2002a.

Notes: Data are three-year averages centered on 1973, 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints. An ellipsis (...) indicates quantities less than 0.1 million metric tons when rounded.

50 percent from a peak of over 5 mmt in the late 1980s. Though the fall of the Soviet Union and the associated decline in fisheries subsidies is certainly responsible for some of this decline, overfishing of stocks such as pollock in the Bering Sea is also to blame (FAO 1997a). Japan's production has declined dramatically, while Latin America (notably Chile and Argentina) and Southeast Asia (especially Indonesia, the Philippines, and Thailand) have seen significant growth. Cod has declined from its peak as the largest source of high-value finfish, leaving pollock at the top, although catches have steadily declined since the 1980s. Production of skipjack and yellowfin tuna have increased significantly over the past several decades.

Crustaceans from Capture. Crustaceans from capture—most of which are marine shrimp—make up the smallest capture fisheries commodity group in terms of weight but have the highest unit value (Table 2.5) and are second to high-value finfish in overall export value. Much of these exports come from the developing world, which as a whole was a net exporter of 1.4 mmt to the developed world in 1997. Although developed countries have also increased production in recent decades, the developing world is almost entirely responsible for the more than doubling of global production since the mid-1970s. China is the single largest producer, currently accounting for nearly half the world's crustacean production from capture. As with other fisheries commodities, China has dramatically expanded its production over the past three decades, and accounts for 63 percent of the global increase in crustacean production from capture fisheries since 1973.

Mollusks from Capture. Cephalopods—mainly squid—dominate this category in terms of weight. The overall composition of production is somewhat deceptive because the live weight tonnage reported includes the shells of clams, oysters, mus-

Table 2.5 Approximate unit values of IMPACT commodity groups, 1997

	Unit value (U.S. dollars/metric ton)	
Commodity	**Imports**	**Exports**
Low-value food fish	1,592	1,370
High-value finfish	2,973	2,787
Crustaceans	8,034	7,584
Mollusks	3,351	2,727

Source: Calculated by authors from FAO 2002a.
Notes: Import/export unit values reflect processed weight in a three-year average from 1996 to 1998, approximated by dividing aggregate value by quantity. IMPACT categories were approximated by aggregating detailed FAO "Production and Trade 1976–98" categories.

sels, and so on. As global production has boomed, the developing world has taken an increasing share of mollusk production from capture, accounting for two-thirds in 1997. Japan's once-dominant role as the largest producer has been usurped by China, which now produces nearly a third of the world total.

Fishmeal and Fish Oil. Fishmeal is created from the cooking, pressing, drying, and milling of wild-caught, small pelagic fish such as anchovies and menhaden. Fish oil is usually a byproduct of the reduction process by which fishmeal is created (hence the term "reduction" fish as already mentioned). As a result, annual global production of fishmeal and fish oil are highly correlated (r = 0.8, 1976–98). Approximately 30 percent of the total global catch of fish is reduced to fishmeal (and thus is not counted as "food fish" in the totals presented here), with a typical reduction ratio of 5 kg of live fish for each kilogram of fishmeal. About two-thirds of the world's fishmeal is derived from "dedicated" fisheries devoted entirely to the production of fishmeal (New and Wijkstrom 2002).

Table 2.6 Production of fishmeal, 1977–97

	Total production (thousand metric tons)			Annual growth rate (percent)
Region	**1973**	**1985**	**1997**	**1985–97**
China	3	54	542	21.1
Southeast Asia	173	250	458	5.2
India	20	32	15	–6.0
Other South Asia	16	33	42	2.0
Latin America	1,188	2,259	2,763	1.7
West Asia and North Africa	25	57	95	4.4
Sub-Saharan Africa	10	8	46	16.3
United States	289	329	300	–0.8
Japan	769	1,103	359	–8.9
European Union 15	517	540	627	1.3
Eastern Europe and former Soviet Union	651	769	217	–10.0
Other developed countries	837	602	624	0.3
Developing world	1,451	2,752	4,008	3.2
Developing world excluding China	1,449	2,698	3,466	2.1
Developed world	3,062	3,342	2,126	–3.7
World	4,514	6,094	6,133	0.1

Source: Calculated by authors from FAO 2002a.

Notes: Data are three-year averages centered on 1973, 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Peru and Chile dominate fishmeal production, making use of the world's most heavily exploited fish in terms of weight—the Peruvian anchoveta (*Engraulis ringens*). The combined global share of production from Peru and Chile averaged 44 percent during the 1990s. Other major producers include China, Japan, Russia, Denmark, Norway, and the United States (Table 2.6). A similar pattern is observed in the production of fish oil, though China and Russia are not major producers. Japan's production of fishmeal and fish oil has dropped off significantly in the past decade.

Global production of fishmeal in 1997 totaled 6.1 mmt, while fish oil production totaled 1.1 mmt. Supply exhibits significant interannual variation, the result of fluctuations in the catches of the Peruvian anchoveta induced by El Niño events in the eastern equatorial Pacific. The collapse of the Peruvian anchoveta fisheries, which coincided with the El Niño event of 1973, brought down global production to about 4.5 mmt during the mid-1970s. The Peruvian fisheries eventually recovered (though production has been punctuated by sharp declines in El Niño years), and fishmeal production has hovered near 6.5 mmt for well over a decade. Fish oil production has shown similar variation around a lower mean.

AQUACULTURE PRODUCTION TRENDS

Despite the stagnation in capture fisheries production, overall food fish production grew at an average annual rate of 3.1 percent between 1985 and 1997. This rapid growth is almost entirely the result of the global boom in aquaculture production, which grew at 11.2 percent per year over the same period. The boom was widespread, across all four categories of fisheries commodities, though growth in the low-value fish category was most prominent.

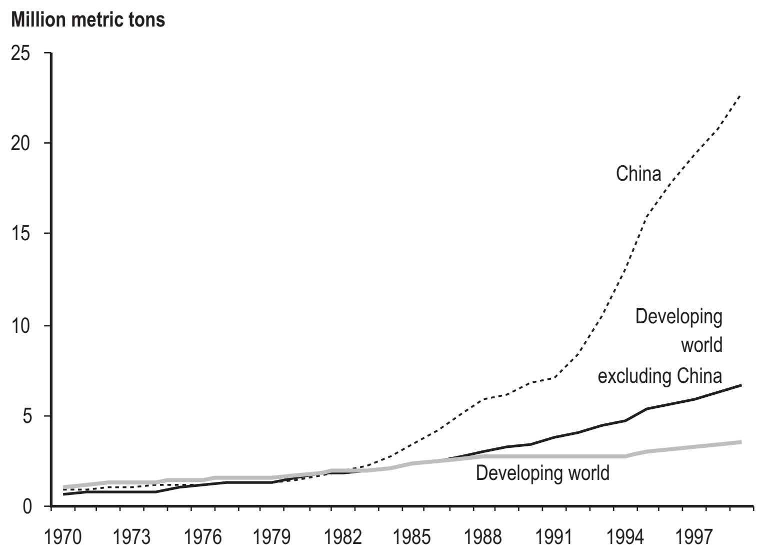
Production by Region

Aquaculture is primarily a developing world activity. In 1973, developing countries produced 58 percent of the world's aquaculture products, but that share had grown to 89 percent by 1997. Developing-country production has grown at a rate of 13.3 percent per year since 1985, dwarfing the corresponding growth rate for developed countries (2.7 percent). More precisely, however, aquaculture is predominantly an activity of Asian developing countries. Asia accounts for 87 percent of global aquaculture production by weight, and China alone commands a stunning 68 percent share, up from 32 percent in 1973.

Rapid development in aquaculture production was part of China's five-year plan from 1986 to 1990, and state investment in extension and technology development contributed to the boom in Chinese production (Wang 2001; World Bank 1998). The FAO reports that aquaculture development in China has resulted in large part from government policies promoting aquaculture as a means of improving domestic food supply and increasing foreign exchange earnings, including policies targeted at seed and feed inputs (Hishamunda and Subasinghe 2003). The gradual removal of food grain self-sufficiency policies may have allowed aquaculture production to rise especially rapidly by freeing farmland for use as pond area. In 1999, 62 percent of Chinese aquaculture production came from inland freshwater ponds, many of which provide supplemental income to other farming activities.

The dominant role of Chinese aquaculture in global totals by weight can be seen in Figure 2.2. India and Southeast Asia are also large producers, accounting for a combined 15 percent of production in 1997 (Table 2.2). Although South Asia, Southeast Asia, and Latin America have experienced rapid growth in total production, China's expansion has equaled the others in percentage terms, and dwarfed the others in absolute terms. Much of the boom in aquaculture is attributable to expanded area; improved productivity in aquaculture, though important for a few high-value species, is in its relative infancy for most species under cultivation (see Chapter 6).

Figure 2.2 Total aquaculture production, 1970–99



Source: Calculated by authors from FAO 2002a.

Of the three major categories of production environment listed by the FAO, freshwater aquaculture accounts for the majority of global production at 58 percent in 1999, followed by mariculture (aquaculture practiced in a marine environment) at 36 percent, and brackish water at 6 percent. These three categories mask considerable variation in production systems. Aquaculture ranges from simple ponds utilizing naturally occurring food sources to highly intensive systems with water control, aeration, and supplemental feeding. Aquaculture is practiced inland, along the coast in brackish water systems, and in marine cages and net pens. Farm size can range from thousands of hectares down to the size of a backyard.

Aquaculture Production By Market-Based Commodity Category

Low-Value Food Fish from Aquaculture. The most striking growth of all fisheries occurred in the production of low-value food fish from aquaculture. As can be seen in Table 2.4, the farmed production of low-value food fish has soared in recent years, more than tripling during 1985–97. Nearly all of this growth has come from China, whose production grew at an average annual rate of 14.1 percent over this time. Low-value food fish accounted for 60 percent of global aquaculture production by weight in 1997, and China represented three-quarters of this total. The majority of fish in this category are freshwater carp. Carp accounted for 75 percent of low-value food fish from aquaculture in 1997. India is the second-largest single producer, accounting for 1.8 mmt or 11 percent of global production in 1997.[5] Low-value food fish represent nearly all of India's aquaculture production (96 percent). Most low-value food fish are domestically consumed and not traded because of transport and marketing costs.

High-Value Finfish from Aquaculture. Farmed production of high-value finfish is relatively small by volume, representing only 5 percent of total aquaculture production. Nevertheless, high-value finfish supplied 39 percent of all export revenue generated from fisheries in 1997—the largest share of all market-based fisheries commodity groups. Farmed production of these fish has garnered much attention in recent years for its rapidly expanding production in coastal areas. As the name implies, the high-value finfish category includes relatively higher price-to-weight fish such as salmon, trout, and sea bream. Atlantic salmon (*Salmo salar*) dominate farmed production in this category, representing 48 percent of high-value finfish production.

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[5]This is the "carps, barbels, and other cyprinids" grouping from the International Standard System for Classification of Aquatic Animals and Plants (ISSCAAP) (FAO 2002a).

Production of high-value finfish from aquaculture has exploded since the mid-1980s. During 1985–97, global production grew at an average annual rate of 13.4 percent. High-value finfish is the only fisheries category in which developed countries have a larger production share than developing countries; this is especially true for farmed production. Developed countries accounted for a 76 percent share of production in 1997, the bulk of which was salmon and trout. Norway, Chile, the United Kingdom, Japan, and Canada are the largest producers (in that order), exploiting their large coastal areas.

Mollusks from Aquaculture. Capture production of each commodity group far exceeds aquaculture production, with the notable exception of mollusks. In the past 10 years, aquaculture has passed wild fisheries as a source of mollusks. Mollusks produced from aquaculture are exclusively shellfish such as oysters, mussels, clams, and scallops. Mollusk production is generally a coastal activity, often undertaken in mudflats. Excluding China, global farmed production of mollusks has grown at the relatively slow rate of 1.7 percent since 1985, to a total of 2 mmt in 1997. Over the same time span, however, Chinese production has grown from under 1 mmt to nearly 7 mmt, at an average annual rate of 19.5 percent. While yields have risen, expanded cultivated area is responsible for the bulk of the increases. Over half of China's mollusk production from aquaculture is supplied by 2 species: the Pacific cupped oyster (Crassostrea gigas) and the Japanese carpet shell clam (*Ruditapes philippinarum*). China was a net exporter of 0.34 mmt of mollusks (in live weight) in 1997.

Crustaceans from Aquaculture. The farmed production of crustaceans has been one of the more high-profile manifestations of aquaculture, in part because it has transformed many coastlines in the developing world into mosaics of ponds oriented toward high-value exports. By weight, the global production of crustaceans from aquaculture is roughly equivalent to that of high-value finfish, totaling 1.3 mmt in 1997. Production growth has been dramatic and widespread, averaging 13.3 percent per year on a global basis from 1985 to 1997.

Developing countries accounted for nearly all (98 percent) of crustacean aquaculture in 1997. In Southeast Asia (especially Indonesia, Thailand, and Viet Nam), farmed crustaceans have become a major source of export revenue, as rice paddies and mangrove forests have made way for shrimp ponds along the coasts. Land-use conflicts have drawn attention from environmental organizations (see Chapter 5) in Southeast Asia and in Latin America, where Brazil, Ecuador, and Mexico have also become large shrimp aquaculture producers.

OUTLOOK FOR SUPPLY

The Sustainability of Capture Fisheries

With most wild fisheries near maximum sustainable exploitation levels, capture fisheries production will most likely grow slowly to 2020. Predicting long-term trends for a single fish stock, however, is extremely difficult, and forecasting for the world as a whole is an extraordinarily uncertain exercise at best. Conventional fisheries are probably near the ceiling of their potential, though higher levels of production could probably be obtained by targeting small pelagic species, mesopelagic species, and krill. This strategy, however, would have severe consequences for the environment, as it would result in large species composition shifts and indirect harm to predator species.

While most would agree that large increases in production are unlikely, it is less easy to say with certainty that large fisheries collapses are impossible. History is replete with examples of anthropogenic marine extinctions and wholesale changes in marine ecosystems (Jackson et al. 2001). Levels of fishing pressure, changes in management regimes, climatic shifts, alteration of fisheries habitat, and synergistic combinations of these factors are difficult to forecast. Nonetheless, they may have strong negative consequences on the population of marine and freshwater resources.

Opportunities and Constraints for Expansion of Production in Aquaculture

The possibilities of expanding fisheries production are greatest for those commodities that can be produced through aquaculture. Production of freshwater fish suitable for aquaculture, such as carp and tilapia, will likely see large increases. Mollusk and crustacean production may also expand significantly, as they did in the 1990s. As with terrestrial crops, increased aquaculture production can be achieved either through expanding the area under cultivation or by increasing the yield per unit area. Yield increases can come either from increased inputs or greater efficiency of inputs. It is likely that in the next several decades, aquaculture production will benefit from both these sources of yield growth. Greater use of compounded aquafeeds in the diets of farm-raised fish, along with improvements in rearing technology and selective breeding (see Chapter 6), has the potential to significantly increase the productivity of many forms of aquaculture.

As a consequence of the probable slow growth in capture fisheries, the trajectory of aquaculture will play a large role in determining the relative prices of fisheries commodities. Aquaculture's course is far from certain, however. Several major challenges must be overcome if the rapid growth of the past 10 years is to be sustained. Aquaculture will face competition for land and marine resource use from other activities ranging from terrestrial agriculture to recreation. Fresh water will become an increasingly scarce resource over the next 20 years (Rosegrant, Cai, and Cline 2002), making further expansion of freshwater aquaculture activities more difficult. Increased pathways for transmission will allow disease to remain a major constraint to aquaculture production growth (Subasinghe, Bondad-Reantaso, and McGladdery 2001). The availability of fishmeal and fish oil—wild-caught feed inputs that are currently indispensable for certain varieties of carnivorous aquaculture—may also become a limiting factor in production growth (see Chapter 6).

The emergence of land, water, and input constraints will place pressure on technology to find other ways to increase productivity. Some possible pathways for achieving this include selective breeding, better health management, water control, and modification of feed inputs. It seems clear that the level of public and private investment in aquaculture technology and extension will play a large part in the growth of aquaculture production over the next several decades.

Chapter 3

DEMAND FOR FISH AS FOOD AND FEED THROUGH THE 1990S

Global consumption of fish as food has doubled since 1973, and the developing world has been responsible for over 90 percent of this growth. The FAO reports that growth of fish consumption as food in the relatively richer countries has tapered off; food fish consumption in the poorer countries has grown rapidly (FAO 1999a). In particular, the consumption of freshwater fish has grown massively in recent decades, primarily in East Asia. Large increases have also occurred in the consumption of crustaceans and noncephalopod mollusks such as oysters and clams. In both cases, this growth in consumption has been matched by an equally rapid growth in production from aquaculture, primarily but not exclusively within Asia.

These aggregate trends raise the perennial question: which came first, the supply push or the demand pull? While both may be at work in different proportions in different places, two elements suggest that demand is the primary motor of these changes. First, demand theory and the experience of developing countries with regard to other animal-source foods suggest that increases in income, population, and urbanization in developing countries leads to diversification of diets into higher priced calories. Increases in developing-country fish consumption since the 1970s are consistent with this phenomenon. Saturation of diets in developed countries, coupled with low rates of population and urban growth, are a consistent explanation as to why total fish consumption in developed countries has stagnated despite greater access to production technologies. Second, real prices for fish have generally increased over the past 20 years, and relative prices for fish have soared compared with steeply declining meat and grain prices over the same period. Higher relative fish prices may have stimulated further production but could only result from excess demand.

It is also likely that the rapid growth of freshwater aquaculture in Asia is partly driven by policy and the desire to diversify production out of rice monoculture;

this phenomenon has allowed fish to join the basket of animal-source foods that are increasingly consumed in the developing world in response to demand shifts. Although per capita increases in fish consumption have been widespread throughout Asian developing countries, a dominant share of the aggregate global increase in food fish consumption during 1985–97 is accounted for by China, whose consumption increased by 24 mmt in live weight over this time.[6] China pursued an aggressive aquaculture development strategy throughout the 1980s and 1990s, marked by significant investments in technology and extension (Wang 2001; World Bank 1998), and also realized significant gains in capture production.

FOOD FISH CONSUMPTION AND TRADE TRENDS

Trends by Region and by FAO Commodity Groups[7]

Total Food Fish. According to the FAO (1999a), the amount of food fish consumed on a global scale has increased from 45 mmt in 1973 to over 90 mmt in 1997 (Table 3.1). Over this span, world per capita food fish consumption[8] has also risen from 12 kg/year to 16 kg/year (Table 3.2). These increases have not been uniform across geographic or economic categories, however. Growth in food fish consumption has primarily been a developing-country phenomenon. China dominated aggregate consumption of fisheries products in 1997, with over 36 percent of global consumption, rising from only 11 percent in 1973. India and Southeast Asia together accounted for another 17 percent in 1997, with total consumption doubling since 1973.

The share of developing-country fish consumption has risen from 45 percent in 1973 to 70 percent in 1997, mainly because of the rapid growth in these regions. Meanwhile, levels of per capita fish consumption have hardly increased in Sub-Saharan Africa over the past 30 years; in fact, per capita fish consumption has declined significantly in Sub-Saharan Africa since the mid-1980s. In the developed world, aggregate consumption levels have also declined since 1985, mainly as a consequence of dramatically lower per capita consumption in the former Eastern Bloc countries.

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[6]All aggregate and per capita fish consumption data in this book are measured in live as opposed to processed weight.

[7]Data presented in this subsection are from FAO (1999a). Fisheries and regional categories differ between FAO and IMPACT; these aggregation differences are explained in this chapter and in Appendixes A and B.

[8]Per capita food fish availability is taken here as a proxy for per capita consumption.

Table 3.1 Total consumption of food fish, 1973–97

	Total consumption (million metric tons)			Annual growth rate (percent)
Region	**1973**	**1985**	**1997**	**1985–97**
China	4.9	8.7	33.2	11.8
Southeast Asia	5.4	7.9	11.3	3.1
India	1.8	2.8	4.5	4.3
Other South Asia	1.1	1.3	2.0	3.3
Latin America	2.1	3.6	3.8	0.6
West Asia and North Africa	0.6	1.6	2.1	2.4
Sub-Saharan Africa	2.6	3.7	3.7	0.0
United States	2.9	4.5	5.4	1.5
Japan	7.6	7.4	7.9	0.5
European Union 15	6.3	7.3	8.8	1.6
Eastern Europe and former Soviet Union	7.3	9.0	4.4	–5.8
Other developed countries	0.9	1.2	1.6	2.3
Developing world	20.4	32.5	63.2	5.7
Developing world excluding China	15.4	23.8	30.1	2.0
Developed world	25.0	29.4	28.1	–0.4
World	45.4	61.9	91.3	3.3

Source: Calculated by authors from FAO 2002c.
Notes: Data are three-year averages centered on 1973, 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Fish are an important source of protein, especially in the developing world. Fish account for 20 percent of animal-derived protein in low-income food deficit countries, compared with 13 percent in the industrialized countries.[9] While low-income food deficit countries have more than doubled per capita fish consumption from 6 kg/year to 14 kg/year, per capita consumption has leveled off in industrialized countries since the late 1980s. The absolute levels of fish consumption in poor countries, however, are still much lower than those in richer countries. Per capita consumption in industrialized countries was double that of low-income food deficit countries in 1997 (28 kg/year compared with 14 kg/year). Of course, average consumption even within a similar income range varies considerably across countries based on geography and cultural preferences. For example, Japan's per capita seafood consumption is well over 60 kg/year, while Switzerland's is under 15 kg/year.

[9]"Low-income food deficit countries" and "industrialized countries" are FAO categories distinct from "developing" and "developed" countries.

Table 3.2 Total per capita consumption of food fish, 1973–97

	Total consumption (kg/capita/year)			Annual growth rate (percent)
Region	1973	1985	1997	1985–97
China	5.5	8.1	26.5	10.4
Southeast Asia	17.6	19.8	23.0	1.3
India	3.1	3.6	4.7	2.3
Other South Asia	6.2	5.4	6.0	0.9
Latin America	7.0	9.0	7.8	–1.2
West Asia and North Africa	3.4	6.2	6.2	0.0
Sub-Saharan Africa	9.0	9.2	6.7	–2.6
United States	13.5	18.5	19.7	0.5
Japan	70.2	61.5	62.6	0.2
European Union 15	18.2	20.3	23.6	1.3
Eastern Europe and former Soviet Union	20.3	22.7	10.6	–6.1
Other developed countries	11.2	13.4	14.7	0.8
Developing world	7.3	9.0	14.0	3.8
Developing world excluding China	8.1	9.4	9.2	–0.1
Developed world	22.6	24.3	21.7	–1.0
World	11.6	12.8	15.7	1.7

Source: Calculated by authors from FAO 2002c.
Notes: Data are three-year averages centered on 1973, 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Freshwater and Diadromous Fishes. The FAO commodity group showing the most rapid increases in consumption over the past several years has been "freshwater and diadromous fishes." This grouping contains freshwater fish, such as carp, as well as diadromous fish (fish that migrate between fresh and saltwater), such as salmon. Consumption of both types of fish has skyrocketed in recent years, largely because of the rapid growth in Asian freshwater aquaculture and the marine net pen farming of salmon. China has led the way: aggregate consumption of freshwater and diadromous fish rose from 1.3 mmt in 1981 to 13.2 mmt in 1997, while per capita consumption increased nearly tenfold.

Demersal, Pelagic, and Other Marine Fish. Meanwhile, global consumption of demersal fish (fish that live near the bottom of a body of water) has remained at the same absolute level since the 1970s, while the growing population has caused per capita consumption to decline. This trend has resulted, in part, from the decline in the Atlantic cod and Alaskan pollock fisheries, and from the low farmed production of demersal species. Over the same time span, global per capita consumption of pelagic fish and of unspecified marine fish has remained relatively constant, while aggregate consumption has grown slowly. Consumption of marine finfish species, broadly speaking, has been limited by the relative difficulty of aquaculture production combined with the already high levels of exploitation in capture fisheries.

Cephalopods, Other Mollusks, and Crustaceans. Consumption of both crustaceans and noncephalopod mollusks has increased rapidly over the past several decades. In the case of crustaceans, the rising consumption of farmed shrimp and wild-caught marine shrimp has led the way; global per capita consumption of crustaceans has nearly tripled since 1970. At the same time, per capita consumption of noncephalopod mollusks—mostly shellfish such as oysters and clams—has also tripled. The rise in consumption of shellfish has been centered in Asia, where growing aquaculture production of mollusks, especially in China, led to an incredible 13-fold increase in per capita consumption from 1981 to 1997. Aggregate cephalopod consumption, mostly consisting of squid, has more than doubled in 30 years, but per capita levels have remained fairly low—0.4 kg/year on a global basis in 1997.

Trends by Market-Based Category

This section outlines historical consumption trends based on fisheries commodity aggregates devised according to market-based criteria (Box 3.1). Global per capita consumption of market-based fisheries commodities is led by low-value food fish at 7.5 kg/year in 1997, followed by high-value finfish consumption at 4.4 kg/year, mollusks at 2.4 kg/year, and crustaceans at 1.2 kg/year. Consumption levels of total food fish are highest in China, Southeast Asia, and the developed world (Table 3.2).

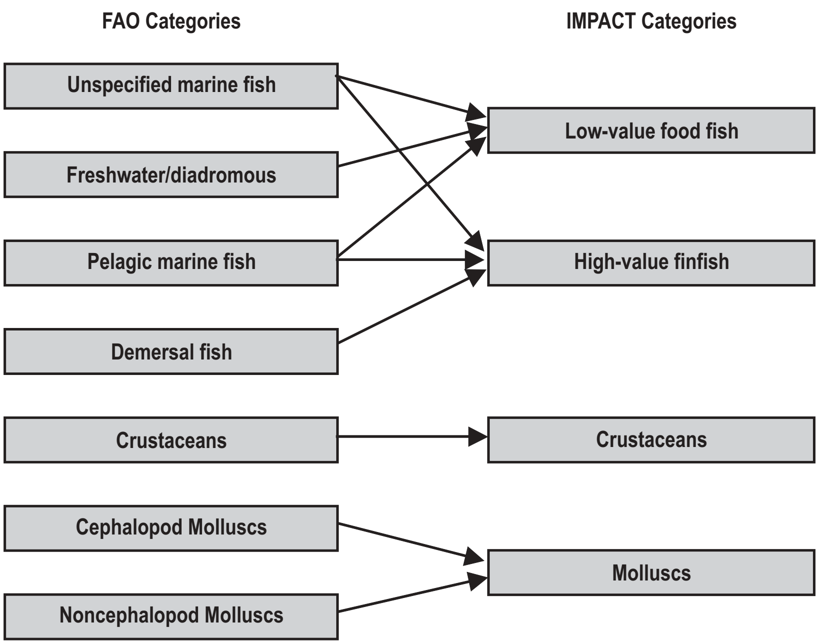
Low-Value Food Fish. Consumption of low-value fish has seen the largest absolute increases during the past several decades, as the poor in Asia have added diversity to their diets through increased consumption of farmed freshwater fish. Global aggregate consumption of low-value food fish rose from 18 mmt in 1973 to 43 mmt in 1997 (Appendix Table E.15). Chinese consumption drove most of this increase, rising from 4 mmt to 20 mmt as per capita consumption grew at an average annual rate of 9.2 percent during 1985–97. The developing world as a whole is a large net importer of low-value food fish, receiving approximately 2.3 mmt in 1997 in imports from the developed world.

Interestingly, the overall share of low-value food fish in total food fish has decreased from the early 1970s to the late 1990s in both developing and developed countries, yet it has increased in the world as a whole, from 41 to 47 percent over the same period (Table 3.3). This non-intuitive result stems from continued

Box 3.1 Apportioning aggregate food-fish consumption data by market categories

Aggregating fish consumption data into the market categories introduced in Chapter 2 is considerably more difficult than aggregating fish production data. Published FAO fish-utilization data, like production data, are aggregated by live weight into commodity groups according to biological and ecological criteria (see Figure 3.1). The data, however, are not available at the disaggregated levels of the production data. These broad categories have a drawback for consumption analysis: ecological categories such as "pelagic" lump together commodities like tuna and herring, which clearly belong in separate market-based categories because they have very different demand responses to price and income changes. As prices and incomes change, analysis of tradeoffs in demand with nonfish food commodities requires the reassignment of consumption data into the market-based aggregates described earlier.

Figure 3.1 Re-aggregating consumption data



(continued)

Box 3.1 Continued

Most of the FAO utilization categories map easily into these market-based categories, as was the case for production. The FAO category crustaceans is self-explanatory. Cephalopods (such as squid) are mollusks, and therefore go into that market category, as do noncephalopod mollusks like clams, oysters, mussels, and scallops (as described in Box 2.1). Demersal fish are primarily high-value marine fish like flounder, cod, sole, halibut, and seabass, which are considered as high-value finfish. Unspecified marine fish are categorized as low-value food fish. The two remaining categories—pelagic fish and freshwater/diadromous fish—are more problematic.

Pelagic fish include high-value species such as tuna and swordfish; however, they also include lower-value species like herring and anchovies. The differences in valuation of these commodities suggest that they have very different consumption characteristics, and may in fact be consumed by different sets of people. Freshwater/diadromous fish are similarly heterogeneous in value, ranging from carp on the low end to salmon and trout on the high end. Apportioning the demand for these categories between low-value and high-value fish requires clear decision rules using reasonable assumptions about country-level uses. Hence, fish from these categories that are consumed in or imported by developed countries are categorized as high-value finfish; fish that are consumed in or imported by developing countries are categorized as low-value food fish.[†]

[†]This approach is imperfect, and will inevitably introduce some error; however, the general validity of the approach was confirmed by aggregating processed-weight trade data into categories roughly corresponding to IMPACT and FAO categories. See Appendix C for further details on the assignment, error correction, and balancing of production, trade, and consumption data.

rapid growth in low-value food fish consumption in absolute terms in developing countries (albeit more slowly than mollusk and crustacean consumption). Because the relative share of low-value food fish consumption is much higher in developing than in developed countries, its relative global share has continued to increase. This has occurred even as consumers in both developing and developed countries are more rapidly expanding their consumption of higher valued items.

High-Value Finfish. High-value finfish represents the only category of fish that has decreased in overall per capita consumption since 1973 (Appendix Table E.28). Declines in high-value finfish consumption in Japan and the former Soviet Union have offset increases in Asia, the United States, and elsewhere. Nonetheless, the

Table 3.3 Changing relative importance of low-value food fish as a share of total food fish consumption, 1973–97

	Annual growth rates of food fish consumption 1985–97 (percent)			Low-value food fish as a share of total food fish consumption (percent)		
Region	High-value finfish	Low-value food fish	Total food fish	1973	1985	1997
Developing world	3.4	4.8	5.7	76	73	65
Developing world excluding China	1.7	1.6	2.0	77	74	72
Developed world	–0.2	–5.7	–0.4	13	14	7
World	0.7	3.8	3.3	41	45	47

Source: Calculated by authors from FAO 2002c.
Notes: Data are three-year averages centered on 1973, 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

levels of annual per capita consumption in Japan (33 kg), the European Union (15 kg), and the United States (13 kg) still dwarf the levels in developing countries (2 kg). Developed countries are by far the largest consumers of high-value fish; they accounted for 73 percent of global consumption in 1997. Nonetheless, this share has decreased from 86 percent in 1973—a phenomenon driven largely by growth in Chinese and Southeast Asian consumption.

Developing countries have rapidly entered export markets for high-value finfish since the 1980s. Latin America in particular has emerged as a major net exporter of high-value finfish, notably Chilean salmon produced from aquaculture. The Latin American region's net exports grew by 1.5 mmt from 1985 to 1997, while during the same period, developed countries expanded their net imports by 2.5 mmt.

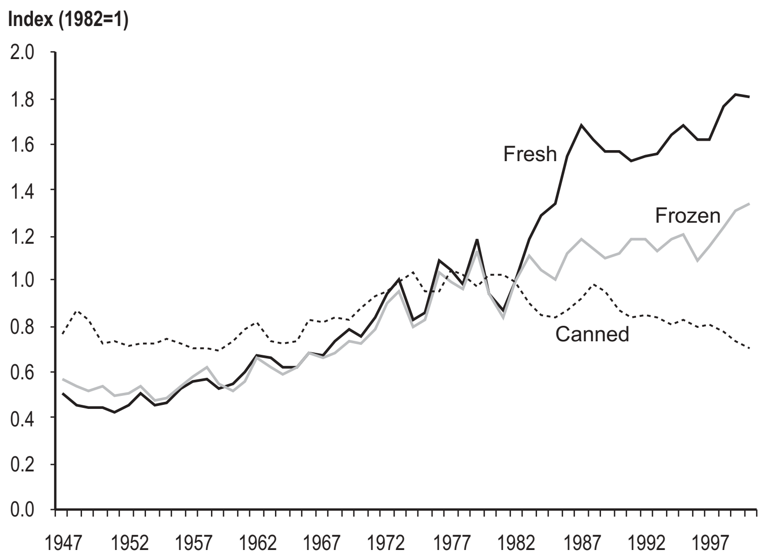
Mollusks. As mentioned above, mollusk consumption has boomed in China. The 14.5 percent growth rate in Chinese per capita consumption of mollusks from 1985 to 1997 dwarfed the comparatively modest growth in the rest of the developing world (2.1 percent, Appendix Table E.29). Europe and Japan are major importers of mollusks, with combined net imports of 1 mmt in 1997, while Latin America and China are fairly large exporters.

Crustaceans. Crustacean consumption is also centered in Asia, where China, India, and Southeast Asia have all seen robust growth (Appendix Table E.30). Per capita consumption of crustaceans in the developed world (2.0 kg/year) is still double that of the developing world. Latin America and Southeast Asia are large exporters of crustaceans; the farmed production of shrimp in Ecuador, Indonesia, Thailand, and Viet Nam has provided a major source of export revenue for these countries.

Price Trends

Unlike the behavior of red meat prices, which lost up to half their value on world markets between the early 1980s and the late 1990s (Delgado et al. 1999), fresh and frozen fish have shown a long-term increase in their real prices since the second world war, as shown in Figure 3.2 for the United States. An exception is canned finfish products, which have become less favored in the consumption baskets of developed countries since the early 1970s. Other exceptions are the specific cases of shrimp and salmon, where the rapid entry of aquaculture has lowered prices for these luxury goods, even as it has greatly broadened the market for these goods.

Figure 3.2 U.S. producer price indexes for fish and seafood products, 1947–2000



Source: Calculated from U.S. Bureau of Labor Statistics 2002.
Note: Data were deflated by the U.S. Producer Price Index for all commodities.

Because fisheries commodities and markets are extraordinarily diverse, price trends in different regions for different commodities are also diverse. Survey data from China, for example, indicate that real fish prices increased very slightly during 1980–2000, with increases during the 1980s and smaller decreases during the 1990s (Huang, Liu, and Li 2002). However, long-term price series for broad fisheries commodity groups in developing countries are generally unavailable. Export unit values provide a useful substitute. These should be treated with caution because export unit values are not a perfect proxy for price, and the bundle of actual commodities within each group changes over time and across countries. Nonetheless, the weighted average prices represented by export unit values do give an indication of the direction of price changes.

Table 3.4 shows nominal and real export unit values over time of fisheries commodities of particular interest, reported in processed weight. For the commodities shown, real export unit values declined during 1977–85, though this decline generally reversed or slowed during 1985–97. It is noteworthy that export unit values for salmon, shrimp, and freshwater fish have seen real declines from 1985 to 1997, a phenomenon that can probably be attributed to the rapid growth of aquaculture production of these commodities. Meanwhile, real export unit values for tuna and cod have risen.

The commodity unit values listed in Table 3.5 are for processed-weight commodities and follow the broad, market-based categories defined above. Crustaceans have by far the largest export unit value, while low-value food fish have the lowest. Real export unit values declined for all categories of food fish commodities from 1977 to 1985 but increased from 1985 to 1997. High-value finfish unit values increased the most during this time span (42 percent), reflecting increased demand and stagnant production in this category. During 1985–97, combined production of high-value finfish grew only 9 percent, the slowest growth of all market-based fisheries commodities. The reported values are global averages; naturally, variation exists across regions and commodities.

DRIVERS OF FISH CONSUMPTION TRENDS

Responses of Food Fish Demand to Income Growth and Demographic Shifts

It has been shown that animal product consumption grows fastest in countries with rapid population growth, rapid income growth, and urbanization (Rae 1998; Delgado and Courbois 1998). This pattern is also observed with fisheries products in particular. Across countries, per capita fish consumption is significantly correlated with average per capita national income (Figure 3.3). Consumer theory sug-

Table 3.4 Nominal and real export unit values of fisheries commodities

	Export unit values (U.S. dollars/kg)			Change (percent)	
Commodity	**1977**	**1985**	**1997**	**1977–85**	**1985–97**
Nominal prices					
Frozen shrimp[a]	4.75	6.41	7.87	35	23
Salmon[b]	3.70	3.90	3.62	5	–7
Tuna[c]	1.13	1.49	2.42	32	62
Cod[d]	1.64	1.67	2.67	2	60
Freshwater fish[e]	1.91	2.60	2.51	36	–3
Noncephalopod mollusks[f]	1.36	1.89	3.54	38	87
Real prices					
Frozen shrimp	7.28	6.26	6.22	–14	1
Salmon	5.67	3.81	2.86	–33	–25
Tuna	1.74	1.46	1.92	–16	31
Cod	2.51	1.63	2.11	–35	29
Freshwater fish	2.92	2.54	1.99	–13	–22
Noncephalopod mollusks	2.09	1.84	2.79	–12	52

Sources: Calculated by authors from the production and trade dataset of Fishstat Plus (FAO 2002a).
Notes: Data are three-year averages centered on 1977, 1985, and 1997, respectively. Unit values are reported in processed weight. The deflator used for real values is the U.S. Producer Price Index for all commodities, with a base year of 1982.
[a]Defined according to the FAO (2002a) Standard Industrial Trade Classification (SITC) category "shrimps, prawns, frozen."
[b]Defined according to the SITC categories "salmon, frozen ex. roe," "salmon, fresh, chilled ex. roe," and "salmon, whole or pieces, prepared, preserved."
[c]Defined according to the SITC categories "tuna, fresh, chilled ex. roe," "tuna, frozen ex. roe," and "tuna, whole or pieces, prepared, preserved."
[d]Defined according to the SITC categories "cod, fresh, chilled ex. roe," "cod, frozen ex. roe," "cod, salted," and "cod, dried, not fillets."
[e]Defined as all carp, catfish, freshwater fish, miscellaneous freshwater fish, Nile perch, perch, pike, and tilapia products from the disaggregated trade and production data in FAO (2002a).
[f]Defined according to International Classification for Standards (ICS) noncephalopod mollusk categories "molluscs canned," "molluscs cured," "molluscs excluding cephalopods," and "molluscs frozen."

gests that as individuals become wealthier, they tend to substitute higher-priced calories for lower-priced ones, once basic food needs are met.

The demand for fish products at the household level, as at the national level, is quite responsive to changes in income. A review of studies by Asche and Bjorndal (1999) shows income elasticities of demand for fisheries products to be generally high, often over 1.0. An income elasticity of 1.2, for example, implies that a 1 percent rise in income is associated with a 1.2 percent rise in fish consumption. Theory suggests that these income responses will be greater for lower income groups, and greater for luxury goods. Other evidence suggests that urban-

Table 3.5 Nominal and real export unit values of IMPACT categories

	Export unit values (U.S. dollars/kg)			Change (percent)	
Category	**1977**	**1985**	**1997**	**1977–85**	**1985–97**
Nominal prices					
Low-value food fish	0.87	0.97	1.37	12	41
High-value finfish	1.59	1.58	2.78	–1	76
Crustaceans	4.10	5.13	7.69	25	50
Mollusks	1.38	1.90	2.73	38	44
Total food fish	1.48	1.73	2.67	17	55
Real prices					
Low-value food fish	1.33	0.95	1.08	–29	14
High-value finfish	2.44	1.55	2.20	–37	42
Crustaceans	6.28	5.01	6.07	–20	21
Mollusks	2.12	1.86	2.16	–12	16
Total food fish	2.27	1.69	2.11	–25	25

Sources: Calculated by authors from the production and trade dataset of Fishstat Plus (FAO 2002a).
Notes: Unit values are reported in processed weight. Export values were aggregated into IMPACT categories according to the definitions in Appendix B. The deflator used for real values is the U.S. Producer Price Index for all commodities, with a base year of 1982.

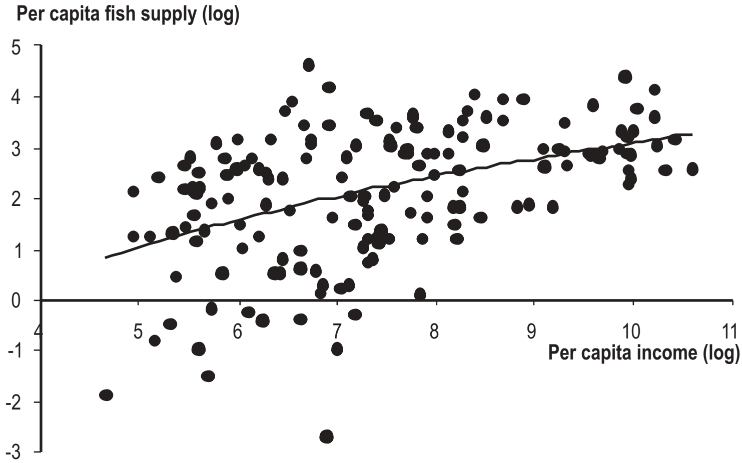
ization also drives increased fish consumption through changing preferences (Huang and Bouis 1996).

Given the structural responsiveness of food fish demand to income and urbanization as argued above, it is not hard to see why the preponderance of demand growth has occurred in developing countries. Since the early 1980s, aggregate consumption of fisheries products has grown rapidly in the developing world, at an average annual rate of 6 percent (Table 3.1). In China, where income and urbanization grew particularly rapidly from the early 1980s to the late 1990s, fish consumption grew at an astonishing 12 percent per year.

Moreover, population growth has played a significant role. As shown in Table 3.6, population hardly grew in the developed world during 1985–97 (0.6 percent per annum), while growth in the developing world was robust (2.1 percent per annum excluding China). Even without per capita income growth, developing countries will consume significantly more fish each year. Rates of urbanization have also been much higher in developing countries than in the developed world. Urbanization has been a major factor in China, even if population growth has not.

Table 3.6 also shows that China distinguishes itself from other large regions of the world in the extraordinarily high income growth rate it has sustained since the mid-1980s. It is hard to understand the major changes that have occurred in Chinese fisheries over the same period without taking this into account. Household surveys from China (Huang, Liu, and Li 2002) show that urbaniza-

Figure 3.3 The relationship between per capita income and fish consumption



Sources: Calculated by authors from FAO 1999a and World Bank 2002.
Notes: Each point represents an average of data from 1961–99 for each country. R-squared = 0.20.

tion and income growth have fueled the rapid growth in fisheries consumption there. Income growth and urbanization both in the North and the South have also fueled the demand for the high-value products of carnivorous aquaculture, such as shrimp and salmon.

Responses of Food Fish Demand to Price Changes

Although the demand parameter literature is diverse, and conclusions are difficult to draw out of context, the survey in Asche and Bjorndal (1999) suggests that demand for food fish is fairly price-elastic. For modeling purposes, a reasonable assumption for own-price elasticities of demand for food fish would be in the range of –0.8 to –1.5. The interpretation is straightforward: real price rises will cut into fish consumption on average in developing countries (a 1 percent price increase is associated with a 0.8 percent decline in fish consumption if the own-price elasticity is –0.8). Furthermore, consumer theory suggests that the cut is likely to be stronger for the lower income groups.

Table 3.6 Factors contributing to differential growth rates for food fish in developed and developing countries, 1985–97

	Average annual growth rates, 1985–97 (percent)		
Region	**Total population**	**Urban population**	**GDP per capita**
Developing countries excluding China	2.1	3.4	2.1
China	1.3	3.7	7.6
Developed countries	0.6	0.9	1.9
World	1.6	2.5	1.4

Source: Calculated by authors from World Bank 2002.
Notes: Growth rates are exponential, compounded annually using three-year averages as endpoints.

Poultry may be the best substitute for fish in developing regions, though cross-price elasticities with red meat products are fairly small (Delgado and Courbois 1998). A cross-price elasticity of 0.3, for example, implies that a 1 percent rise in poultry prices, *ceteris paribus,* induces a 0.3 percent rise in fish demand.

It is certainly true that aquaculture growth has been instrumental in making fish widely available in developing countries, especially in China. The resulting increased local availability (theoretically akin to a local price decline) is also undoubtedly a factor in many situations; the existence of rural markets for fish in China is a significant factor in household fish consumption (Huang, Liu, and Li 2002). Improvements in processing technology and cold chains that prevent spoilage of fisheries products also contribute to increasing consumption by making fish available in markets at a distance from the source of production.

Nonetheless, aquaculture production meets an increased general demand for animal products. In general, fish prices have risen relative to other food products, driven partly by rapid consumption growth. In developed countries, overall per capita consumption of fish has stagnated as saturation levels in the diets of consumers have been reached, though there has been growth in demand for crustaceans on the higher end of fisheries commodities, consistent with consumer theory. In developing countries, per capita consumption of all fisheries commodities has grown, with consumption of the relatively expensive crustaceans and mollusks rising fastest. The developing countries still have great latitude for increasing demand for low-value fish, but it is to be anticipated that the "upgrading" observed in the developed countries is also occurring among the better-off segments of the developing world. This move toward higher value fish products from aquaculture may also be leading to increased demand for fish used as feed, or reduction fish.

Determinants of Demand for Reduction Fish

Fishmeal and fish oil are products derived from wild-caught fisheries that are used for feeding terrestrial livestock and farmed fish. The global supply of fishmeal and fish oil has changed little over the past several decades, as supply is limited by resource constraints (described in Chapter 2). Demand for fishmeal and fish oil is primarily determined by the underlying demand for livestock and fish, but is also determined by a wide range of other factors, including feed conversion efficiency, the relative prices of competing feeds, and the outlook for competing sectors that also consume fishmeal and fish oil. High-value aquaculture that produces carnivorous fish and crustaceans has strong demand for these feed inputs. In fact, aquaculture's share of demand for fishmeal and oil has grown significantly over the past several decades. Historical use patterns for fishmeal are shown in Table 3.7. Regions with rapidly growing poultry, pig, and aquaculture sectors, such as China and Southeast Asia, have increased their shares of global use.

Aquaculture is likely to grow rapidly over the next 20 years, raising concerns that rising demand for fishmeal and fish oil could place heavier fishing pressure on threatened stocks of reduction fish. Addressing questions regarding the potential

Table 3.7 Use of fishmeal, 1973–97

	Total use (thousand metric tons)			Annual growth rate (percent)
Region	1973	1985	1997	1985–97
China	112	554	1,573	9.1
Southeast Asia	135	238	728	9.8
India	17	32	25	–2.0
Other South Asia	1	35	47	2.6
Latin America	483	672	451	–3.3
West Asia and North Africa	99	217	252	1.3
Sub-Saharan Africa	15	12	14	1.6
United States	334	463	267	–4.5
Japan	828	1,052	731	–3.0
European Union 15	1,104	1,191	1,070	–0.9
Eastern Europe and former Soviet Union	992	1,148	361	–9.2
Other developed countries	379	421	557	2.4
Developing world	877	1,821	3,148	4.7
Developing world excluding China	765	1,266	1,575	1.8
Developed world	3,637	4,273	2,985	–2.9
World	4,514	6,094	6,133	0.1

Source: Calculated by authors from FAO 2002a.

Notes: Data are three-year averages centered on 1973, 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

impacts of aquaculture growth on reduction fish stocks requires a framework that allows for price-mediated interactions among terrestrial livestock, aquaculture, fishmeal and fish oil, and other feed substitutes. Chapter 6 addresses this question in detail.

The picture that emerges for feed fish demand, as for food fish demand, is one of rapid changes driven particularly by events in Asia. Substitutions are taking place on both the consumption and production sides. Relative prices are changing, which creates new incentives for substitution. Furthermore, all these changes are occurring in the context of technological progress. The next chapter discusses a methodological approach that simulates all these factors simultaneously.

Chapter 4

PROJECTIONS TO 2020 UNDER DIFFERENT SCENARIOS

Quantitative simulation into the future of the relation of fisheries to other components of world food supply and prices has not been done at the global level to date, at least not with any degree of disaggregation. Many of the methodological difficulties inherent in the task were discussed in Delgado et al. (2000). This chapter reports results of the projections to 2020 for 10 major economic categories of fisheries items, disaggregated into 12 geographic regions of the world.[10]

A difficulty in undertaking formal inquiry of this type is the complexity involved with using data produced independently and then aggregated to the global level in broad commodity groups. All policy analysts wishing to examine the price interactions among disaggregated food sectors at the global level are compelled to use national-level data from the FAO, the only source of such information. These data are based on submissions from national statistical agencies.

MODELING FISH TO 2020 WITHIN A GLOBAL MODEL OF FOOD SUPPLY AND DEMAND

Besides providing a framework for assessing the consistency of assumptions about fish production, feed requirements, consumption, and trade, the main contribution of economics as a discipline to forecasting fisheries outcomes is to explicitly accommodate the reality that producers, traders, input suppliers, and consumers

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[10]Parts of this chapter were presented for discussion at the biennial meetings of the International Institute of Fisheries Economics and Trade, August 20, 2002, Wellington, New Zealand (Delgado et al. 2002a).

all react to changes in relative prices, and choose among alternate inputs and outputs—including nonfisheries alternatives—based on perceptions of changing relative costs and benefits. Thus projections of long-term massive changes in relative prices for specific fisheries items need to be treated with caution, because over time people in the real world are likely to find a better way of achieving their goals as consumers or producers before those massive relative price changes actually occur.

The tool of choice for taking into account the impact of price changes on production, consumption, and trade trends is a supply and demand model that calculates demand and production outcomes for different commodities and locations, and estimates an equilibrium set of prices and trade flows that allows all food markets (including food items used as feeds) in all locations to match local demand with local availability (production plus net trade). Furthermore, the model needs to take into account the main nonprice drivers of change, such as changing demographics and income levels. Finally, the model should allow iterative changes, in the sense that producers, consumers, and traders should have a chance to refine their strategies periodically in light of changing conditions (say once a year in the case of a long-term model), as do participants in the real world.

IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), developed and maintained by a team led by Mark Rosegrant, meets these conditions (Rosegrant et al. 2001). IMPACT is specified as a set of country or regional submodels, within each of which supply, demand, and prices for agricultural commodities are determined. The present version of IMPACT (July 2002) covers 36 countries and regions (accounting for virtually all world food production and consumption) and 22 nonfish commodities, including all cereals, soybeans, roots and tubers, four meats, milk, eggs, oils, oilcakes, meals, sweeteners, fruits, and vegetables.

IMPACT uses a system of supply and demand elasticities for each commodity, different for each of the 36 markets and incorporated into a series of linear and nonlinear equations, to approximate the underlying supply and demand functions. Cross-price elasticities and intermediate demands (such as feed grains for livestock production) ensure the interlinkage of markets within each of the 36 country groupings. Demand within each of the 36 country-group markets is a function of prices, income, and population growth specific to that market. Growth in crop production in each country-group is determined by crop prices and an exogenous rate of productivity growth specific to that group.

Prices are endogenous in the system. Domestic prices consist of world prices modified by country- and commodity-specific price differentials. The effects of country-group specific price policies are expressed in terms of producer subsidy equivalents (PSE), consumer subsidy equivalents (CSE), and marketing margins. PSE and CSE measure the implicit level of taxation or subsidy borne by producers or consumers relative to world prices and account for the wedge between domestic and world prices.

Marketing margins reflect factors such as transport costs. All prices and quantities are in live-weight equivalents, so processing costs are not included. The possible effects of major structural changes in world trade, such as China's entry into the WTO or the effects of a possible agreement during the Doha round of trade talks beginning in 2001, are not explicitly incorporated in the model.[11]

The 36 country-group submodels for each commodity are interlinked through trade with a separate, unique "world market" for each commodity, a specification that highlights the interdependence of commodity prices across countries and commodities in global agricultural markets. Commodity trade by country-group is the difference between domestic production and demand for that country-group. Countries with positive trade are net exporters, while those with negative values are net importers. This specification does not permit a separate identification of countries that are both importers and exporters of a particular commodity.

The world price of a commodity is the equilibrating mechanism such that when an exogenous shock is introduced in the model, the world price will adjust and each adjustment is passed back to the effective producer and consumer prices via price transmission equations. Changes in domestic prices subsequently affect supply and demand of the commodity concerned and of complements and substitutes for that commodity, necessitating myriad iterative readjustments for all commodities and regions until world supply and demand balance, and world net trade is again equal to zero. World agricultural commodity prices are thus determined annually at levels that clear world and regional markets.[12]

Forecasts of changes in relative prices from 1997 to 2020 are the principal insight offered by global supply and demand models such as IMPACT. The changes that are forecast are devoid of inflation and can be shown as percentage

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[11]It could be argued that such effects could be incorporated through the use of more optimistic income growth assumptions. In keeping with the generally conservative philosophy of IMPACT, this was not done.

[12]The model is written in the General Algebraic Modeling System (GAMS) programming language. The solution of the system of equations is achieved using the Gauss-Seidel algorithm. This procedure minimizes the sum of net trade flows at the international level and seeks a world market price for a commodity that satisfies the market-clearing condition that all country-group level excess demands for a given commodity sum to zero, and that this condition holds simultaneously for all commodities. See Rosegrant, Meijer, and Cline (2002) for a technical description of IMPACT prior to the incorporation of fish.

changes over the entire period relative to an actual base level in 1997. They provide insights into the net effect of thousands of simultaneous assumptions and parameters, adjusting over time to demographic changes, income growth, technological changes, and to changes in relative prices themselves. The latter occur through substitution effects in both consumption and production. Consumption effects occur as consumers re-orient their consumption basket to handle price changes. Production effects occur as producers modify their behavior in response to relative price changes, and as intermediate products such as animal feeds are affected by changing demands for their use as inputs to livestock products and fish.

The fisheries components of IMPACT follow the same general approach as the rest of the model. The number of fisheries commodity groups must be limited to a manageable number. Yet demand response parameters to price and income changes must be fairly similar across subcomponents of each aggregate category; supply parameters must also be comparable. The new version of the model includes four categories of food fish, as discussed in Chapter 3. These are high-value finfish (such as salmon and tuna), low-value food fish (such as herring and carp), crustaceans (such as shrimp and crabs), and mollusks (such as clams and squid). It also includes two animal feed items made from fish: fishmeal and fish oil.

Commodities produced by aquaculture and capture need to be differentiated, given that they have different production parameters, even if treated as the same good in consumption. Thus the four food fish categories are further subdivided on the production side into separate categories for capture and aquaculture outputs. On the consumption side, the model collapses aquaculture- and capture-produced food items into four categories plus fishmeal and fish oil. Supply (aquaculture and capture) and demand (combined) for these six composite items interact to produce six equilibrium fisheries prices in each geographic market, and these interact with markets in other countries, and for other food and feed commodities.

Another difficult modeling problem is that supply, demand, and trade must be balanced for the 36 country groups. This is a problem in any global modeling exercise because independently collected global datasets rarely balance, and would be slightly suspect if they did. Furthermore, simplifications adopted in aggregating commodities into economic commodity and country groups, while eliminating a few non-animal or minor commodities (see Appendixes A and B), are likely to create inconsistencies in the end product. For the purposes of this study, balance across production, consumption, and net trade (see Appendix D) for each country group and consumption category has been imposed ex post for the base year of the projections (1997), as discussed in Appendix C; consistency in the projections thereafter is achieved by model construction.

Finally, constructing a basic model of fisheries supply and demand within IMPACT, according to the principles discussed above, requires adding thousands of parameters for the fisheries section alone: 36 country groups multiplied by 10 commodities in production and 6 in consumption, multiplied by the number of relationships and parameters in each fisheries relationship. Existing literature on supply and demand for fish was used as much as possible, but it was clearly necessary to extrapolate many of the parameters given that no specific estimates exist for these items.

CHOOSING PARAMETERS

The determinants of fisheries demand in the IMPACT model can be separated into two broad categories: price-mediated drivers and nonprice-mediated drivers. On the demand side, IMPACT models responses to changes in own-prices, prices of competing and substitute goods in consumption, income, and population. On the supply side, IMPACT models responses to changes in own-prices, prices of competing and substitute goods in production, and input prices. The model also includes a trend yield growth factor to capture nonprice influences on growth of production. Parameters are modified every five years to allow for expected changes, such as declining income responsiveness (as income grows, demand becomes less sensitive to further increases in income) over time, or the impact of increasing urbanization on demand for higher priced calories (Rosegrant, Meijer, and Cline 2002).

Demand Parameters

Population growth trends are a major determinant of demand growth in the IMPACT framework. Population growth estimates are based on medium-variant predictions from the United Nations (1998); they are specified for each IMPACT country group, and different rates are specified for each five-year period to 2020. World population doubled from 3 billion in 1960 to 6 billion in 1999; the average annual growth rate has declined to 1.4 percent in 1998. Population growth rates will likely decline further over the next 20 years. High population growth will occur in Sub-Saharan Africa, where a population of nearly one billion people is projected for 2020 (United Nations 1998). The huge population bases in China and India will mean that, despite comparatively low population growth rates, these two countries will account for nearly a third of the global population increase to 2020, and thus for a large share of the growth of demand for food.[13]

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[13]See Rosegrant et al. 2001 for further discussion of this issue.

Income changes in IMPACT affect demand through a set of country-group and commodity-specific income elasticities of demand. These are typically higher in poorer countries and for higher value products such as fish. Income elasticities are typically specified to decline every five years over the projections period, adding curvature to the relationship between consumption and income, as is the case with increasing satiation of food demand over time. The decline in income elasticities over time is kept smaller for high-value items in countries still thought to be subject to rapid urbanization, such as China, because of assumed shifting preferences in favor of higher value fish.

Income change is measured by growth rates in future national income projected by the World Bank (World Bank 2002). Generally cautious GDP projections show highest growth in China, India, and Southeast Asia. Developed world GDP growth projections are generally between 2 and 3 percent per year. Per capita GDP growth translates into increased consumption for fisheries products when passed through income elasticities that reflect the demand response to changes in income. These elasticities are specified for each region based on the best available literature and are comparable to those specified for livestock products. Income elasticities are generally lower for low-value food fish and also tend to be lower in high-income countries because consumption patterns tend to be less sensitive to changes at higher levels of income.

Price-mediated drivers of consumption are those in which consumers alter their behavior based on changes in the price of a commodity relative to those of its substitutes and complements. Consumer responses to relative price changes are modeled in IMPACT through a system of regionally specific own-price and cross-price elasticities. Own-price elasticities are generally lower for low-value food fish, reflecting their role as a protein staple in many diets in low-income countries. Price elasticities for fisheries commodities are also in the same range as livestock products because they occupy similar roles in the diets of consumers. Cross-price elasticities among fisheries products, and between fisheries and livestock products, allow consumers in the model to substitute toward or away from commodities depending on relative prices.

When dealing with broad aggregates such as "low-value food fish," considerable variation will arise in the basket of commodities represented across the 36 country groups of the model, adding to the need to have different production and response parameters across the 36 country groups.[14] The demand elasticity with

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[14]Although IMPACT uses 36 country groups, we have chosen to further aggregate results to 12 country groups for the purposes of expository convenience. The tables in this report use these 12 groups, though the actual modeling was done at a more disaggregated level.

respect to price for low-value food fish in China is related to commodities such as grass carp, whereas in western Europe it is related more to herrings and sardines. Therefore, for each commodity category, hundreds of demand and supply response parameters must be specified.

The model links demand for fishmeal and fish oil to the demand for livestock and aquaculture products through regionally specified feed demand elasticities and feed conversion ratios. In the case of aquaculture, for example, a given level of production of high-value finfish from aquaculture in country X in year T will generate a certain amount of initial demand for fishmeal and fish oil in country X in year T. The actual amount consumed by this activity in country X, year T, is then iteratively affected by responses to changing relative input and output prices and quantities in country X, year T, which in turn iteratively interact with prices in other countries in year T. The feed conversion ratios that lead to initial resource demands by aquaculture products are assumed to become more efficient over time with technological innovation.

Supply Parameters

Nonprice factors in supply, including technological change and changes in investment, are modeled through trend growth factors that are allowed to differ across commodities, country groups, and every five years through 2020. These "growth factors" address the important effects—present and future—of myriad nonprice factors in fisheries production, particularly in the capture fisheries sectors. These factors might include technologies that affect productivity and subsidies that affect desired investment levels.

Specified future growth rates in technical change for capture fisheries are rather modest in the IMPACT model, reflecting the past decade of stagnating catches. Precise estimates of changes in wild fish stocks are extraordinarily difficult to calculate, in contrast with the comparatively easier task of estimating past changes in global stocks of livestock such as pigs and poultry. Our approach is to piece together a reasonable but generally conservative scenario for capture fisheries, using geographically disaggregated assumptions from the extrapolation of recent trends that show declining growth rates over time. These assumptions are part of our "baseline scenario"; actual projections in the baseline depend not only on exogenous trend factors but also on responses to endogenous price changes across all sectors.

Investment and technological change have also been important in aquaculture, which has provided most of the growth in global production over the past 15 years. Much of these investment and productivity trends are independent of price factors and are specified as such, although favorable prices may tend to be associated with lower subsidies and increased investment. Price responsiveness of supply is typically specified to be higher in aquaculture than in capture fisheries. Capture fisheries face resource and regulatory constraints that limit price responsiveness, at least in the medium-term (less than five years); capital stock is a primary determinant of capture fisheries supply, and capital stock is heavily influenced by national policies toward fisheries. Studies show generally price-inelastic supply in case studies of capture fisheries (Pascoe and Mardle 1999). Aquaculturists in both the model and the real world are more able to adjust production levels in response to yearly changes in prices.

Sensitivity to Assumptions and Scenario Analysis

It is clearly infeasible to fully test the sensitivity of results to the thousands of separate assumptions built into the baseline model. The baseline is our best guess given available data, and it embodies sensible assumptions about nonprice trend factors and responses to income and price changes. It is generally conservative, so the error is likely to be in under- rather than overforecasting change to 2020. This is a deliberate strategy to add strength to predictions of major changes; hence the likelihood is that—if anything—such changes will be more important in reality than predicted.

That said, it is not absolutely necessary to agree with the assumptions of the baseline scenario to derive value from the simulations. Whether or not one agrees with the baseline assumptions, the model structure is useful for examining the sensitivity of fisheries outcomes to changes in assumptions. A number of scenarios were developed with sweeping changes in different classes of the underlying assumptions to see what happens. The choice of scenarios was dictated by the underlying objective of assessing the prospects, constraints, and issues for policies toward aquaculture, particularly in the face of major uncertainties in the outlook for capture fisheries.

In this vein, the main point of adding capture fisheries to the model is to include its relationship with aquaculture through income and price substitution relationships. A more optimistic outlook for growth in capture fisheries would put downward pressure on fish prices relative to other items, even though relatively lower prices by themselves encourage some increased fish consumption, which mitigates any price fall. Thus a more positive outlook for capture fisheries implies somewhat less incentive for growth of aquaculture, even though the price of feed inputs also declines if the capture of feed fish rises along with food fish. A more pessimistic outlook for capture fisheries is likely to be associated with higher prices for fish, on a net basis raising incentives for increased aquaculture output, even though the price of feed fish also rises.

A major concern is the possibility that the outlook for capture fisheries is more pessimistic than is embodied in the baseline; hence an extremely pessimistic scenario is investigated for capture fisheries ("ecological collapse"). Table 4.1 describes the project scenarios investigated. The baseline itself is hardly rosy. For example, the growth trend factor (the nonprice side of production growth) is negative for most of the developed countries at the start of the simulation (–0.4 percent per annum for low value food finfish in Japan, for example). For most of the developing countries, low positive trend growth of +1.0 to +1.5 percent per annum is built in, and declines every five years to 2020. In both cases, actual growth is also influenced by response to prices. The ecological collapse scenario imposes a uniform –1 percent per annum trend decline in capture fisheries, including reduction fish, in all countries through 2020. If producer and consumer responses were not allowed to occur to modify the final result, this would cause the projection of global production of fish from capture in 2020 to decline by more than half relative to 1997, a more radical change than any serious fisheries analyst has yet proposed.

Another set of assumptions that could have major implications for results concerns nonprice-mediated trends in aquaculture growth. These can be thought of as investment flows to aquaculture or productivity increases beyond those in response to price changes. As was discussed in Chapter 2, the explosion of pond finfish aquaculture in China during the 1990s was significantly assisted by a policy focus on this sector. Accordingly, in China for example, a 2.7 percent per

Table 4.1 Description of IMPACT projection scenarios

Scenario	Description
1. Baseline	Judged to be the most plausible set of assumptions.
2. Faster aquaculture expansion	Production growth trends, excluding supply response to price change, for all four aquaculture output aggregate commodities are increased by 50 percent relative to the baseline scenario.
3. Lower China production	Chinese capture fisheries production is reduced by 4.6 mmt in base year 1996–98 following Watson and Pauly (2001). Consumption is reduced an identical amount to maintain balance. Reductions are spread proportionately among fish commodities. Income demand elasticities, production growth trends, and feed conversion ratios are adjusted downward, consistent with the view that actual growth in production and consumption over past two decades was in fact slower than reported.
4. Fishmeal and oil efficiency	Feed conversion efficiency for fishmeal and fish oil improves at twice the rate specified in the baseline scenario.
5. Slower aquaculture expansion	Production growth trends, excluding supply response to price change, for all aquaculture commodities is decreased by 50 percent relative to the baseline scenario.
6. Ecological collapse	–1 percent annual growth trends in production, excluding supply response to price change, for all capture fisheries commodities including fishmeal and fish oil.

Source: Devised by authors.

Notes: The assumed growth trend components in supply capture the effects of technological change and other nonprice effects; end results are also affected by price responses.

annum trend growth in high-value finfish aquaculture is built into the baseline scenario at the beginning of the simulation, declining to 2.0 percent per annum by 2020. These growth rates are in fact much smaller than actual growth in the 1990s and are further modified in the projections by price effects. The "faster aquaculture expansion" scenario arbitrarily increases the trend components for aquaculture growth in every country and for every aquaculture commodity by a further 50 percent relative to baseline values. The "slower aquaculture expansion" scenario does the opposite. In both cases, "expansion" could occur through changes in resource use or productivity, or both. Again, price effects also influence final outcomes.

Another set of important assumptions concerns the rate of technological progress in aquaculture. The "faster aquaculture expansion" scenario increases assumed trend growth components but does not modify the relationship between reduction fish for feed and output fish for food. Consequently, the "fishmeal and oil efficiency" scenario increases the assumed growth in feed conversion efficiency for fishmeal and fish oil to twice the assumed rate in the baseline; this varies across countries and commodities but is generally in the range of 1 percent per annum in the baseline.

As discussed in Chapter 2, controversy lingers over the official Chinese fisheries statistics—specifically that production data may be too high. The baseline incorporates starting figures for 1997 from FAO datasets that have undergone the balancing procedures discussed in Appendixes C and D to reconcile production, consumption, and trade. Furthermore, the baseline trend growth, price and income responses, and feed conversion efficiency parameters for China are all consistent with reported trends in FAO data from the early 1980s to 1997.

The "lower China production" scenario attempts to modify the baseline scenario to fit the over-estimates of marine fisheries output in the late 1990s posited by Watson and Pauly (2001). This is done by reducing total capture fisheries production in China in 1997 by 4.6 mmt—an amount equivalent to Watson and Pauly's suggested over-estimate of marine capture. These reductions are spread proportionately over the capture fisheries commodities modeled in IMPACT. However, maintaining consistency among production, consumption, and trade required balancing to accommodate the lower estimate of production. Since trade is small in China relative to consumption, and the trade figures are almost certainly more accurate than the consumption figures, the latter were reduced to match the new production estimate. Finally, given that the production figures for the early 1980s are not disputed, the lower estimates of production and consumption in 1997 necessarily imply that the baseline production and consumption parameters implied by the FAO data are inconsistent with the new estimates. Consequently, the baseline estimates of supply and demand parameters were adjusted in the lower China production scenario to be consistent with less rapid historical growth in fisheries. The results are not intended to better represent reality in China; rather, they serve to investigate the global implications of downgrading Chinese marine production estimates in the late 1990s.

IMPACT PROJECTIONS TO 2020

Outlook for Fish Prices in 2020 and the Importance of Aquaculture

Net forecast price changes to 2020, given as percentage changes relative to 1997 levels, are shown in Table 4.2. The baseline version of the model projects that long-term real prices for high-value finfish and crustaceans increase by a total of 15 percent over 1997 levels (above any inflationary change). This result is particularly striking compared with the projected price trends in other food commodities, which indicate nearly uniform real price declines. Fishmeal and fish oil prices increase more than food fish commodities under the baseline scenario, at 18 percent. Mollusks and low-value food fish show significantly lower—though still

Table 4.2 Projected total change in prices under different production scenarios, 1997–2020

	Projected total change in prices, 1997–2020 (percent)					
Commodity	Most likely (baseline)	Faster aquaculture expansion	Lower China production	Fishmeal and fish oil efficiency	Slower aquaculture expansion	Ecological collapse
Low-value food fish	6	–12	6	5	25	35
High-value finfish	15	9	16	14	19	69
Crustaceans	16	4	19	15	26	70
Mollusks	4	–16	3	3	25	26
Fishmeal	18	42	21	–16	0	134
Fish oil	18	50	18	–5	–4	128
Beef	–3	–5	–3	–4	–2	1
Pigmeat	–3	–4	–2	–3	–1	4
Sheepmeat	–3	–5	–3	–3	–1	2
Poultry meat	–2	–5	–2	–3	0	7
Eggs	–3	–5	–3	–4	–2	3
Milk	–8	–10	–8	–9	–8	–5
Vegetable meals	–1	3	0	–7	–4	16

Source: Projections for 2020 are from IFPRI's IMPACT model (July 2002).
Note: See Table 4.1 for scenario descriptions.

positive—real price appreciation (4 and 6 percent respectively). Prices for meat and eggs, on the other hand, are forecast to decline by about 3 percent in real terms—still good news for producers in a sector where real prices are currently half what they were 20 years ago.

On this basis, fish become about 20 percent more expensive relative to livestock-derived substitutes by 2020, even taking into account price-motivated substitutions by consumers. On the other hand, fishmeal and fish oil become slightly more expensive (3 percent) relative to high-value finfish, 12 percent more expensive relative to low-value food fish, 19 percent more expensive relative to vegetable meals, and 20 percent more expensive relative to poultry.

Fishmeal and fish oil prices are likely to shoot up under a variety of possible scenarios (Table 4.2). The worst case is under ecological collapse of capture fisheries, wherein the direct effect on fishmeal output, coupled with the increased demand pressure from aquaculture, results in a more than doubling of current prices in 2020.[15] Even the faster aquaculture expansion scenario causes significant upward pressure on fishmeal prices, in addition to hastening its departure from poultry rations. Interestingly, faster growth in aquaculture is associated with further price declines for livestock products, while ecological collapse in marine fisheries is associated with a net increase in real livestock prices by 2020. Both of these effects in the model result from consumers substituting cheaper sources of animal protein in their diets as relative prices change.

Rapid technological progress in aquaculture, represented by higher fishmeal and oil conversion efficiency, is the one scenario that leads to slightly lower real fishmeal prices. This scenario suggests potentially high returns to the carnivorous aquaculture industry by investing in higher fishmeal and fish oil efficiency. Chapter 6 discusses this issue in greater detail.

Finally, the faster aquaculture expansion scenario is associated with a decrease in the projected real prices of low-value food fish, despite a significant rise in the price of fishmeal. This is in part a result of the model construction, whereby fishmeal demand cannot be met by diverting supply of low-value food fish to reduction; this reflects the separate nature of reduction fisheries and food fisheries (New and Wijkstrom 2002). However, the model result also offers the insight that aquaculture supplies a large share of the low-value food fish consumed by the poor, and that investing in improving the productivity and sustainability of low-value food fish aquaculture is a good way of making it more obtainable by the poor. Prices for

[15]A forecast long-term price change of this magnitude is far more significant for analytical purposes than a year-to-year change from a transitory event, such as an El Niño effect, to which the system can adjust over time.

the other food fish commodities under the faster aquaculture growth scenario either decline, or increase less, than they do in the baseline. The slower aquaculture growth scenario results in real price increases for all food fish commodities—increases that are significantly higher than in the baseline.

Production

Baseline Scenario. Production levels and trends for food fish from the baseline projections are shown in Tables 4.3 and 4.4. Global food fish production is projected to total 130 mmt in 2020, equivalent to an annual rate of increase of 1.5 percent from 1997 onward (Table 4.3). Of the 37 mmt increase in global food fish production, over two-thirds comes from aquaculture, which is projected to represent 41 percent of global food fish production in 2020 (up from 31 percent in 1997).

Table 4.3 Total production of food fish, 1997 and 2020

	Actual 1997		Projected 2020		Projected annual growth rates 1997–2020 (percent)		
	Million metric tons	Share from aquaculture (percent)	Million metric tons	Share from aquaculture (percent)	Capture	Aqua-culture	Total
China	33.3	58	53.1	66	1.1	2.6	2.0
Southeast Asia	12.6	18	17.5	29	0.8	3.6	1.4
India	4.8	40	8.0	55	1.0	3.7	2.3
Other South Asia	2.1	23	3.0	39	0.6	4.0	1.7
Latin America	6.4	10	8.8	16	1.1	3.5	1.4
West Asia and North Africa	2.2	9	2.8	16	0.6	3.6	0.9
Sub-Saharan Africa	3.7	1	6.0	2	2.0	5.8	2.1
United States	4.4	10	4.9	16	0.1	2.7	0.5
Japan	5.2	15	5.2	20	–0.3	1.2	0.0
European Union 15	5.9	21	6.7	29	0.0	2.1	0.5
Eastern Europe and former Soviet Union	4.9	4	5.0	4	0.1	0.4	0.1
Other developed countries	4.8	12	5.8	20	0.5	2.9	0.8
Developing world	68.0	37	102.5	47	1.0	2.8	1.8
Developing world excluding China	34.6	17	49.4	27	1.0	3.6	1.6
Developed world	25.2	13	27.6	19	0.1	2.1	0.4
World	93.2	31	130.1	41	0.7	2.8	1.5

Sources: Actual data were calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year averages centered on 1997. Projected growth rates are exponential, compounded annually using three-year averages as endpoints.

Table 4.4 Regional shares of global food fish production, 1997 and 2020

	Share of world total (percent)			
	Actual			Projected
Region	1973	1985	1997	2020
China	10	13	36	41
Southeast Asia	11	12	14	13
India	4	4	5	6
Other South Asia	2	2	2	2
Latin America	5	6	7	7
West Asia and North Africa	1	2	2	2
Sub-Saharan Africa	4	4	4	5
United States	4	6	5	4
Japan	17	14	6	4
European Union 15	13	9	6	5
Eastern Europe and former Soviet Union	17	14	5	4
Other developed countries	6	6	5	4
Developing world	44	51	73	79
Developing world excluding China	33	38	37	38
Developed world	56	49	27	21

Sources: Actual data were calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).
Notes: Actual data are three-year averages centered on 1973, 1985, and 1997, respectively.

This table shows that aquaculture growth trends projected to 2020 are almost twice as high as those for capture food fish in most of the world.

The emerging picture of changes for food fish production to 2020 under the baseline scenario can be summarized as three sets of points. First, the developing-country production share rises from 73 percent in 1997 to 79 percent in 2020, and China is responsible for about 5 of the 6 percentage point increase. This projection is consistent with trends observed in the past 30 years, including China's expansion into distant-water fisheries previously occupied by fleets from developed countries. The absolute increase in annual aquaculture production outside China in 2000 compared with 1970 was only 11 mmt (FAO 2003). Second, the share of aquaculture worldwide, including China, is projected to increase from 31 to 41 percent in 2020. While China's share of food fish production from aquaculture increases from 58 to 66 percent, the production share from aquaculture for other developing countries increases from 17 to 27 percent, a larger relative change. The share of aquaculture increases worldwide but especially in the developing countries—and not just in China. Third, the share of low-value fish in total food fish is remarkably stable, at about 48 percent. Although the production share of low-value food fish from wild fisheries declines, the production share of

Table 4.5 Total projected production of food fish under various scenarios, 2020

		Projected production, 2020 (million metric tons)					
Region	Actual 1997	Most likely (baseline)	Faster aqua-culture expansion	Lower China produc-tion	Fishmeal and fish oil efficiency	Slower aqua-culture expansion	Ecolo-gical collapse
China	33.3	53.1	61.7	45.7	53.3	46.1	47.7
Southeast Asia	12.6	17.5	19.5	17.5	17.6	16.2	13.5
India	4.8	8.0	9.8	8.0	8.0	6.7	6.8
Other South Asia	2.1	3.0	3.5	3.0	3.0	2.6	2.5
Latin America	6.4	8.8	9.4	8.8	8.9	8.5	6.1
West Asia and North Africa	2.2	2.8	2.9	2.8	2.8	2.7	2.1
Sub-Saharan Africa	3.7	6.0	6.0	6.0	6.1	6.0	3.0
United States	4.4	4.9	5.1	4.9	4.9	4.8	4.2
Japan	5.2	5.2	5.1	5.2	5.2	5.2	4.8
European Union 15	5.9	6.7	7.0	6.7	6.8	6.5	6.0
Eastern Europe and former Soviet Union	4.9	5.0	5.0	5.0	5.0	5.1	4.2
Other developed countries	4.8	5.8	6.1	5.8	5.8	5.5	4.7
Developing world	68.0	102.5	116.2	95.1	103.0	92.0	84.3
Developing world excluding China	34.6	49.4	54.5	49.4	49.7	45.9	36.6
Developed world	25.2	27.6	28.3	27.6	27.8	27.1	23.9
World	93.2	130.1	144.5	122.7	130.8	119.1	108.2

Sources: Actual data were calculated by authors from FAO 2002a; projections for 2020 are from IFPRI's IMPACT model (July 2002).
Note: See Table 4.1 for scenario descriptions.

low-value food fish from aquaculture rises sufficiently by 2020 to compensate for this.

Alternative Scenarios. Modeling results for total food fish production under the various scenarios are shown in Table 4.5. Assumptions about technological change or increased investment in aquaculture are shown to be crucial, with a difference of 25 mmt between the faster and slower aquaculture expansion scenarios, neither of which incorporates outlandish assumptions about the trend rate of growth. The vast majority of this difference is in low-value food fish and mollusks, which represented a combined 91 percent of aquaculture production by weight in 1997.

The scenario with a more rapid improvement in the feed conversion efficiency of fishmeal results in a 1 mmt (13 percent) decline in fishmeal production relative to the baseline, because of price effects—a significant result in terms of fishing pressure on reduction stocks. Greater efficiency of aquaculture production has a negligible effect on total food fish production but a larger relative effect on the production of high-value finfish and crustaceans (in the order of 5 percent). In the extremely pessimistic ecological collapse scenario, total food fish production surprisingly declines by only 17 percent, with greater production declines mitigated by production responses to major output price increases in both capture fisheries and aquaculture.

Aggregate and Per Capita Consumption and Net Trade

Baseline Scenario. Aggregate consumption trends largely mirror production trends in terms of composition and region of production, except that annual rates of growth of consumption in developing countries outstrip rates of growth of production by 0.2 percent per annum through 2020 (0.3 percent, excluding China), suggesting decreasing net exports of food fish from developing to developed countries. Aggregate consumption of both high- and low-value food fish is projected to continue to increase in the developing world, at 2.3 and 1.6 percent, respectively, whereas it is static in the developed world. The rates hardly change if China is removed from the calculation, suggesting that this is a widespread structural phenomenon driven by population growth, urbanization, and income growth.

Per capita consumption is projected to grow throughout the developing world under the baseline scenario, while developed-country consumption remains virtually unchanged (Table 4.6). The most rapid growth in percentage terms continues to be in China, where per capita consumption is projected to grow at an average annual rate of 1.3 percent to 2020. Mollusk and crustacean consumption per capita are projected to grow most rapidly on a global level (1.0 and 0.7 percent per annum, respectively), while per capita consumption of high-value finfish actually declines by 0.2 percent per year. Although aggregate consumption is projected to rise rapidly in Sub-Saharan Africa, this is a consequence of the region's rapid population growth rates; per capita consumption is projected to remain unchanged.

Developing countries became significant net exporters by the late 1990s (4 mmt). China, India, and Latin America are projected to continue net exports in absolute terms to 2020 under the baseline scenario (at 0.5, 0.4, and 3.0 mmt, respectively). But among developing regions, only Latin America's net exports are projected to represent a significant share of total production through 2020 (35 percent). In other developing regions, demand continues to outstrip growing supply. Whereas net exports of food fish were more than 11 percent of food fish production in developing countries, excluding China, in the late 1990s, they are projected to be less than 5 percent in 2020. Chapter 7 discusses trade projections and sensitivity analysis with regard to trade in more detail.

Table 4.6 Total per capita consumption of food fish, 1973–97 and 2020

	Total consumption (kg/capita/year)				Annual Growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	5.5	8.1	26.5	35.9	10.4	1.3
Southeast Asia	17.6	19.8	23.0	25.8	1.3	0.5
India	3.1	3.6	4.7	5.8	2.3	0.9
Other South Asia	6.2	5.4	6.0	6.1	0.9	0.1
Latin America	7.0	9.0	7.8	8.6	–1.2	0.4
West Asia and North Africa	3.4	6.2	6.2	6.4	0.0	0.2
Sub-Saharan Africa	9.0	9.2	6.7	6.6	–2.6	0.0
United States	13.5	18.5	19.7	19.7	0.5	0.0
Japan	70.2	61.5	62.6	60.2	0.2	–0.2
European Union 15	18.2	20.3	23.6	23.7	1.3	0.0
Eastern Europe and former Soviet Union	20.3	22.7	10.6	11.6	–6.1	0.4
Other developed countries	11.2	13.4	14.7	14.0	0.8	–0.2
Developing world	7.3	9.0	14.0	16.2	3.8	0.6
Developing world excluding China	8.1	9.4	9.2	9.9	–0.1	0.3
Developed world	22.6	24.3	21.7	21.5	–1.0	0.0
World	11.6	12.8	15.7	17.1	1.7	0.4

Sources: Actual data were calculated by authors from FAO 2002c; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).
Notes: Actual data are three-year averages centered on 1973, 1985, and 1997, respectively.

Alternative Scenarios. Table 4.7 illustrates the results of the different scenarios in terms of projected per capita food fish consumption in 2020. As already mentioned, the ecological collapse scenario would have the effect of cutting world capture food fish production by more than half through 2020 if price factors did not play a part. Yet projected global per capita consumption in 2020 under this scenario only declines to 14.2 kg/capita/year from the 17.1 kg/capita/year baseline level. The comparable figure from FAO (1999a) for 1997 is 15.7 kg/capita/year. Sharp price increases under this scenario are responsible for the absence of a larger per capita decline in food fish consumption because they slow the decline of production growth in capture fisheries, induce increased aquaculture output, and also reduce demand pressure.

Table 4.7 Total per capita consumption of food fish under different production scenarios, 2020

	Total consumption (kg/capita/year)						
Region	Actual 1997	Most likely (baseline)	Faster aqua-culture expansion	Lower China produc-tion	Fishmeal and fish oil efficiency	Slower aqua-culture expansion	Ecolo-gical collapse
China	26.5	35.9	41.0	30.9	36.1	32.1	30.4
Southeast Asia	23.0	25.8	28.5	25.8	26.0	23.7	21.7
India	4.7	5.8	6.5	5.8	5.9	5.3	4.8
Other South Asia	6.0	6.1	6.8	6.1	6.2	5.6	5.2
Latin America	7.8	8.6	9.4	8.6	8.7	7.9	7.3
West Asia and North Africa	6.2	6.4	7.1	6.4	6.4	5.8	5.4
Sub-Saharan Africa	6.7	6.6	7.6	6.7	6.7	5.9	5.5
United States	19.7	19.7	20.8	19.6	19.8	18.8	15.2
Japan	62.6	60.2	63.3	60.0	60.3	57.8	50.9
European Union 15	23.6	23.7	25.1	23.6	23.8	22.7	18.9
Eastern Europe and former Soviet Union	10.6	11.6	12.0	11.5	11.7	11.3	8.6
Other developed countries	14.7	14.0	14.8	13.9	14.0	13.4	10.9
Developing world	14.0	16.2	18.2	15.0	16.3	14.6	13.6
Developing world excluding China	9.2	9.9	11.1	10.0	10.0	9.1	8.3
Developed world	21.7	21.5	22.6	21.3	21.5	20.6	17.0
World	15.7	17.1	19.0	16.1	17.2	15.7	14.2

Sources: Actual data were calculated by authors from FAO 2002c; projections for 2020 are from IFPRI's IMPACT model (July 2002).
Note: See Table 4.1 for scenario descriptions.

The lower China production scenario leads to a 1 kg/capita/year decrease in global projected food fish consumption in 2020, but this mostly results from its effects on estimated Chinese consumption. Looking forward, as in the case of the historical trends discussed earlier, controversy over Chinese fish production levels matters in terms of Chinese consumption and global production trends, though it has surprisingly little effect on consumption or production outside China or on world prices for fish.

The plausible scenario with the strongest effects on outcomes is faster aquaculture expansion, which modifies IMPACT's conservative assumptions about the rates of technological change and other exogenous factors affecting aquaculture production. A 50 percent increase in the exogenous rates of change in aquaculture production—modeled primarily to be sensitive to prices, as discussed earlier—

leads to an increase in forecast per capita global consumption of food fish in 2020 of 1.9 kg/capita/year, an increase comparable to the absolute magnitude of the declines forecast under the ecological collapse scenario. Table 4.7 shows that the effect is twice as strong in developing as opposed to developed countries, although it is still significant in both. Not surprisingly, investing in technological change in aquaculture production will be critical to growing aggregate fisheries output in the future, particularly in the developing world.

CONCLUSIONS FROM THE IMPACT MODEL CONCERNING THE CHANGING LOCUS AND MODE OF WORLD FOOD FISH PRODUCTION

Based on the most likely set of assumptions—the baseline scenario—global food fish production will increase slightly faster than global population through 2020. Per capita consumption is projected to rise, and real fish prices are also expected to rise between 4 and 16 percent, depending on the commodity. Livestock product prices, on the other hand, are expected to decline in the order of 3 percent. Low-value food fish continues to account for a fairly constant share of total food fish through 2020 (48 percent), while aquaculture's share of aggregate finfish production increases from 31 to 41 percent.

Although developing countries will continue to dominate world fisheries production (79 percent of world food fish production in 2020, up from 73 percent in 1997), it should be noted that developing countries excluding China just manage to preserve their 38 percent global share of production in 2020 under the baseline scenario. China's gain in share mirrors the loss by industrialized countries, principally Eastern Europe and the former Soviet Union, the European Union, and Japan.

Global increases in consumption of food fish will predominantly take place in developing countries, where population is growing and higher incomes allow purchase of high-value fisheries items for the first time by many people. Barring unforeseen technological progress in the manufacture or use of fishmeal and fish oil, these feedstuffs will become progressively more expensive relative to plant-derived substitutes in the feeding of livestock and noncarnivorous fish. It is to be anticipated that these commodities will eventually exit from the rations of animals other than carnivorous fish, and that fishmeal prices will become progressively delinked from vegetable feed alternatives, such as soymeal.

Sensitivity analysis suggests that the key outcome for the future of fish prices, including the price of low-value food fish to poor consumers, is the successful development and extension of sustainable aquaculture. The latter will keep fish prices lower than would be the case under other production scenarios. A focus on food security in poor countries would suggest concentrating on low-value food fish aquaculture in developing countries. However, the uniform result across scenarios of rising relative prices for high-value fisheries items such as crustaceans and mollusks also suggests the importance for poverty alleviation of finding ways to keep poor fishers involved in these key sectors. Finally, several of our scenarios suggest significant increases in the relative prices of fishmeal. Aquaculture technology investments targeted to low-value fish in developing countries will help ensure that the poor continue to benefit from fisheries development.

On the whole, the projections confirm the growing importance of fisheries for food and natural resource policies in both developing and developed countries. They also show the extent to which considering the effect of relative price changes is likely to change the outlook for these issues when compared with straight-line and other simple projections. The following chapters assess the implications of the projection results for ongoing debates on environmental impacts, technology needs, fisheries trade, and food security issues in developing countries. They attempt to sharpen the focus on key relationships by highlighting existing research, rather than presenting results from field research of the type necessary to answer many of the problems posed.

Chapter 5

INTERACTIONS BETWEEN FISHERIES AND THE NATURAL ENVIRONMENT

Because of the stagnation in capture fisheries production described in Chapter 2, aquaculture has been the sole source of supply growth in the fisheries sector during the 1990s, raising hopes that the growth of aquaculture may ease pressure on threatened wild stocks. However, aquaculture is not without its own environmental problems. For example, frequent outbreaks of disease and pollution of the underlying resource base call into question the overall impact of some forms of intensive aquaculture. The most highly publicized of aquaculture's environmental impacts have occurred in the high-value sector (salmon and shrimp in particular), although low-value aquaculture makes up 70 percent of production by weight and 54 percent by value. As both high- and low-value aquaculture expand during the next two decades, pressure on the environment will inevitably intensify—often in ways that feed back into capture fisheries.

Aquaculture operations can generate considerable negative externalities—costs that affect the surrounding environment but not necessarily the aquaculture operations themselves. Aquaculture development has resulted in the disturbance of capture fisheries habitat through pollution and coastal habitat conversion. Escaped farmed fish, especially in high-value Northern aquaculture, may threaten the genetic pools of wild stocks and disrupt habitat. Demand for wild seed and broodstock to stock aquaculture ponds can place pressure on wild stocks. Most controversially, the increasing use of fishmeal and fish oil in the feeds of farm-raised fish has also raised concerns that some forms of aquaculture may in fact be harming wild fish populations rather than easing pressure on them. These concerns will become increasingly prominent as demand for fish grows over the coming years. In terms of area or number of organisms affected, however, capture fisheries still dwarf aquaculture as a source of negative environmental impacts.

CAPTURE FISHERIES IN CRISIS

The capture fisheries sector is one of the last large-scale human activities that can be classified under the rubric of "hunting and gathering." As such, almost by definition, it is fundamentally dependent on the natural environment. Clearly, a limit exists to the capacity of the world's oceans to supply wild stocks of fish, and the production plateau evidenced since the late 1980s indicates that fisheries may be approaching this limit—at least the limit under current suboptimal management regimes. With limited potential for supply growth, the health of the resource base is essential to maintaining harvest levels in the face of increasing demand. Unfortunately, fishing activities around the world have significant, large-scale negative impacts on the aquatic environment, creating both internal and external costs.

Over-exploitation

Of all the environmental impacts caused by the fisheries sector, overfishing poses by far the greatest environmental threat. Hardin's (1968) tragedy of the commons, in which rational individuals act to the detriment of society as a whole, is as applicable to the open oceans as it is to common land. Although the current regulatory environment is far from "open access," it is clear that management of the oceans is suboptimal. Wild stocks are notoriously difficult to manage for a variety of reasons, including complicated and uncertain access issues, and the fundamental difficulty of accurately assessing the state of a complicated biological resource solely through extraction data. Excess capacity, asset and labor fixity, and technological advances creating even more fishing capacity exacerbate the problem. A study by the World Bank (1998), drawing on work from the FAO (1993), reports that subsidies to the fishing sector, especially in developed countries, have played a large role in excessive investment, and therefore overcapacity and over-exploitation. During the 1970s and 1980s, fisheries harvests grew at only half the rate of fleet size.

As a result of sustained, increasing fishing pressure, most stocks of wild fish today are classified as fully exploited, and an increasing number are over-exploited, in decline, or in recovery (FAO 2000a). Few expect significant jumps in global production from wild fisheries in the future. There have been many recent examples of fishery collapses, including the decline in Northwest Atlantic groundfish stocks through the 1980s and 1990s, and the California sardine fishery collapse of the 1940s. As supply remains stagnant and the profitability of capture fisheries declines relative to other sectors, the slow pace of movement of resources out of the industry further endangers wild stocks through persisting overcapitalization.

Bycatch and Discards

Global fisheries capture, kill, and discard a massive quantity of undersized fish, fish with other undesirable characteristics, and "nontarget species." The catching of nontarget species is known as "bycatch." The majority of bycatch is kept and sold because the species caught are marketable (providing a significant contribution to the revenues of some fishing operations). With some types of fishing, such as trawling, the amount of bycatch landed (and subsequently sold) can be several times the amount of target species landed. However, much bycatch is simply discarded for economic or regulatory reasons. Global discarded bycatch of fish and of other marine organisms is currently estimated at over 20 mmt per year (FAO 2000a), wasting nearly one-quarter of the world fish catch. As nontarget species tend to be neglected by conventional assessment and management, the risk is high that they be overfished with serious consequences on their reproductive capacity as well as on the food sources of the target and other species.

Many of the fish inadvertently caught in this manner are undersized, which harms the ability of stocks to replenish themselves. The most emblematic examples of bycatch have been dolphins, seabirds, and sea turtles; however, the quantity of bycatch represented by fish may be more problematic from a biodiversity standpoint. Shrimp trawling produces the highest rate of nontarget species extraction, and accounts for approximately half the world's bycatch (Clucas 1997). Measures to increase the utilization of bycatch (as surimi or fishmeal, for example) might serve only to discourage the adoption of technologies designed to reduce bycatch levels.

Habitat Destruction

Certain activities involved in the pursuit of fish have severely detrimental consequences for the habitats of marine organisms. Coral reef ecosytems (Smith 1978) have suffered significantly from reef fishing, for both ornamentals and food fish (Johannes and Riepen 1995). Techniques such as blast fishing and poison fishing have had devastating effects on coral reefs in the Indo-Pacific and other regions. Grouper fishing, for example, often involves the use of cyanide. Even traditional methods of catching reef fish can damage coral; approximately one square meter of coral is destroyed for every grouper extracted, according to one study (Pet-Soede, Cesar, and Pet 2000). The damage to coral reef ecosystems is significant both biologically—coral reefs are extremely productive and diverse habitats—and economically. Many coastal communities heavily depend on services provided by coral reefs; such services include fish, tourism, and coastal protection (Cesar 2000). The loss of these services represents a significant cost to the poor who rely upon them.

Bottom trawling, the dragging of weighted nets across the seafloor, causes significant levels of bycatch and substantially disturbs seafloor ecosystems. The repeated, large-scale disruption of the seafloor by trawling has been likened to the terrestrial activity of clear-cutting. Bottom trawling and related activities, such as drag seining, kill organisms on and within the seafloor, remove important benthic structure-forming fauna, and thus fundamentally alter the population dynamics of the seafloor habitat. Fishing gear also damages structures on the seafloor, thus degrading habitat for a wide range of organisms. It is estimated that worldwide trawling disrupts an area as large as Congo, India, and Brazil combined (Watling and Norse 1998).

Ecosystemwide Impacts

The indirect effects of fisheries on ecosystems may also be significant. Removal of massive quantities of a species necessarily engenders wholesale changes in the food web dynamics of that ecosystem. Fisheries have caused documented ripple effects on multiple trophic levels, from seabird and marine mammal abundance on the higher end, to sea urchin and algae abundance on the lower end (Williams 1996). It is suspected that overfishing created circumstances conducive to the invasion and proliferation of an introduced species into the Black Sea, the jellyfish *Mnemiopsis leidyi,* which drastically altered that ecosystem (FAO 2000a).

Over the past few decades, the average trophic level of fish landings has declined, indicating that capture fisheries are increasingly turning to small pelagic fish that are lower on the food chain (Garcia and Newton 1997; Pauly et al. 1998). This shift away from higher trophic levels suggests that the extraction patterns of capture fisheries may not be sustainable. Meanwhile, the use of fishmeal and fish oil in the feeds for farmed fish has prompted concern that the rise of aquaculture could place even greater pressure on capture fisheries. The farmed production of some aquatic species, particularly carnivorous species such as salmon and shrimp, requires the wild harvesting of small pelagic fish as feed input (Naylor et al. 2000). This issue is becoming increasingly prominent as researchers and policymakers try to assess the role of aquaculture in world fisheries.

AQUACULTURE AND THE ENVIRONMENT

Over the past two decades, aquaculture has counterbalanced sluggish growth in production from capture fisheries. Side effects of the astonishing rise of aquaculture have spawned a number of significant environmental concerns among academics, policymakers, fisheries and environmental advocates, and related stakeholders. Much of the growth in aquaculture production has come from expansion of low-value freshwater fish culture in Asia using low-input, low-output systems. But the simultaneous rapid emergence of large-scale aquaculture using high-input, high-output production techniques has brought intensive aquaculture into the policy spotlight.

Chapter 6 looks at the issue of aquaculture intensification in detail. The relationship between intensity of aquaculture production and environmental degradation is not straightforward; intensification can have both positive and negative environmental impacts (NACA/FAO 2001). The following section presents the major environmental impacts associated with aquaculture, and raises issues that have become important in determining the long-term sustainability of aquaculture development.

Environmental Problems Associated With Aquaculture

In theory, net social costs can arise when prices of inputs and outputs do not adequately reflect their impacts on the rest of society. These negative social consequences are known as "externalities" because their costs are not transmitted to producers through appropriate price signals. For example, absent any regulations, producers do not bear the financial costs of releasing pollution into a waterway. Although the financial cost of pollution is zero to the producer, others affected by the pollution can incur significant costs. Negative externalities generated by aquaculture include effluent pollution; escaped farmed species; land and habitat disturbances; and possible ecosystem harm created by demand for wild seed, broodstock, and feed inputs. However, some environmental issues, such as disease outbreaks, directly affect aquaculture producers.

Disease. Over the past several decades, the expansion and intensification of aquaculture production has been accompanied by increased movements of live aquatic animals and aquatic animal products, including broodstock, seed, and feed. This process of expansion, along with globalization, has made the accidental spread of disease into new aquatic populations and geographic regions more likely.

Disease is a major constraint to aquaculture development, often significantly diminishing pond productivity. High stocking densities, poor water quality, and poor seed quality can lead to disease outbreaks within ponds; these can subsequently spread to other ponds through water exchange (Funge-Smith and Briggs 1998). The shrimp industry has been hit particularly hard by disease, with vast areas of ponds going out of production because of viruses like whitespot and yellowhead. One of the primary constraints to the growth of shrimp aquaculture is the threat of disease (Lotz 1997); the horizontal spread of disease from farm to farm is a major concern for the industry (Naylor et al. 2000). The disease issue has major implications for the environment because pond abandonment and land degradation are direct consequences of the spread of disease.

The further expansion and intensification of aquaculture will continue to provoke challenges arising from the emergence and recurrence of disease. Varying levels of development among countries, the transboundary nature of many disease problems, and the need to harmonize approaches all complicate effective cooperation. Without effective coordination, however, epidemics will continue to threaten the productivity of many aquaculture operations (Subasinghe, Bondad-Reantaso, and McGladdery 2001).

Impact on Other Resources. Coastal aquaculture development, especially shrimp farming, has caused the destruction of hundreds of thousands of hectares of mangrove forest over the past few decades. Land conversion of this magnitude represents a significant portion of overall mangrove loss, though aquaculture is by no means the only culprit (Menasveta 1997). Much attention has been drawn to the ecosystem services provided by mangroves, including nutrient filtration and cleansing, flood and storm protection, provision of habitat for many organisms useful to humans, and the protection of coral reefs through the trapping of sediment.

Mangroves provide nursery habitat for numerous species of fish and shellfish that are economically important to wild fisheries and artisanal fishing communities. Since mangroves also provide water filtration services, their removal has impacts on downstream fish habitats such as coral reefs. Naylor et al. (2000) estimate that over 100 kg of fish within mangrove ecosystems are lost for every hectare of mangroves converted; they further estimate that each kilogram of shrimp produced from coastal aquaculture in former mangrove forests results in a loss of over 400g of wild fish. Mangrove conversion has slowed in recent years, and some countries have banned the clearing of mangroves in certain areas. However, the profitability of aquaculture still places pressure on remaining coastal forest. Recognition of the benefits provided by ecosystem services is essential to an understanding of the real costs incurred by conversion of coastal land.

Where aquaculture is expanding, traditional land uses such as rice agriculture may come into conflict with the demand for new ponds. Conversion of agricultural land to aquaculture may not only directly reduce production of staple foods but may also impair the productivity of nearby agricultural systems through soil changes and salinization (Be, Dung, and Brennan 1999). However, the removal of rice self-sufficiency policies and the subsequent promotion of cash crops may be largely responsible for paddy conversion in many areas. Preventing disease is also important with regard to land use; if a farming operation becomes untenable through disease or other factors, the abandoned ponds are frequently unproductive for years afterward, though substitution to other cultured species is sometimes possible. In particular, the long-term effects on the hydrology of coastal areas are often severe.

Effluent and Water Demand. Effluent from aquaculture ponds and pens is often released directly into surrounding waterways, causing pollution problems stemming from fertilizer (to promote growth of phytoplankton), undigested feed, and biological waste in the water. Effluent from ponds can contribute to eutrophication of downstream waters, and waste from marine culture can harm benthic communities, though the latter effect is locally restricted. Nutrient-rich water can cause algal blooms, hypoxia, and direct toxicity to marine organisms. Chemicals and antibiotics used to treat ponds may also have negative consequences for the immediate aquatic environment (Tendencia and de la Pena 2001). Accumulation of organic material, salt, and chemicals can degrade soil quality.

Water is an increasingly scarce resource and a possible constraint to development around the world (Rosegrant, Cai, and Cline 2002). Aquaculture is finding itself in competition with other end-users and with ecosystem services for the high inputs of water that can be required for the activity. Shrimp farming in Southeast Asia has been involved with a number of water conflicts, stemming from extraction of freshwater and the resulting salinization of aquifers (Williams 1996). Pond aquaculture uses more water than most alternative agricultural production systems, though the output per unit of water input is usually higher in value for aquaculture (Boyd and Gross 2000). As aquaculture grows, the industry will need to find ways of minimizing water use so as to avoid conflicts and remain cost-effective, as is discussed in Chapter 6.

The issue of concentration and scale is also important with regard to water pollution. A growing body of literature suggests that many environmental impacts are best modeled by a threshold effect, with acute or irreversible damages occurring beyond a certain level of strain (Costanza, Norton, and Haskell 1992). This consideration implies that the location and density of farms is a significant determinant of environmental damage. With the development of large aggregations of densely situated farms, the chances increase that externalities might drive wholesale ecosystem changes.

Aquaculture's Demand for Fishmeal and Fish Oil. The use of fishmeal and fish oil in intensive aquaculture has generated much attention in recent years. Rapidly increasing demand by aquaculture for these feed inputs has led to concern that the farming of carnivorous and omnivorous fish will place pressure on the wild pelagic stocks from which fishmeal and fish oil are derived. Some assert that the farming of fish such as salmon and trout places heavy pressure on these wild species (Tuominen and Esmark 2003). Others, such as Asche and Tveteras (2000), argue that substitution away from fishmeal in terrestrial livestock production has compensated for increased demand from aquaculture, with no net effect on the price of fishmeal. However, as aquaculture grows, a greater share of demand for fishmeal and fish oil will become relatively less elastic, threatening to cause greater price volatility and, in the long run, to drive up the prices of these inputs. This issue is discussed more fully in Chapter 6.

Escaped Farmed Species. Another interface between aquaculture and wild stocks of fish comes from the escape of cultured species into the wild. For instance, escaped farmed tilapia, which thrive in disturbed habitat where native species are already at risk, have established themselves in waterways in Africa, Asia, Australia, and the United States. Aside from the risks of direct predation on native species or competition for food and habitat, escaped farmed fish may threaten the genetic pools of wild organisms through interbreeding. Studies have shown instances of escaped farmed Atlantic salmon—which number in the hundreds of thousands every year—successfully reproducing, establishing themselves in the wild, mingling with wild Atlantic salmon stocks, and even altering the genetic makeup of these stocks (Clifford, McGinnity, and Ferguson 1998). Traits bred into farmed fish are often different from those conferring reproductive fitness in the wild, and interbreeding between escaped farmed fish and wild fish may result in the loss of important local adaptations. Risk is greatest for small populations that are already threatened. By contrast, a report from the U.S. National Marine Fisheries Service (Nash 2001) argues that escapes of Atlantic salmon in the Pacific Northwest hold little or no risk to native Pacific salmon populations because they cannot interbreed and are poor competitors for resources.

Though concerns exist over the possible spread of disease from farmed populations to wild populations, the primary direction of pathogen flow is from wild stocks to farmed stocks (often through the use of wild broodstock and larvae). The magnitude of disease risk for wild fish is unclear; little is known of harm to wild stocks caused by diseases originating on farms. Salmon hatcheries in the Pacific Northwest, for instance, have similar disease problems as those found in aquaculture, and release far more fish into the wild, but adverse disease effects on wild populations are low (Nash 2001).

Concerns over escaped species are likely to intensify in coming years as aquaculture's scope increases, but particular attention will be focused on the problem as genetically modified fish are developed for aquaculture operations around the world. Although no transgenic fish have yet been approved for commercialization, both developed and developing countries have tested transgenic farmed species ranging from shellfish to freshwater fish to marine fish (FAO 2000a). In addition to the potential for harm to wild stocks that exists with other escaped farmed species, the genetic modification of organisms introduces considerable uncertainty. Simulations have demonstrated the theoretical possibility of transgenic fish introducing a "Trojan Horse" gene that entirely wipes out a native population (Muir and Howard 1999). Those involved in policy debates over introduction of transgenic aquatic species will face the difficult task of weighing the benefits conferred by commercially beneficial traits against the risks of introducing species with these traits into an ecosystem.

ESTIMATING AQUACULTURE'S PRICE-MEDIATED IMPACT ON WILD FISHERIES

Not all potential impacts of aquaculture on capture fisheries are negative, however. Aquaculture will be the most important source of supply growth in fisheries products in the future, and as such has been regarded as a possible savior for overburdened and overexploited wild stocks of fish. The extent to which this is true depends upon a large number of assumptions and uncertainties. It also is influenced by the effects of aquaculture on the prices of both food fish and reduction fish. These effects can work against each other, and the net effect is an empirical issue. The next section presents the results of modeling under a set of assumptions that—while not perfectly representative of many aspects of fisheries—frame price response issues in a reasonable manner and sets the stage for more refined global modeling.[16]

Scenario Analysis of the Impact of Aquaculture on Capture Fisheries

The additional supply of fisheries products from aquaculture could place downward pressure on food fish prices if farmed products and wild products behave as substitutes. It is possible that in the short run, greater fishing effort may be applied in response to declining fish prices because of the high fixed costs in the fishing fleet. Similarly, Copes (1970) pointed out that open access can lead to overharvesting, and hence lower catches despite higher prices. Nonetheless, it seems likely that long-run price elasticities of supply are positive (Pascoe and Mardle 1999). Lower food fish prices, other things remaining equal, are likely to reduce fishing effort in the long run and generally be favorable to the health of stocks.

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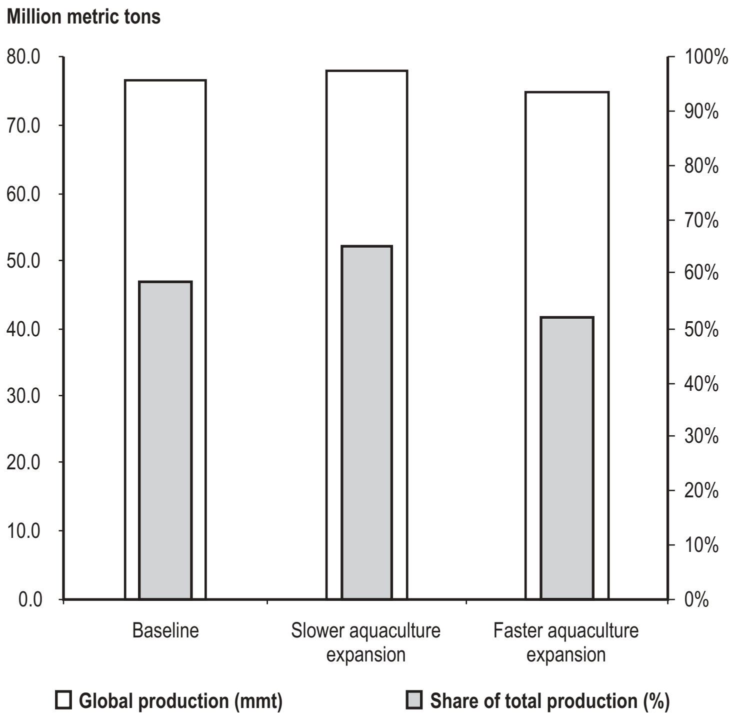
[16]An earlier version of this section was presented at the biennial meetings of the International Institute of Fisheries Economics and Trade, August 20, 2002, Wellington, New Zealand (Wada, Delgado, and Ahmed 2002).

In examining this relationship, the IMPACT model can be helpful because it permits quantitative estimates of interaction across fisheries sectors and among fisheries and other sectors. Modeling substitution across commodities both on the demand and supply sides enables examination of the possible effects of aquaculture production on capture production; further, as understanding of the dynamics of the environmental effects of aquaculture grows, the approach used here will be useful in modeling the negative environmental feedbacks between aquaculture and capture fisheries. Coming to grips with the order of magnitude of tradeoffs between these two production methods will be crucial to reasoned policymaking over the next several decades.

Figure 5.1 Projected capture fisheries production of food fish under IMPACT scenarios, 2020



Source: Projections for 2020 are from IFPRI's IMPACT model (July 2002).
Note: See Table 4.1 for scenario definitions.

Under the IMPACT baseline scenario, aquaculture production is forecast to grow at an average annual rate of 2.8 percent to 2020, nearly doubling from 1997. Capture production, by contrast, is forecast to grow much more slowly, at an average annual rate of 0.7 percent. Prices for all capture fisheries commodities for human consumption rise 4–16 percent. The sensitivity of capture fisheries production to varying degrees of growth in the aquaculture sector is illustrated through the faster and slower aquaculture scenarios, which employ exogenous growth rates that are 50 percent higher and 50 percent lower than the baseline, respectively (see Table 4.1 for scenario descriptions). The supply response induced by relatively lower prices under the faster aquaculture expansion scenario is approximately 4 percent of total global production, with China accounting for about 40 percent of this difference. Although the level of production is not an ideal proxy for effort or fishing pressure, it does give an indication of the extent to which resources flow in or out of capture fisheries in response to various factors. Figure 5.1 shows global capture food fish production under these two IMPACT scenarios as well as under the baseline scenario.

Price movements in large part determine incentives to apply fishing effort. Table 4.2 reported projected price changes for fisheries commodities under different aquaculture scenarios. Under the faster aquaculture expansion scenario, prices for fisheries commodities actually decline, as discussed in Chapter 4, while under the slow growth scenario, prices rise 19–25 percent over the projection period. By far the largest price rises occur under the ecological collapse scenario where capture fisheries production declines significantly, resulting in price increases ranging from 26–70 percent for the commodities modeled. Fishmeal and fish oil prices are 18 percent higher in 2020 than in 1997 under the baseline scenario, and approximately 50 percent higher than in 1997 under the faster aquaculture expansion scenario. The scenario with rapid efficiency improvements in the utilization of fishmeal and oil, however, results in real price declines for these commodities; feed efficiency improvement under this scenario occurs at twice the rate of the baseline scenario, diminishing aquaculture's demand for fishmeal and fish oil and causing price declines of 16 and 5 percent for these commodities, respectively.

Implications of IMPACT Scenarios for Environmental Issues

In the context of policy discussions of fisheries and aquaculture development, it is important to determine general orders of magnitude for environmental impacts. Although a significant price differential exists between the faster and slower aquaculture growth scenarios, the difference between the two scenarios in the quantity of capture production is fairly small. Because of the relatively low supply elasticities assumed for the capture fisheries sector, rapid aquaculture production growth and the resulting lower food fish prices only result in a modest reduction in

Box 5.1 Price substitutability of aquaculture and capture products

A crucial assumption made in the IMPACT model on the demand side is the equivalence of fisheries products from capture and fisheries products from aquaculture. This assumption inevitably overstates the extent to which aquaculture-derived and capture-derived products behave as substitutes.[†] The assumption of substitutability provides a favorable case for the view that increased aquaculture production will drive down capture production through price effects (Anderson 1985; Ye and Beddington 1996). Contrary findings would be accordingly strengthened by the assumption of perfect substitutability.

The assumption of equivalence between capture-derived and aquaculture-derived products in the IMPACT model is a simplification but no more so than treating all rice varieties, corn varieties, fruits, pork products, and so on, as single commodities as is done within most food models, including the present version of IMPACT. Although there are certainly real and perceived quality variations between capture- and aquaculture-derived products (and hence price differentials between the products may exist), the literature shows that the two categories do behave as substitutes (Bene, Cadren, and Lantz 2000; Clayton and Gordon 1999). Although the overall market relationship between aquaculture- and capture-derived fisheries products is more complicated than simple equivalence (Pascoe et al. 1999), it is difficult to believe, for example, that the rapid entry of farmed salmon into the market has not been the major factor in the crash of wild-caught salmon prices. It is the substitute relationship, and not the differential in prices, that is most relevant to dynamic modeling.

Price response in IMPACT is mediated through supply elasticities that are specified to be higher in aquaculture than in capture fisheries. Few empirical studies of supply elasticities in capture fisheries exist because of inherent estimation difficulties; Pascoe and Mardle (1999) show generally price-inelastic supply in North Sea fisheries. Resource and regulatory constraints limit positive production responses to higher prices; subsidies and slow movement of resources out of the capture fisheries sector in many countries indicate that price responsiveness in the other direction is likely to be fairly low as well. Consequently, supply elasticities for capture fisheries are set to be fairly low. In contrast, supply elasticities for aquaculture-derived commodities in the IMPACT model are generally more than double those for capture-derived commodities, reflecting the greater capacity for expansion and intensification of production (and, conversely, the greater ability for the sector to contract) in aquaculture. Other modeling efforts have made similar supply elasticity assumptions (Chan, Garcia, and Leung 2002).

[†] If goods X and Y behave as substitutes, consumers will increase their consumption of good X if the price of good Y increases, and vice versa.

capture fisheries production (and, most likely, fishing effort—at least in the medium term). This result is obtained even under the assumption of perfect interchangeability of products from capture and aquaculture (see Box 5.1).

Rapid aquaculture growth will, however, likely put greater pressure on reduction fisheries. A large environmental issue in aquaculture over the coming years will be the rate at which carnivorous aquaculture is able to substitute away from fishmeal and fish oil, which is explored in the discussion of technology in Chapter 6. Even in the absence of technical change, relatively elastic feed demand elasticities in the terrestrial livestock sector allow for substitution away from fishmeal to vegetable meals but not enough to keep fishmeal prices from rising (up to 50 percent higher than the baseline under the faster aquaculture growth scenario).

ENVIRONMENTAL POLICY ISSUES IN FISHERIES

Capture Fisheries

Environmental problems in capture fisheries often stem from the national or local level, where competition breeds overcapacity and overfishing (though competition also occurs among nations). This leads to the transfer of fishing effort elsewhere, either to other species or other areas, and eventually to a regional or global problem. Global management is limited by the inherent difficulty of regulating thousands of participants from different nations and socioeconomic classes who compete for the same resources under imperfect information. A global patchwork of regulatory bodies faces the daunting challenge of managing this resource base under conditions unique among food production systems in terms of the extent to which high information requirements, mobile resources (migratory fish), mobile gear, and high market uncertainty hinder effective management.

Although many of the underlying reasons for environmental problems in capture fisheries have existed for a long time, the response has changed over recent decades. Open access and its attendant resource management problems have gradually been addressed by a number of international agreements. The establishment of EEZs in the 1970s allowed individual nations increased control over waters extending 200 miles from the coast. In 1982, the United Nations Convention on the Law of the Sea further developed the notion of fisheries user rights and established frameworks for bilateral access agreements between nations. Subsequent agreements in the 1990s, including the 1995 signing of the U.N. agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, strengthened property rights and dealt with issues involving stocks that overlapped multiple international zones. In 1995, the development of the nonbinding FAO Code of Conduct for Responsible Fisheries laid out principles for sustainable governance of fisheries by member nations.

The FAO's *State of World Fisheries and Aquaculture* 2000 report points to access/user rights as the fundamental issue in fisheries management. It also highlights the need for concerted international effort to curtail illegal, unreported, and unregulated (IUU) fishing—a pervasive problem in most of the world's fisheries that threatens even the better management regimes. Since the 1990s, considerable effort has been devoted to finding solutions to the IUU fishing problem, as well as to developing indicators of fishery sustainability. This progress, however, has followed two decades during which the fleet size of the world's fisheries increased at twice the rate of growth in catches (Williams 1996). Subsidies and overcapitalization remain a major problem, as does the recalcitrance of employment in the sector. Long-term solutions to overfishing will have to involve programs enabling fisheries workers to successfully move into other sectors of the economy.

Aquaculture

In the sphere of agriculture, solutions to environmental problems almost always require a combination of policy change and new technology. The relative weight of these elements depends greatly on the governmental infrastructure in the countries involved. Similarly, in aquaculture, strict policy solutions to environmental problems may not be as feasible in less developed countries as they are in more developed ones. Effective zoning regulations, bans on certain forms of development, and regulation of production standards can only be accomplished in tandem with requisite governmental capacity and political will—often difficult for developing countries in the face of the large short-term benefits offered by rapid aquaculture development.

Indeed, improved technology may prove to be a necessary component in ameliorating some of the environmental concerns associated with aquaculture in developing countries. Progress in breeding and hatchery technology holds the potential to reduce disease problems in shrimp farms, for example. The development of replacements for fishmeal and fish oil in compound aquafeeds would significantly reduce the pressure placed on wild pelagic stocks. Genetic improvement of farmed freshwater species such as tilapia could, if undertaken with sensitivity to environmental and socioeconomic context, assist the development of sustainable aquaculture (Dey and Gupta 2000). Effective and coordinated extension of best management practices, including use of affordable existing technology from developed countries, would go a long way toward enhancing the sustainability of aquaculture in developing countries.

The potential impact of technology does not, however, address some of the deeper causes of environmental problems in aquaculture, which result from producer responses to incentives. High-value aquaculture offers the potential to rapidly increase income to levels far greater than those allowed by previous uses of the land. Indeed, many problems arise when a relatively short-term perspective promising immediate profits overwhelms the long-term cost of unsustainable techniques. This high implicit discount rate apparently employed by many aquaculturists in developing countries is a natural consequence of poverty interacting with a lucrative industry. The strong short-term incentives offered by aquaculture, combined with a lack of access to information and technology, can lead to management decisions that place little emphasis on long-term sustainability. Governments may exacerbate the problem through lack of effective regulation. This situation has consequences for the willingness of lenders to supply capital to what is perceived as a risky industry. The future growth of aquaculture will depend in part on whether the industry demonstrates an ability to manage long-term risk effectively.

Governments and lending agencies can promote environmental sustainability in aquaculture by creating an economic context in which long-term planning is rewarded. Loans with longer repayment schedules, for example, may reduce the incentives to pursue unsustainably high levels of farming intensity to repay large short-term loans. Lending agencies can require that funded aquaculture development projects meet certain environmental criteria, or follow best management practices. If subsidies to land or capital mask the full costs of aquaculture development in an effort to generate foreign exchange, the environment may suffer as a result of this social cost-benefit miscalculation. Ultimately, little can substitute for credibly enforced environmental regulations, but developing countries seldom have the political or financial resources to follow this route effectively.

Domestic zoning regulations are the only appropriate and realistic means of ensuring that ponds are sited in appropriate locations. Such regulations may range from input or system specifications to outright bans. Thailand, for example, has zoning laws regulating the construction of inland shrimp farms, while Ecuador has placed strong restrictions on mangrove conversion. Zoning may also serve to limit the number and density of operations in sensitive areas. Ideally, integrated coastal zone management plans should serve as the framework for decisionmaking with respect to coastal aquaculture development. In the absence of an established environmental regulatory framework in many developing countries, pressure from nongovernmental organizations has proved to be an important factor in the controversy over land conversion and mangrove destruction.

Creating international standards for aquaculture and the environment is made difficult by the wide diversity of countries and farming systems engaged in aquaculture. Nonetheless, significant efforts have been made in the past decade to create an internationally applicable framework for decisionmaking in the aquaculture sector. The aforementioned 1995 Code of Conduct for Responsible Fisheries, in addition to dealing with capture fisheries, also provided a set of principles intended to guide nations in the development of responsible aquaculture policies. The FAO and organizations such as the Network of Aquaculture Centers in Asia-Pacific (NACA) have developed technical recommendations and held regional workshops addressing environmental issues associated with aquaculture. In 2000, the FAO and NACA organized a major conference on aquaculture development, giving rise to the Bangkok Declaration and Strategy (NACA/FAO 2000). This document encourages states and the industry to adopt a number of measures for improving the environmental impact of aquaculture, including environmental sustainability indicators, integrated coastal management, institution-building, regional cooperation, and stakeholder participation.

Indeed, decisionmaking in the realm of aquaculture development should involve a wide range of issues and stakeholders so as to reduce the chances of producing detrimental outcomes and externalities for traditionally disenfranchised groups such as artisanal fishers. By refraining from treating aquaculture as a hermetically sealed activity, governments and lending agencies can encourage the adoption of best management practices that improve the overall fit of aquaculture within its environment. Ultimately, only this wider perspective can ensure the sustainable growth of aquaculture.

Chapter 6

IMPLICATIONS FOR FISHERIES TECHNOLOGY NEEDS AND PROSPECTS

As demand for fisheries products grows over the next several years, technology will play a crucial role in the ability of supply to keep pace. As a consequence of the heavy exploitation of capture fisheries discussed in previous chapters, increased rates of extraction are undesirable from a global perspective. Rather, technologies are needed that confer the ability to better manage existing stocks in capture fisheries while minimizing waste and improving the value of products through processing and handling. It may be difficult, however, to implement technologies in the capture sector that have a positive impact on the environment without lowering the quantity of landings, at least in the short term.

By contrast, the aquaculture sector has the potential to help meet rising demand. Aquaculture will require technology that allows for large sustainable increases in production if this is to be the case (NACA/FAO 2001). Without an emphasis on minimizing environmental impacts, the potential for aquaculture to significantly boost its long-term contribution to world fish supplies will be diminished. Technology will be especially important in this regard in developing countries, where the regulatory approach is less effective than in developed countries. One of the most critical roles for technology will be in mediating the interaction between capture fisheries and aquaculture through its effects on the use of fishmeal and fish oil in feeds for farmed fish.

REDUCING AQUACULTURE'S RELIANCE ON CAPTURE FISHERIES FOR FEED INPUTS

Nearly one-third of the world's wild-caught fish is not consumed directly by humans, but rather is consumed indirectly as a feed ingredient for farm-raised animals such as chickens, pigs, and other fish. The wild-caught fish that are reduced to fishmeal and fish oil each year amount to approximately 4–5 kg (live weight) for every person on the planet. Although fish destined for reduction to meal and oil are generally undesirable for human consumption (New and Wijkstrom 2002), the practice of feeding fish to fish has raised questions about aquaculture's negative impact on wild fish stocks.[17]

In recent years, aquaculture has grown at an explosive rate, and aquaculture has commanded an increasing share of fishmeal and fish oil use. With the continued growth in production of aquatic organisms with relatively strong feed requirements for fishmeal, this share will only continue to grow, increasing the likelihood that aquaculture will influence fishmeal and fish oil prices. This possibility has caused some concern among those who fear that higher fishmeal and oil demand will lead to greater fishing pressure on stocks of reduction fish (Naylor et al. 2000).

Trends in Use of Fishmeal and Fish Oil

Overall Importance of Fishmeal Use. Fishmeal is created from the cooking, pressing, drying, and milling of wild-caught pelagic fish; fish oil is largely a by-product of this process. A remarkably large share of global capture fisheries production is used to produce these feed ingredients. About 80 percent of wild-caught pelagic fish are reduced to meal and oil (Durand 1998). The quantity of landed fish from capture fisheries destined for reduction into meals and oils grew up to about 1990, but growth has stalled since then. This quantity has been variable, fluctuating from a low of 15.6 mmt in 1973 to a high of 30.5 mmt in 1994. In 1999, it was reported that 26.5 mmt or 28.5 percent of the total fish and shellfish catch was used for reduction (FAO 2001b). However, this figure only refers to whole fish destined for reduction and so excludes other fish scraps and processing wastes. Industry estimates for the quantity of fish reduced into meals and oils are therefore higher, at around 30 mmt (Barlow 2000).

Roughly two-thirds of all fishmeal production comes from fisheries that are specifically equipped and integrated with production chains to produce fishmeal (New and Wijkstrom 2002). Small pelagic fish species form the bulk of capture fisheries landings destined for reduction, with anchovies (Family *Engraulidae*) forming 46 percent; and herring, pilchards, sprats, sardines, and menhaden (Family *Clupeidae*) forming 40 percent of estimated landings for reduction in 1999 (FAO 2000a).

Fishmeal species are typically not used as food; very low-value fish and bycatch have been used on an industrial scale for fishmeal. Yields of fishmeal and

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[17]An earlier version of this section was presented at the biennial meetings of the International Institute of Fisheries Economics and Trade, August 20, 2002, Wellington, New Zealand (Wada, Delgado, and Tacon 2002).

fish oil from wild fish vary according to species, season (depending on the nutrient composition and moisture content of the reduction fish species), and the fish processing method employed. Typically, processing yields 20–22 percent fishmeal and 4–5 percent fish oil by weight. Fishmeal production grew from the 1970s to the 1980s, following the collapse of the Peruvian anchoveta stock in 1972–73, but has remained near 6–7 mmt since the mid-1980s. Fish oil production has remained slightly above 1 mmt during this period.

Approximately 90 percent of fishmeal is destined for indirect human consumption through farmed poultry, pigs, carnivorous aquatic species, and noncarnivorous aquatic species. Available data and specialized studies suggest that aquaculture's share of fishmeal demand has been rising rapidly since the early 1980s (Table 6.1). In 1984, aquaculture represented 8 percent of world fishmeal consumption (New and Wijkstrom 2002). Barlow and Pike (2001) estimate that in 1988, aquaculture used 10 percent of the world's fishmeal as opposed to poultry's 60 percent. In 1994, aquaculture used an estimated 17 percent of the world's fishmeal, with poultry feeds using 55 percent and pig feeds using 20 percent (Pike 1997). By 2000, it is estimated that aquaculture consumed 35 percent of the world's fishmeal compared with 24 percent for poultry and 29 percent for pigs (Barlow and Pike 2001).

Fish oil has nonfood and direct human consumption uses. As in the case of fishmeal, aquaculture has become an increasingly large end-user. As seen in Table 6.2, aquaculture's share was 16 percent in 1988, and this share grew to an estimated 54 percent by 2000 (Barlow and Pike 2001). The increasing farmed production of high-value carnivorous species such as salmon has led to increased use of fish oil within aquafeeds, as fish oil provides essential omega-3 fatty acids that are currently unavailable elsewhere.[18]

Table 6.1 Estimated shares of fishmeal use by sector

	Share of total use (percent)			
Sector	1984	1988	1994	2000
Aquaculture	8	10	17	35
Poultry	n.a.	60	55	24
Pigs	n.a.	20	20	29
Other	n.a.	10	8	12

Sources: Data for 1984 are from New and Wijkstrom 2002; data for 1988 and 2000 are from Barlow and Pike 2001; and data for 1994 are from Pike 1997.
Note: n.a. indicates that data are not available.

[18]Biotechnology opens the possibility of putting these nutrients in vegetable sources.

Table 6.2 Estimated shares of fish oil use by sector

	Share of total use (percent)	
Sector	**1988**	**2000**
Aquaculture	16	54
Human consumption	76	34
Industrial/pharmaceutical	8	12

Source: Barlow and Pike 2001.

Geographic Concentrations of Fishmeal Production and Use, and Resultant Trade Flows. A large share of fishmeal production comes from the harvest by Peru and Chile of just one species of fish, the Peruvian anchoveta (*Engraulis ringens*). The harvest of this fish is extremely variable because of population fluctuations induced by warm modes of the El Niño-Southern Oscillation (ENSO), commonly known as El Niño (Pauly and Tsukayama 1987). El Niño warming events, which reduce upwelling along the Peruvian coast that provides nutrients for the anchoveta, are linked to catastrophic declines in the fishery.

Since 1976, the combined share of Peru and Chile in world fishmeal production has averaged 34 percent, from a low of 13 percent in 1977 to a peak of 54 percent in 1994 (FAO 2002a). China has become the next largest fishmeal producer in recent years, with an 11 percent share of global production in 1999. Denmark, Iceland, Japan, Norway, Thailand, and the United States together accounted for 31 percent of global production in 1999. Japan's production of fishmeal dropped significantly during the 1990s as a consequence of the rapid decline of the pilchard fishery, a decline that may be the result of natural environmental variability (FAO 1997a). The patterns of fish oil production are similar, with Peru and Chile usually commanding over 50 percent of production, though China is much less important in fish oil production than it is in fishmeal production.

China is by far the largest consumer of fishmeal, rising from relatively low levels in the 1980s to over 25 percent of total consumption in 1997, though it consumes only small amounts of fish oil. With the exceptions of Chile and Peru (and Thailand in the case of fishmeal), the countries with high levels of both fishmeal and oil consumption are in the developed world, reflecting the intensive production of livestock and carnivorous aquaculture in these countries. As a consequence of these production and consumption patterns, net trade in both fishmeal and fish oil flows from the developing to the developed world (Table 6.3). Overall global fishmeal exports have doubled since the mid-1970s and recently totaled about half of production. In 1999, as in most years, the largest exporters of fishmeal were those who led production. However, the amount of fishmeal and fish oil available for export has been steadily decreasing within exporting countries (including

Table 6.3 Net exports of fishmeal and fish oil, 1997

	Net exports (thousand metric tons)	
Region	**Fishmeal**	**Fish oil**
China	–1,031	–13
Southeast Asia	–270	–7
India	–9	0
Other South Asia	–4	0
Latin America	2,312	175
West Asia and North Africa	–157	3
Sub-Saharan Africa	31	3
United States	33	80
Japan	–372	–59
European Union 15	–443	–145
Eastern Europe and former Soviet Union	–144	0
Other developed countries	67	–29
Developing world	859	154
Developing world excluding China	1,890	167
Developed world	–859	–154

Source: Calculated by authors from FAO 2002a.
Notes: Data are three-year averages centered on 1997. Negative values indicate net imports.

Chile, Japan, Norway, and Thailand) that also have rapidly growing domestic aquaculture sectors and consequently increasing domestic fishmeal and fish oil demands. China led fishmeal importers by a large margin, though Germany and Japan are also large importers. As with fishmeal, about half of fish oil production is traded across international borders. Latin America (primarily Chile and Peru) is the largest source of fish oil exports.

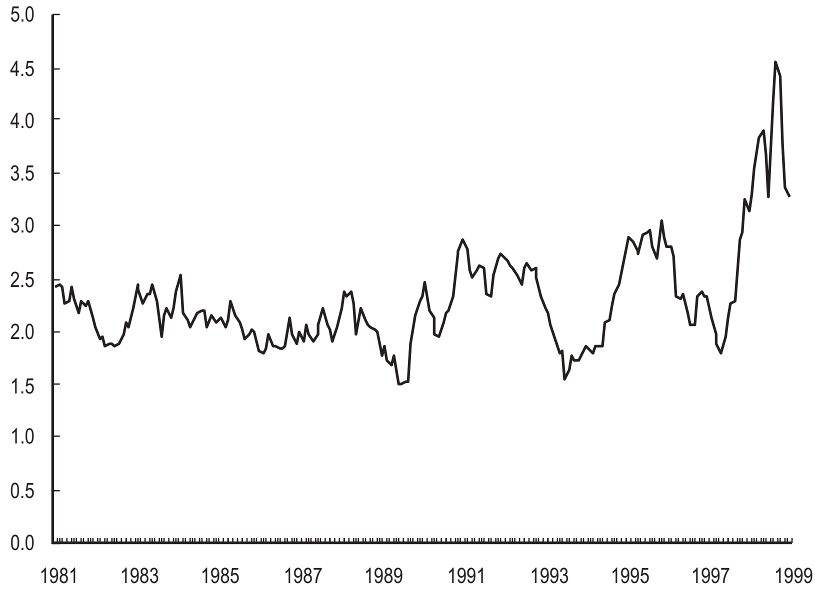
Trends in Global Fishmeal Prices and Price Volatility. Fishmeal is not traded on a centralized market or a futures market; transactions between buyers and sellers are generally private, sometimes on a forward contract basis (Durand 1998). Because of the general unsuitability of reduction fish for human consumption, it is likely that markets for fishmeal and for low-value food fish are separate (New and Wijkstrom 2002); there is no evidence in the literature of broad price linkages between the two sectors.

Asche and Tveteras (2000) and others (Durand 1998) have shown that fishmeal and soymeal (another high-protein feed ingredient) behave as substitutes, with their relative prices historically stable. Soymeal is the primary substitute for fishmeal in animal feeds (Vukina and Anderson 1993); the price ratio of fishmeal to soymeal has stayed near 2:1 for the past three decades, despite fluctuations in prices. The differential between fishmeal and soymeal prices is partly the result of fishmeal's higher protein content (Durand 1998).

The market for soymeal is over 10 times larger than the fishmeal market; annual soymeal production has grown 4 times faster than annual fishmeal production over the past decade. The growing size disparity between the industries has likely muted any soymeal price response to the fishmeal production shocks that occur quasi-periodically as a consequence of climatic variability.

The Peruvian anchoveta fishery, which represented over one-third of the total estimated landings destined for reduction in 1999, faces heavy fishing pressure aggravated by extreme volatility because of environmental conditions. Landings over the past 40 years have ranged from a high of 13 mmt in 1970 to under 0.1 mmt following the 1982–83 El Niño. The combination of El Niño events and fishing pressure has been blamed for past anchoveta declines. Furthermore, high prices can create the perverse incentive to increase fishing effort when anchoveta are scarce, although the generally poor stock management in the fishery has improved somewhat during the past decade (Asche and Tveteras 2000).

Figure 6.1 Ratio of fishmeal price to soymeal price, 1981–99



Sources: Fishmeal prices are from OilWorld 1999. Soymeal prices are from Commodity Research Bureau, various years, through December 1997 and from USDA/FAS 1999 thereafter.

Notes: Fishmeal prices are c.i.f. Hamburg. Soymeal prices are 44 percent protein at Decatur, Illinois, from January 1981 to September 1984; and 48 percent protein at Decatur, Illinois, from October 1984 to January 1999.

Drastic declines in the catch of the Peruvian anchoveta have been associated with temporary fishmeal price increases. Substitution by poultry and pork producers into soymeal and other vegetable meals has likely buffered these shocks, keeping the price ratio stable over time. The most recent El Niño event, however, coincided with a significant perturbation in the ratio of fishmeal prices to soymeal prices. Figure 6.1 shows this price ratio from 1980 to 1999; the ratio had stayed near 2:1 but soared to 4:1 in September 1998.

Factors Underlying the Demand for Fishmeal and Fish Oil

Nutritional Properties of Fishmeal and Fish Oil. Fishmeal has a number of favorable nutritional properties for the growth and survival of farmed pigs, poultry, fish, and crustaceans. Fishmeal is a dense source of high-quality animal protein with a well-balanced essential amino acid profile. It is also a good source of digestible energy, minerals, trace elements, and vitamins. Importantly, fishmeal provides omega-3 fatty acids that monogastric animals such as poultry and pigs cannot synthesize. Lysine, methionine, and cysteine levels are all higher in fishmeal than in vegetable protein meals (Lim, Klesius, and Dominy 1998). Fishmeal competes with a broader range of other feedstuffs when used strictly as a supplier of vitamins, minerals, and energy.

Omega-3 fatty acids are particularly rich within fish oils, and therefore play an important role in immune function and health in fish. Fish oil is at present the only commercially available and utilizable source of highly unsaturated fatty acids required for carnivorous fish species.

In general, regular fishmeals (about 60 percent of total global fishmeal production) are used as dietary protein sources for poultry, pigs, and omnivorous farmed aquatic species such as carp, tilapia, and catfish. By contrast, the higher-quality[19] and higher-priced fishmeals are used primarily by carnivorous finfish and crustacean farming systems. The amount of fishmeal included in diets of farmed species differs among farming systems, depending on the market value of the farmed species and ingredient availability and cost. Typically, however, carnivorous fish (such as salmon) in intensive aquaculture systems consume aquafeeds containing 30–70 percent fishmeal, while omnivorous fish (such as carp and tilapia) may in some cases consume up to 25 percent fishmeal, though lower inclusion levels are more common (Tacon 2001). Marine shrimp, such as black tiger prawns, consume aquafeeds of 20–50 percent fishmeal. These proportions dwarf the amounts

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[19]These fishmeals are produced from rapidly processed whole fish and dried at low temperatures, enhancing nutrient composition.

contained in the feeds of terrestrial animals. Poultry and pigs, the two other leading consumers of fishmeal, consume 1–10 percent in their feeds.

Demand Characteristics for Fishmeal and Fish Oil in Aquaculture. As aquaculture expands its production over the coming years, its use of inputs derived from capture fisheries will become an increasingly important issue. The aquaculture sector as a whole consumed the equivalent of approximately 11.5 mmt of wild-caught pelagic fish in 1999. Intensive cultivation, especially of carnivorous species, requires the supply of supplementary and/or nutritionally complete, artificially compounded aquafeeds. The price and availability of fishmeal and fish oil inputs is a nontrivial issue to aquaculturists practicing intensive culture of carnivorous species; feed costs represent up to 60 percent of their total operating costs (Stickney 1994).

Richness in energy, amino acids, and fatty acids accounts for the inclusion of fishmeal and fish oil in many aquafeeds, especially those destined for carnivorous species such as salmon and shrimp. Though these two categories represent only 13 percent by weight of all aquaculture production, they use 41 percent of the fishmeal and 47 percent of the fish oil consumed by the industry. For such farmed species, it has been suggested that aquaculture can be regarded as a means of transforming low-value species into high-value species (Guttormsen 2002). Marine fish, in general, require higher levels of omega-3 fatty acids than do freshwater fish (Sargent et al. 1995). Herbivorous and omnivorous freshwater fish are better able to process vegetable-based proteins and oils, and thus require less fishmeal and fish oil in their diets; however, even feeds for freshwater fish like carp and tilapia frequently contain fishmeal to boost growth.

Table 6.4 presents the estimated utilization of fishmeal and fish oil within compound aquafeeds for each of the major species groups in 1999. Compound aquafeeds consumed about 2.3 mmt of fishmeal and 0.6 mmt of fish oil in 1999, or the equivalent of 35 percent and 46 percent of the total global production of fishmeal and fish oil, respectively. Carnivorous finfish species consume the bulk of fishmeal and fish oil used within aquafeeds; the amount of fishmeal fed to salmon equals the amount fed to carp, tilapia, and catfish combined.

Aquaculture's Competition for Fishmeal Use with Terrestrial Livestock. The proportion of fishmeal and fish oil in feed is typically governed by dozens of considerations for balancing growth versus cost (Vondruska 1981). Different zones in a hypothetical demand curve for fishmeal in animal feed each reflect a different role in growth. Within the terrestrial livestock sector, substitution to and from fishmeal occurs in response to price changes. Estimates of the long-run price elasticity of demand for fishmeal in 1970 ranged from –0.48 to –3.0, but this was long before

Table 6.4 Use of fishmeal and fish oil in aquafeeds for various categories of fish, 1999

	Use in aquafeeds as a share of total (percent)	
Category of fish	Fishmeal	Fish oil
Salmon	21	41
Marine shrimp	20	6
Marine fish	20	19
Carp	14	11
Trout	7	16
Eels	7	3
Freshwater crustaceans	4	1
Tilapia	3	1
Catfish	2	1
Milkfish	1	1
Total usage in aquafeeds (thousand metric tons)	2,312	626
Total share of aquaculture (percent)	35	46

Sources: Tacon 2001.

aquaculture represented a significant fraction of fishmeal demand (Roemer 1970). Aquaculture's increasing share may be changing the overall price responsiveness of fishmeal demand, as is discussed in subsequent sections.

Substitution into nonfishmeal protein sources is significantly more constrained in carnivorous aquaculture than in poultry or pig farming. In times of high fishmeal and fish oil prices, many aquaculturists have little latitude in their feed composition choices. Studies have shown lower growth rates and higher mortality in several aquatic species when vegetable protein is substituted for fishmeal in varying amounts (Lim, Klesius, and Dominy 1998). Fishmeal has higher digestibility coefficients (the proportion of energy utilized by the animal) than its competitors for many carnivorous species (Allan 1998).

Although poultry is in most years still the largest end-user of fishmeal, aquaculture's share has grown considerably over recent years (Table 6.1). The growing share of aquaculture in fishmeal demand cannot be explained by the industry's growth alone. Global poultry production grew at over 5 percent per year during 1985–97, a rate slower than aquaculture's growth, but still considerable. However, the poultry sector has reduced its absolute level of consumption of fishmeal over the past decade. Technological innovations, especially the use of processed plant protein, have reduced the proportion of fishmeal in poultry feeds, though double the amount of poultry feed is now produced. Fishmeal has been reallocated to the aquaculture sector because as overall demand has grown, supply has remained roughly the same, and terrestrial livestock producers have switched to vegetable-based meals.

Increasing demand for fishmeal by the booming aquaculture sector has not been associated with a proportionate increase in the overall fishmeal demand; instead, the high price elasticity for fishmeal in the livestock sector appears to have allowed a distributional change in the end-uses of fishmeal. As aquaculture has consumed more fishmeal, the terrestrial livestock sector, which in general has greater latitude with regard to fishmeal substitutes, has consumed less. A similar situation exists with fish oil, though in this case, usage has shifted from the edible food industry to the aquaculture sector. Some project that aquaculture will become the sole consumer of the world's fish oil within the next two decades (New and Wijkstrom 2002).

Likely Increased Overall Price Inelasticity of Demand for Fishmeal and Oil in the Future. The traditional relationship between fishmeal and soymeal may be changing as a result of the rapid growth in aquaculture's share of fishmeal demand. Aquaculture's relatively inelastic demand for fishmeal could lead to an overall decreasing elasticity of demand for fishmeal, and especially for fish oil. Combined with the supply shocks from climate variability, this could be responsible for an increasing frequency of price spikes during times of shortage, such as the severe price spike that occurred during the 1997–98 El Niño event (Figure 6.1). As prices soared because of fishmeal shortages, substitution to less expensive plant-based meals occurred extensively among poultry and pig feeds but only to a limited extent in aquaculture feeds (IFOMA 1998). Consequently, aquaculture was the largest end-user of fishmeal in 1998 (IFOMA 1999), most likely for the first time ever. This compares with aquaculture's modest 8 percent share of fishmeal demand just 12 years earlier in 1986 (New and Wijkstrom 2002). More volatility can be expected, given that El Niño events occur at irregular intervals every 3 to 7 years.

Without technological change in aquaculture, its share of demand for fishmeal and fish oil is likely to continue increasing. A changing profile of fishmeal and fish oil use over time is likely to be associated with changing price responsiveness of demand. If this demand becomes less price-responsive, the price of fishmeal will become even more volatile during the large supply shocks that characterize the market. Demand from aquaculture could eventually drive prices higher and thus place pressure on wild fish populations, though effective management of wild stocks would minimize the danger of overfishing (Asche and Tveteras 2000). This concern is not confined to environmental advocates; a report from the Chilean fishing industry predicts that future growth in farmed salmon production will push fishmeal prices higher over the next few years (WorldCatch 2001). There is general concern that supply cannot keep pace with demand, and that the relative prices of these finite commodities will increase in the long term.

The Outlook for Fishmeal. The IMPACT model permits examination of future trends in fishmeal and fish oil use through endogenous determination of country group-specific use levels. The model allows for competition among sectors for feed inputs, and prices of these inputs are the consequence of numerous factors including output levels, feed efficiency, prices of substitutes, demand elasticities, and exogenous supply trends. Parameters for fishmeal and fish oil were specified using available literature, with consideration given to the nutritional factors considered above and the magnitude of parameters specified for competing inputs in the model. In general, own-price feed demand elasticities for fishmeal and fish oil use in carnivorous aquaculture were set at approximately half the corresponding values for other end-uses. Also included in the model is a technological change parameter, allowing for yearly improvements in feed conversion efficiency.

Because substitution away from fishmeal in the terrestrial livestock feed sector has compensated for increased demand from aquaculture, there is little evidence that aquaculture's growth has thus far been responsible for placing sustained, increased pressure on reduction fisheries. However, IMPACT projections suggest that real fishmeal and fish oil prices will increase by about 18 percent from 1997 to 2020 under the baseline scenario. In this scenario, production of both crustaceans and of high-value finfish from aquaculture nearly doubles by 2020, contributing to higher demand for feed inputs. Strikingly, under the faster aquaculture expansion scenario, real fishmeal and fish oil prices increase by about 50 percent by 2020. Slower growth in aquaculture results in a real price decline for fish oil, and no change in real prices for fishmeal, by 2020. The scenario of rapid technological change (doubling the rate of improvement in feed conversion efficiency) results in real price declines for both fishmeal and fish oil, and even slightly lower prices for aquaculture commodities than in the baseline (Table 6.5).

These results demonstrate the crucial role that aquaculture will play in determining demand for reduction fisheries commodities in coming decades. Most of the world's fishmeal comes from specialized fisheries (New and Wijkstrom 2002), and it appears that there is little overlap between the markets for food fish and reduction fish at present. As such, it is unlikely that fishmeal price increases would immediately result in large-scale conversion of low-value food fish to fishmeal, thus robbing food fish from the diets of the world's poor.

However, it is probable that a long-term increase in the relative price of fishmeal to low-value food fish could, at some point, cause low-value food fish to be processed into feed. This has occurred at a local level in Lake Victoria with the processing into fishmeal of *omena,* traditionally a food fish for the poor, to support the burgeoning local poultry industry (Abila and Jansen 1997). The point at which this would occur on a broad scale depends on the costs involved in switching to fishmeal production and processing systems. In any case, fishmeal price

Table 6.5 Projected real price change of fisheries commodities under various scenarios, 1997–2020

	Projected overall change (percent)			
Commodity	Most likely (baseline)	Faster aquaculture expansion	Slower aquaculture expansion	Fishmeal and oil efficiency
Low-value food fish	+6	–12	+25	+5
High-value finfish	+15	+9	+19	+14
Crustaceans	+16	+4	+26	+15
Mollusks	+4	–16	+25	+3
Fishmeal	+18	+42	–0	–16
Fish oil	+18	+50	–4	–5
Poultry meat	–2	–5	+0	–3

Sources: Projections for 2020 are from IFPRI's IMPACT model (July 2002).
Note: See Table 4.1 for scenario definitions.

increases should be worrisome both to aquaculturists, for whom feed costs are a significant proportion of operating expenses, and to those concerned with increasing pressure on the resource base.

Prospects for Replacement of Fishmeal and Fish Oil in Aquafeeds. Technology can reduce the risks of higher prices and overfishing by providing alternatives to the use of capture fishery-derived inputs. Replacement of fishmeal and fish oil in aquafeeds with nutritionally comparable feedstuffs would remove the dependence of many forms of aquaculture on wild stocks. Such replacement may also, in the long run, diminish pressure on prices of feed inputs derived from capture fisheries, as is demonstrated by the IMPACT scenarios. Fishmeal inclusion rates in aquafeeds have declined in recent years; promising results have been obtained by substituting protein-rich oilseed and grain by-product meals for fishmeal in the diets of carnivorous finfish and marine shrimp. Such vegetable-based substitutes include soybean, rapeseed, corn gluten, wheat gluten, and to a lesser extent pea and lupin meals. Other prospects for replacement include terrestrial animal by-product meals such as meat-and-bone meal, although these bring with them real and perceived risks for the spread of disease.

In fact, bans on meat-and-bone meal as the result of Bovine Spongiform Encephalopathy (BSE) fears might create additional demand for fishmeal (New and Wijkstrom 2002). On the other hand, they also create the need for credible certification of fishmeal purity in markets where importers are motivated by the precautionary principle to ensure that fishmeal has not come into contact with meat-and-bone-meal. The absence of this certification in Latin America led to a European Union ban on Peruvian fishmeal from fear of adulteration. If the price of fishmeal should rise, it is likely that such certification schemes will emerge.

The main factor limiting the replacement of fishmeal is the presence of factors within vegetable meals inhibiting nutrition for carnivorous fish species and the consequent need to minimize these anti-nutritional effects either through genetic selection of the cultivated fish species or through the use of improved feed processing techniques (Francis, Makkar, and Becker 2001). However, in addition to the productivity of the cultivated species, factors such as flavor, appearance, and nutritional content must be considered by producers when attempting to substitute vegetable products for fishmeal and fish oil. Soybeans and other crops have long been modified through breeding to produce feed ingredients with more favorable commercial qualities, both by removing anti-nutritional factors and increasing the content of desirable proteins. Increasingly, genetic modification will be used to make further changes to existing vegetable crops. The replacement of fishmeal and fish oil in feeds will certainly be targeted through a variety of means (Watanabe 2002), including transgenic improvement of nutritional factors in vegetable feeds.

The total replacement of fish oil with commercially available plant and animal oils is more problematic than the replacement of fishmeal. For many carnivorous fish species, fish oils serve as the only readily available source of essential fatty acids, and their total omission from rations would have a negative effect on the final gastronomic and nutritional properties of the flesh (Sargent and Tacon 1999). Some plant oils, including soybean, rapeseed, and linseed oils, have achieved a degree of success as fish oil replacers (depending on the species farmed). At present, the most likely avenues for the commercial production of oils rich in highly unsaturated fatty acids are micro-organisms such as the microalga *Phaeodactylum tricornulum* produced through controlled fermentation processes (Reis et al. 1996), or extraction from largely untapped fisheries resources such as krill (Farstad 1999).

RAISING PRODUCTIVITY IN AQUACULTURE

Technological development and transfer will be essential to sustainable increases in aquaculture production, especially in the developing world, where systems dominated by extensive methods of production will likely intensify (NACA/FAO 2001). Increases in production can occur through the provision of more inputs, such as compound aquafeeds. The growth of aquaculture to 2020 will undoubtedly involve the commercialization and intensification of aquaculture systems. Production growth can also be achieved through improvements in the productivity of cultivated organisms per unit of input, either through technological modifications to the inputs, or through modification of the cultivated organism itself. The latter means will be an important and controversial issue in aquaculture during the next two decades.

Selective Breeding in Aquaculture

Compared with the advances achieved in the production of terrestrial animals, breeding technology in aquaculture is in its relative infancy. Selective breeding of fish began only about 20 years ago, even though fish farming has been practiced in some regions for thousands of years (Fernando and Halwart 2000). Significant productivity increases have been achieved for a few commercial species such as salmon, trout, and tilapia. Developed countries have particularly benefited from selective breeding; at the industry level, breeding has increased the productivity of the Norwegian salmon industry by more than 60 percent and reduced the average cost of production of Atlantic salmon by 65 percent during 1985–95 (Aerni 2001). The successful cultivation and breeding of species such as bluefin tuna, a lucrative and endangered fish that up until now has only been wild-caught or grown without producing viable offspring, would be a tremendous boost to high-value aquaculture (Iioka, Kani, and Nhhala 1999).

Genetic improvement of tropical finfish is a recent phenomenon, which began with the application of selective breeding technology to Nile tilapia (*O. niloticus*) at WorldFish in the 1990s (Dey et al. 2000). Similar technology is currently being applied to a range of Asian carps under collaborative agreements between WorldFish and countries in the region. These efforts have resulted in a total of 85 percent growth increases over six generations for *O. niloticus,* and an average value of around 10 percent growth per generation for three carp species in Asia (ICLARM 2001). Selectively bred Nile tilapia outperformed the most widely farmed strains of tilapia in Asia both in terms of growth and survival rates, showing a yield improvement of 25–78 percent depending on local conditions (ICLARM 1998).

Genetic Modification and Biotechnology

Methods such as gene transfer, chromosome set manipulation, and interspecies hybridization hold tremendous potential for improving the quality and quantity of fish reared in aquaculture, though not without significant controversy and risk. Biotechnology has the potential to enhance reproduction and the early developmental success of cultured organisms, as well as to expand periods of gamete and fry availability. Improved feed conversion efficiency in genetically altered fish would reduce the amount of feed inputs and waste per unit of output, possibly placing less pressure on the environment. Genetic technology may also address consumer issues such as taste and aesthetics, and could conceivably be used to improve the reproductive success and survival of endangered aquatic species. Improved growth and survival rates of cultured fish could reduce production costs per unit of output, possibly bringing down the price of fish to consumers (Pew Initiative on Food and Biotechnology 2003).

Genes that regulate growth hormones, resistance to freezing, disease resistance, hatching, osmoregulation, behavior, and general metabolism have already been identified and transferred into aquatic species. Firms are already developing strains of genetically modified salmon for potential use in cage aquaculture. Such an approach is not confined to the developed world; China, Cuba, and India are among the developing countries that have tested and in some cases developed transgenic fish for use in aquaculture (FAO 2000a). To date, at least 10 species of fish have been modified for enhanced growth, although none of these transgenic fish has yet been approved for commercialization. They include common carp, crucian carp, channel catfish, loach, tilapia, pike, rainbow trout, Atlantic salmon, chinook salmon, and sockeye salmon (Aerni 2001).

Biotechnology in aquaculture could improve productivity in an environmentally beneficial manner, depending on the progress of regulatory and infrastructure development (Hishamunda and Subasinghe 2003). However, some analysts warn of risk in the lack of effective monitoring and regulatory mechanisms (Pew Initiative on Food and Biotechnology 2003). In the United States, regulatory power over the approval of transgenic fish is held by the Food and Drug Administration, which may not be adequately constituted to assess environmental impacts (Pew Initiative on Food and Biotechnology 2003). Concerns similar to those regarding transgenic technologies in terrestrial crops also apply to aquaculture. The possible environmental impacts of genetically modified aquatic organisms are not well-understood (see Chapter 5), and concerns exist over possible human health risks associated with transgenic fish. The documented escapes of farmed salmon and their threat to native wild populations through interbreeding and competition demonstrate that caution is necessary in considering the introduction of a new species into an ecosystem. Aquaculture cannot be perfectly contained with regard to the species under cultivation, and control of invasive species is extraordinarily difficult. The existence of a strong regulatory environment for dissemination, monitoring, and enforcement is a requirement for the responsible development of improved cultured species in both developed and developing countries (Gardiner, Lim, and John 2002). This prerequisite is lacking in much of the world, particularly in developing countries.

Finally, the successful adoption of transgenic technology in aquaculture will also depend on consumer acceptance of the new products. Consumer perceptions of environmental and food safety risks associated with genetically modified organisms will partially determine the market viability of transgenic fish.

Consumer risk perception also helps drive the adoption of regulations such as labeling and traceability laws (both of which have been applied to genetically modified food products in the European Union, for example), and may have eventual impacts on the strictness of regulatory approval processes.

TOWARD SUSTAINABLE AQUACULTURE INTENSIFICATION

As in the previous two decades, aquaculture will continue to comprise a broad spectrum of users, systems, practices, and species operating along a continuum from backyard operations to large-scale industrial systems. It is likely that economic pressures will induce the progressive intensification of aquaculture around the world to 2020. Yet optimal policies to align incentives with actions will be diverse, as will be the ways in which this intensification unfolds.

This section attempts to establish a working definition for intensification, a term often used with many implicit meanings relating to aquaculture. "Intensification" is used in the literature to refer to a wide variety of ways to increase input use, with or without technological change, and with or without growth in the quality of inputs used. Because aquaculture intensification may involve such a broad array of changes, its relationship to environmental impacts of the kind discussed in Chapter 5 is not clear-cut. Some activities related to intensification are detrimental to the environment, while others alleviate environmental damage.

Intensification: Broad Definitions and Trends

Generally speaking, intensification may be thought of as the process of producing more outputs from the same level of the limiting factor of production, usually by increasing the levels of other purchased inputs or factors of production, or by technological change, or both. Boserup (1965) had cereal crops in mind in writing her seminal work on agricultural intensification, and used the definition of increased output per unit of land area. More recently, the concept of "total factor productivity" (TFP) has been linked to the issue of intensification (see Alston, Norton, and Pardey 1995). In this framework, intensification is viewed as growth in TFP, equivalent to growth in the ratio of an index of outputs to an index of inputs. This is a useful approach in examining sources of productivity growth, such as changes in quantities of specific inputs used, changes in the composition of inputs, and technological change, but it is an abstract concept that unnecessarily obscures the issues related to intensification for present purposes.

Aquaculture intensification is taken here to mean increases in the quantity and quality of inputs or factors of production used with one unit of the limiting factor of production, be it land, labor, or embedded capital, with or without technological change of the type associated with increases in TFP. For most of the world's aquaculture, including pond finfish culture in Asia, pond area is probably the factor most limiting output growth. Intensification in practice under these circumstances may involve increasing labor input per hectare of pond surface, adding artificial feeds, improving dissolved oxygen content in water, increasing stocking density, controlling temperature, adding antibiotics or fertilizer, improving rearing or hatchery techniques, water re-circulation techniques, selective breeding of the organism under cultivation, or a number of other methods and technologies.

Although the two are sometimes used synonymously, intensity should be distinguished from stocking density, a measure of concentration of organisms per unit of surface area (or volume). Although intensive systems may in fact utilize high stocking densities, intensification encompasses a range of technologies and methods of which the degree of concentration is only one component. Most importantly for this discussion, the degree of concentration and the level of intensification may affect environmental objectives in opposing ways.

Aquaculture operations can be roughly divided into three categories, though the boundaries among them are not rigidly fixed: extensive, semi-intensive, and intensive (Hatch and Tai 1997). Extensive aquaculture includes traditional systems that use few capital inputs, often relying on natural stocking and feeding of the species under cultivation over a wide area. Semi-intensive aquaculture operations use more capital inputs, such as compound aquafeeds and water control technology. Yields from semi-intensive farms are generally higher than those from extensive farms. Finally, intensive farms employ a high level of inputs and produce a high level of outputs. Intensive farms almost always use compound feeds, use seed from hatcheries, and stock at relatively high densities. They may use such inputs as pesticides, antibiotics, aerators, and sophisticated water control technology. The output per unit area from intensive farms is high relative to extensive and semi-intensive systems.

Aquaculture has been practiced in traditional, extensive form for thousands of years in some areas. Freshwater fish culture dates back over 3,100 years in China (Guo 2000), and centuries-old techniques for raising marine organisms are still common in many regions of Asia. Traditional methods, however, have been increasingly replaced with higher-yielding systems. Over the past few decades, as aquaculture has boomed, the increased production has come not only from expanded area but also from a progressive intensification of production in many regions. For example, in Southeast Asia, shrimp has been cultivated for centuries by allowing natural stocking of low-lying impoundments, with low yields and few or no inputs. In countries such as Bangladesh, India, Indonesia, Taiwan, Thailand, and Viet Nam, semi-intensive and intensive production of shrimp now dominate production. These systems often use compound aquafeeds, hatchery-raised seed, and other capital inputs.

The degree of aquaculture intensification is typically a response to relative factor and input prices, which reflect the economic and regulatory environments facing producers. For example, extensive, low-yield systems tend to be more common when skilled labor is scarce and land is ample (Kusumastanto, Jolly, and Bailey 1998). As demand for aquaculture products grows and investment levels rise, the value of cultivated area rises relative to labor and purchased inputs, provoking substitution of the latter for the former. As a consequence, aquaculture—particularly high-value aquaculture—has intensified over time.

The Relationship Between Intensification and Environmental Impacts

Because large-scale and intensive systems use higher levels of inputs, and often generate higher levels of outputs, they can potentially generate high levels of environmental externalities. Intensive aquaculture has drawn most of the negative attention from environmental damage caused by the sector. However, intensification of aquaculture can also have positive effects on the environment (Barg and Phillips 1997). Capital-intensive production systems often allow for more control over negative impacts such as effluent pollution and the spread of disease. There may, in fact, be economies of scale in the control of environmental problems through the use of technology. Intensive systems also demand less land and water per unit of output than do extensive systems, though the profitability of intensive farming has encouraged the spread of such systems over wide areas. The demand for wild-caught seed stock can increase with higher stocking densities, but development of hatcheries and internalization of the rearing process serve to take pressure off wild stocks.

Disease. The overall risk of disease is determined by numerous factors, and, correspondingly, numerous possibilities exist for reducing this risk. Stocking at high densities tends to degrade water quality and increase stress on the organisms, thus contributing to disease risk. Controlling disease may be partially addressed by management techniques such as rotation of culture species and stocking organisms at lower densities. However, water control technology (for example, aerators and water re-circulation systems) and antibiotics, both of which are associated with intensive production, can mitigate the stress caused by high concentrations of organisms.

A major cause of disease in shrimp culture (and other forms of aquaculture) is poor seed quality. Technological advances that internalize the life cycle of farmed organisms would be of great value in minimizing disease risk and reducing reliance on wild broodstock. Although complete domestication may be several years away, much can be done to minimize disease risks in the existing production chain. Except in large vertically integrated systems, it is difficult at present for farming operations in developing countries to obtain a traceable, reliable source of disease-free postlarvae. Advances in hatchery technology and the development of infrastructure to improve control over seed stock would significantly lower the risks of intensive culture. Domestication and improved rearing techniques would not only reduce disease risk but also ease pressure on wild stocks. As aquaculture continues to expand, these developments may help to minimize impacts on the environment while simultaneously sustaining the possibility for future growth.

Effluent, Water Quality, and Water Demand. Poor water quality can result from feed wastage, lack of oxygen circulation, and exchange of polluted water with neighboring ponds. Minimizing water exchange through recirculation has the dual benefit of reducing water demand and minimizing the effluent problem for both the environment and surrounding farms (Boyd and Gross 2000). Other steps to improve water quality include calibration of the amount of applied feed so as to minimize waste, integrated systems that raise complementary organisms to reduce unwanted outputs, and capital improvements such as aerators and pumps.

Capital-intensive approaches to the effluent problem such as containment and treatment are not scale-neutral, and are probably not economically viable for the majority of the world's producers. Similarly, pond lining is a relatively expensive but effective technique to prevent water loss; less expensive water conservation measures include water re-use (as opposed to water exchange) and weed control to limit transpiration (Boyd and Gross 2000).

Potential also exists for aquaculture development in under-exploited waterbodies, such as rice paddies, irrigation canals, reservoirs, and seasonal or perennial ponds in developing countries (Fernando and Halwart 2000). Technology for such expansion need not be based on intensive commercial operations; rather, basic principles of aquaculture can be applied and adapted to local knowledge systems and different political and cultural contexts. The gathering of information on existing forms of aquaculture practiced under different conditions can aid in the successful transfer of practices from one region to another. The relatively inexpensive exploitation of existing water resources could augment incomes, help increase fish availability in domestic markets, and increase the affordability of low-value food fish in developing countries (Li 1999).

Management/Technological Strategies to Minimize Risks and Externalities. Areas of concern in achieving sustainable aquaculture development include water management, effluent control, disease control, and minimization of land use

(NACA/FAO 2001). Some technologies long employed in traditional aquaculture systems can be useful in addressing these concerns. Polyculture, in which several species of organisms are grown together (or an aquatic species is farmed in tandem with a land-based, often agricultural, system), can help to reduce both the inputs and negative outputs of a system. Integrated agro-aquaculture, often with freshwater fish such as carp and tilapia, has been shown to be a viable means of providing both cash and dietary protein to low-income farmers in Asia, Latin America, and Sub-Saharan Africa (Prein and Ahmed 2000; Hatch and Tai 1997). Freshwater fish aquaculture in China is dominated by systems that are closely integrated with farming systems, utilizing agricultural wastes as feed inputs. These farms have low resource demands and waste outputs but similarly have low yields (Gomiero et al. 1999).

Successful introduction of technological change in aquaculture depends on effective communication and extension. These constraints are particularly acute in developing countries (Jagger and Pender 2001), where institutions and infrastructure to promote dissemination of information are lacking. Nonetheless, the development and dissemination of inexpensive sustainable technologies to assist aquaculturists is crucial in light of the weak environmental regulatory environment in many developing countries. Investment in aquaculture technologies for intensive systems in developed countries may have positive spillover effects.

The *Bangkok Declaration and Strategy* (NACA/FAO 2000) outlined a framework for aquaculture development strategies that emphasize sustainable income growth and environmental responsibility. Among its recommendations are investments in research, training, and extension, especially as they pertain to the development of aquaculture systems that are managed according to best available practices and integrated with surrounding ecosystems. The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP 2001) also provides a comprehensive list of guidelines and tools to be used by planners and researchers concerned with sustainable aquaculture development.

NEEDS AND PROSPECTS IN THE CAPTURE FISHERIES SECTOR

Higher relative fish prices will provide a strong incentive to improve production and processing efficiency, but can have negative consequences for resource use by encouraging greater fishing effort. Technology can play a major positive role by reducing discarded bycatch and postharvest losses, especially because significant productivity increases are unlikely through increased catches of conventional species. Technology will also be essential in improving the quality and safety of fisheries products in the market. Ensuring sustainability in capture fisheries production will require technologies that enable a better understanding of fish stocks and their movements, and make management and monitoring tools more user-friendly. Technologies will also be needed to minimize the sources of pollution and damage to coastal fisheries from land-based activities.

Information Technology

Production from capture fisheries grew rapidly from the 1950s through the 1970s, aided in large part by the use of technologies like nylon fishing nets, hydraulic power, electronic fish-finding equipment, larger vessels, freezing, and better storage capacity. However, the world's oceans have likely neared their production ceiling under current management regimes. Technological advances that improve management methods and information are even more necessary than those that further increase capacity.

Technology can play an important role in providing better information to those charged with managing fisheries. Information about the location, size, structure, and growth potential of stocks is essential to the effective management of fisheries. Unfortunately, gathering information about fisheries resources is extremely challenging because the extent of the resources in question is generally unknown and can only be inferred with complex calculations based on years of landings or survey data. Moreover, many countries with a large fisheries sector lack the capacity to devote significant resources to scientific stock assessment. Reliable data can be difficult to obtain even in developed countries, and even about landings. Although information technologies can also improve catching efficiency, their benefits to management may well outweigh their risks in terms of overfishing.

Currently, acoustic techniques provide the best means of remotely assessing fish stocks and remotely identifying species, though long time series are needed for reliable assessment. Improvements in these techniques, along with improvements in the analysis and display of data provided by these techniques, promise to greatly add to the knowledge base within fisheries management. Developed-country investment in a new generation of fisheries research vessels and remote sensing projects would also considerably enhance the information available to stakeholders and policymakers in fisheries. Satellite-based systems have already improved the ability of vessels to track down fish (thus increasing capacity) but also have the potential to address a management need—the monitoring of fishing activity and fishing vessels themselves. Satellite technology could also aid in communication (often limited by the range of radio and telephone) and facilitate the rapid reporting of fish landings.

Finally, the traceability of seafood products will be increasingly important for consumers, who will in all likelihood wish to know more about the origins of their seafood than can currently be gleaned in most markets. Consumers may wish to have more information concerning the health of the stock (in the case of wild-caught fish), the biotechnology employed in breeding or raising the fish (in the case of aquaculture), the risks of chemical or heavy metal contamination, or the manner of postharvest handling. Greater traceability would also be useful for management purposes because it could help exclude seafood products from markets when their production fails to conform with established guidelines. Certification schemes such as that of the Marine Stewardship Council (an independent non-profit organization) provide a means for companies to recoup the extra costs of employing technology to conform to guidelines, as long as consumers are willing to pay a premium for certified products.

Capture Fisheries Management

Even if information were perfect, the problem of effective management of fisheries resources would remain. Although a growing number of international agreements involving fisheries management are in place, the industry is not managed by an international body; it is usually managed nationally. As such, access rights to fisheries are subject to considerable regional and national variation, often leading to suboptimal outcomes that place excess pressure on stocks—analogous to the "tragedy of the commons" (Hardin 1968). The reluctance of industrialized nations to deal with the difficult issue of allocation (thereby allowing wasteful competition and overcapacity) has led to progressive expansion of fleets and overfishing in expanding areas. Developing countries have the same reluctance but must also approach the problem with limited fiscal resources and management capacity. These factors have contributed to a poor management outcome in capture fisheries worldwide.

The creation of exclusive user rights, changing the nature of resource ownership by converting publicly owned and used resources into publicly owned but privately used ones, may lead to increased cooperation among user groups and their acceptance of some of the responsibilities of management (FAO 1997b). However, the notion of exclusive user rights means that some participants must be excluded from some fisheries to reduce fishing capacity. Developing countries face a special dilemma in managing their fisheries, dominated as they are by subsistence and small-scale participants (Ahmed et al. 1999). Rights-based management systems such as individual transferable quotas (ITQs) are often perceived as unfair at the state level given unequal distribution of wealth and negotiating power (Aerni 2001). Such systems may exclude part-time fisheries users, and the initial allocation of quotas may be biased toward more politically powerful stakeholders.

Transaction costs may also be considerable. Instead, decentralized forms of management drawing on stakeholder participation and collective action, such as co-management and community-based management, may be better suited in some cases to the governance of capture fisheries (Pinkerton 1989).

Successful management of the world's diverse and widely distributed capture fisheries resources will depend on coordination of technology and policy. Technology can facilitate information gathering and exchange. The application of geographic information systems (GIS) technology to fisheries management, for example, will facilitate a better and more systematic exchange of information across local, national, regional, and global levels (Caddy and Garcia 1986). A good example of the possibilities offered by technology working in tandem with regulation is vessel monitoring system (VMS) technology, which employs satellite tracking to allow onshore tracking of vessel movements, thereby enhancing the enforcement and deterrence of regulations. With limited resources available for patrolling vast areas of ocean, remote monitoring will be an extremely valuable and cost-effective management tool. VMS is already used as a regulatory tool in several countries including the United States.

Minimizing Externalities and Waste

Technology is crucial to the avoidance of externalities created by commercial fishing, such as the damage wreaked on the seafloor by trawling; though in terms of seafloor disturbances, bans on certain kinds of gear may ultimately prove to be more effective than anything else. Modifications to existing gear have, however, produced favorable results by minimizing seafloor contact (National Research Council Ocean Studies Board 2002).

Some types of gear, such as bottom trawls or certain nets, generate more bycatch than others, especially when used with excessively small-sized mesh or in nursery areas. Efforts to limit discards or bycatch of sensitive species may take the form of outright bans on technology deemed to result in excessive waste of marine resources. Often, however, modifications to existing gear may produce highly favorable outcomes. Bycatch reduction devices, or BRDs, are increasingly employed in fishing operations to lower the amount of unintended catch. BRDs may be designed to specifically exclude marine mammals, turtles, undersized fish, or other organisms.

Although they can potentially diminish the catch of target species, many BRDs (along with selective fishing methods) have proved successful in reducing bycatch while maintaining high levels of target catches. BRDs employed in Australian prawn trawls, for instance, have resulted in bycatch reductions of over 60 percent while increasing the average size of prawns caught (Broadhurst et al. 1999). Nevertheless, some target and nontarget species that pass through excluder devices do not survive (Samonte-Tan and Griffin 2001). In an industry suffering from economic hardship, new technology that minimizes unwanted bycatch while not significantly affecting target landings is essential.

Appropriate policies must complement the implementation of bycatch reduction technology. BRDs will remain unused or ineffectively used without proper policy incentives, along with training and extension. Catch quota systems often worsen discarded bycatch problems, though ITQ management systems allow for the trading of some bycatch. Surveillance and observation are also key components of any selective fishing regime, though again, developing countries usually do not have the resources to implement effective observation programs on national fleets. The U.S. National Observer Program, which is operated in partnership with the National Marine Fisheries Service and involves the placement of observers aboard fishing vessels, is the primary source of discard and bycatch data in the United States. Both fishers and conservationists can benefit from accurate data presented objectively in this manner.

THE CRUCIAL ROLE OF TECHNOLOGY IN THE OUTLOOK FOR FISHERIES

With global fish supply struggling to keep pace with demand over the next 20 years, technology will play a crucial role in determining the prices of food fish both to the poor and to developed-country consumers. In capture fisheries, information technology and waste reduction will be useful in stabilizing production; more intense exploitation is unlikely to yield significant growth on a global scale. Aquaculture has much greater potential for growth, and requires a broader array of technologies not only to increase productivity but also to deal with the attendant problems of intensification. In high-value aquaculture, the possible limiting constraints of fishmeal and fish oil can only be surmounted through feed replacements, and this need will become more important both for aquaculture and the health of reduction fish stocks as aquaculture's demand for fishmeal and fish oil increases.

Production growth in aquaculture will come from expansion of area; from increased intensity of input use, especially feed; and from technological improvements in both inputs and organisms. Breeding and biotechnology have tremendous potential to boost production, especially for species that are widely cultivated in resource-poor systems (such as carp and tilapia). The introduction of new species and new traits into ecosystems, however, must be regulated and monitored with great caution. As global aquaculture intensifies, technology's role in controlling externalities and minimizing net resource demands will become even more important.

Chapter 7

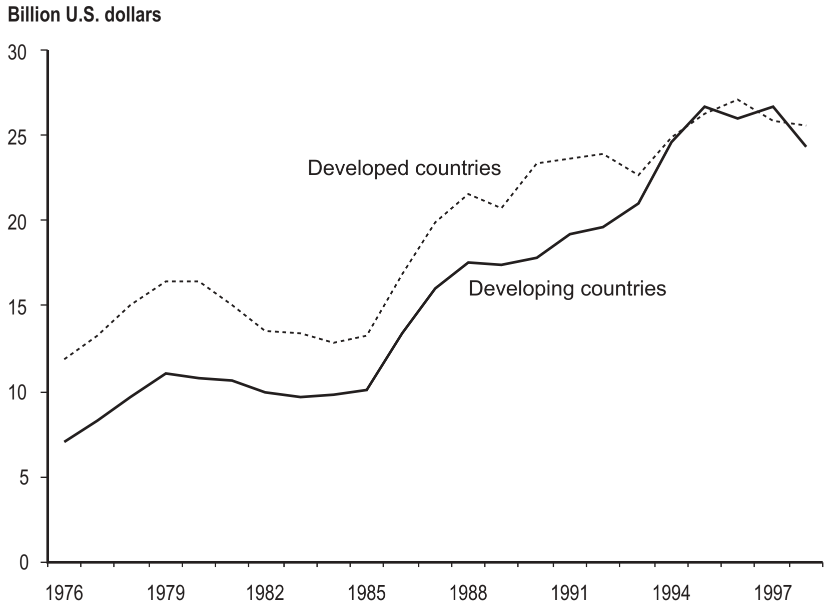
RAPIDLY GROWING FISHERIES TRADE AND ITS IMPACTS

Roughly 40 percent of global fish output by value (about 33 percent by weight) was traded across international borders in 1998 (FAO 2001b), compared with less than 10 percent for meat (Delgado et al. 1999). The high trade share of fish is astounding for such a highly perishable commodity group, and mirrors major changes in human diets around the world, changing supply conditions in both the North and South, and the ongoing globalization of high-value food chains. If fishmeal is included, more than 90 percent of fish trade is comprised of commodities that have been processed in some form. Food fish are primarily traded as fillets, cleaned and packaged frozen fish, and canned fish (FAO 2001b). By the late 1990s, almost 80 percent of all fish imports by value (including fishmeal) were accounted for by the OECD countries, whereas over 50 percent of exports originated in developing countries. About 40 percent of developing-country fisheries exports originated in low-income food deficit countries (FAO 2001b).

Global fish trade in the mid-1990s (including fishmeal) totaled well over US$50 billion (FAO 2002a), over three times the corresponding value in nominal terms in the early 1980s. By comparison, food and agricultural trade as a whole (including fish) only doubled in nominal value terms over the same period (FAO 1999b). Developing countries increased their value share in world fish exports from 40 percent in 1980–82 to 50 percent in 1995 (FAO 1999b).

During the period 1980–98, the average annual growth of fish exports in developing countries was almost 10 percent, and in 1998 the fisheries sector accounted for more than 2 percent of the total export earnings of developing countries (United Nations 2002). Net exports of fish and fish products from developing to developed countries surpassed US$16.5 billion in the year 1999 (FAO 2001b). Figures 7.1 and 7.2 show the rapid expansion of fish trade since the 1970s, in both export and import values.

Figure 7.1 The rapid rise of fish in cross-border trade: Real export value of fisheries products, 1976–98



Source: FAO 2002a.
Notes: Definitions of country groups are from the FAO. Values were deflated using the Implicit U.S. GDP deflator from the U.S. Department of Commerce.

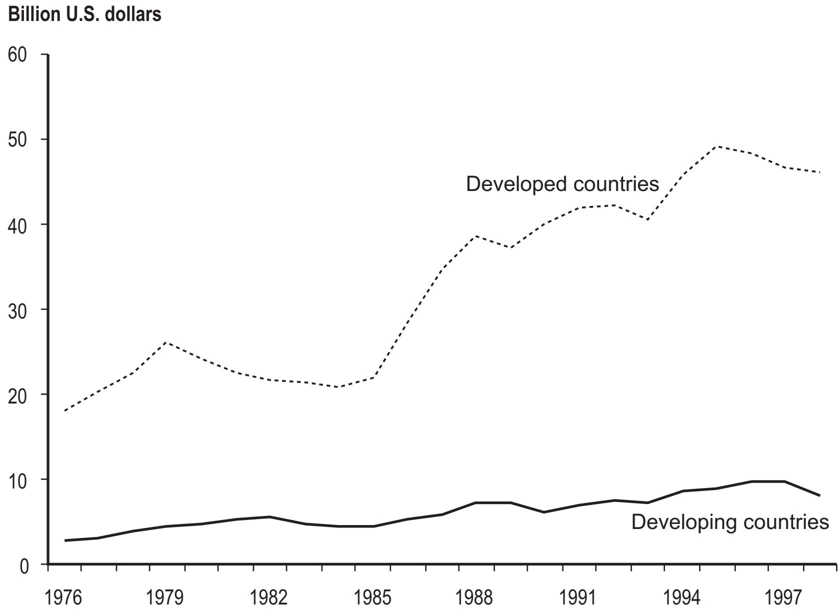
The impact of these robust trends on poverty reduction and environmental sustainability in developing countries are important issues, as is the question of whether they will continue. This chapter looks at the trends and model projections to 2020 in more detail, assessing the underlying context of trade liberalization, the impacts of these trends at both the macro (national) and micro (household) levels, and emerging barriers to the benefits of trade for both developing countries and the poor within those countries.

TRENDS AND PROJECTIONS OF NET EXPORTS TO 2020

Trends by Individual Fish Species and Country to 1998

Over time, changes in categories such as high-value finfish include changes in the composition of the basket of goods, as well as changes in the amounts of specific

Figure 7.2 The rapid rise of fish in cross-border trade: Real import value of fisheries products, 1976–98



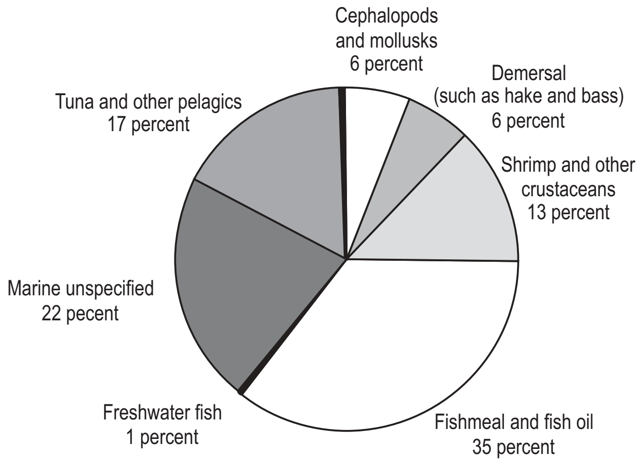
Source: FAO 2002a.
Notes: Definitions of country groups are from the FAO. Values were deflated using the Implicit U.S. GDP deflator from the U.S. Department of Commerce.

commodities consumed. Consequently, it is useful to look at past trends in the trade of specific fish species in addition to looking at changes over time in broader categories. The trends since 1977 show significant growth in trade and major increases in developing-country net exports (FAO 2002a).

The share by weight of gross major fish exports from developing countries[20] is illustrated in Figure 7.3 for 1977 and 1997. The share by weight of high-value items such as scallops, squid, and other mollusks has doubled (from 6 to 12 percent), whereas the share of fishmeal and fish oil has fallen by 8 percent of the total weight (from 35 to 27 percent). The impact of these changes is better shown in value terms (Figure 7.4). By 1997, high-value items such as mollusks, crustaceans, tuna, demersal fish (such as basses), freshwater fish (mostly white fish fillets), and

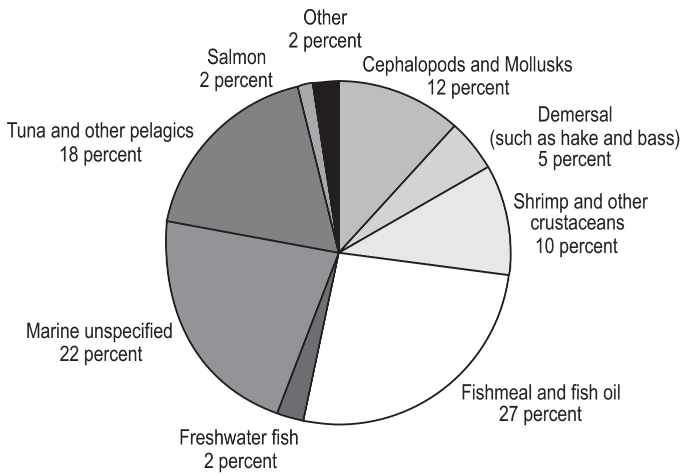
[20]This is the summation of national exports of all developing countries, including South–South trade and re-exported items.

Figure 7.3 Gross fish-export shares in developing countries by quantity, 1977 and 1997



1977

Total = 2.8 million metric tons



1997
Total = 10.4 million metric tons

Source: Calculated by authors from FAO 2002a.
Notes: Data are three-year averages centered on 1977 and 1997, respectively. Values are the sum of all national data within the IMPACT developing countries.

salmon accounted for nearly three-quarters of gross fisheries exports identified by species. A further 19 percent were only labeled as "marine, not elsewhere specified." Thus 90 percent of the gross fisheries exports of developing countries in 1997 specifically identified by species were high-value items.

Tuna is clearly one of the most important finfish in international trade, and has long been so. Trade is dominated by exports from China and Latin America, and imports to the European Union, Japan, and the United States, as shown in Table 7.1.[21] Thailand is a major developing-country producer of canned tuna, and the major markets for canned tuna are the European Union and the United States (FAO 2002a). China is the dynamic player on world markets; from the early 1970s to the mid-1980s its net tuna exports grew by half, and thereafter they grew more than threefold.

Cod is a venerable product in world food trade going back hundreds of years; it was one of the first perishables successfully exported around the world on a regular basis (Kurlansky 1997). Cod trade continues to be overwhelmingly from the North to the South, as would be expected for this species, which until recently had been a staple in parts of the North. It has become a luxury item in both the North and South over the past couple of decades (Table 7.2). This may in part explain the rise of Russia as a major cod exporter after the fall of the Soviet Union, and the new role for China as a major cod importer over the same period. The United States went from being a small net importer to being a small net exporter of cod products over this time, despite the collapse of the shared Canadian–U.S. Northeast cod fishery in the 1990s.

Salmon has become a much more important commodity in fisheries trade in recent years as a result of aquaculture. As suggested by the regional totals in Table 7.3, the big changes have been the emergence of Chile, Denmark, and Norway as major exporters, and the diminished role of the United States as a net exporter. Denmark's prominence in this regard results from its role as an internal E.U. processor of non-E.U. Norwegian salmon; the processed product is subject to much higher tariffs than the raw product in the European Union. Wild salmon catches in the United States have not declined much over the past 20 years, but the U.S. market has been inundated with farmed salmon from other parts of the world, including Chile. The European Union and Japan have emerged as major and still-growing import markets, while China was a net importer of 33,000 mt per year of salmon (processed weight) in the late 1990s.

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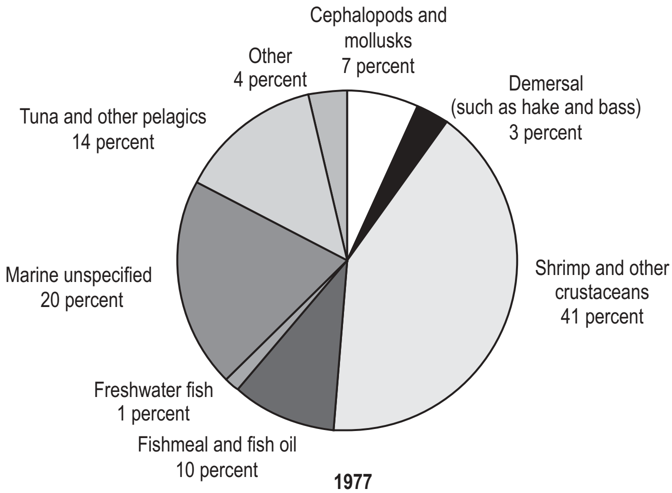
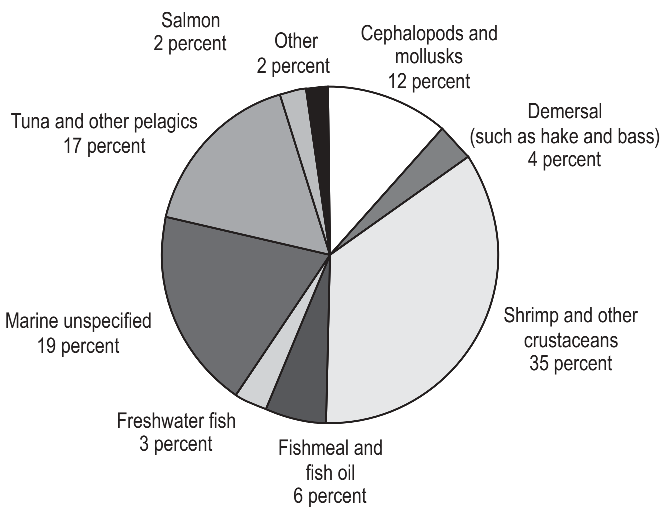
[21]Net exports for a country group are total exports from all countries in the group minus total imports into countries in the group for a given year, averaged over three-year periods for which the middle year is shown in the table. Negative net exports are net imports.

Figure 7.4 Gross fish-export shares in developing countries by value, 1977 and 1997



1977

Total = $3.6 million in nominal terms



1997

Total = $25.2 million in nominal terms

Source: Calculated by authors from FAO 2002a.
Notes: Data are three-year averages centered on 1977 and 1997, respectively. Values are the sum of all national data within the IMPACT developing countries.

Table 7.1 Net exports of tuna products, 1977–97

	Net exports (thousand metric tons in processed weight)			Net change
Region	1977	1985	1997	1985–97
China	79	123	402	279
Southeast Asia	20	42	–11	–53
India	0	0	0	0
Other South Asia	10	17	23	6
Latin America	15	98	127	29
West Asia and North Africa	1	–1	–60	–59
Sub-Saharan Africa	21	21	30	9
United States	–288	–267	–234	33
Japan	–17	–45	–308	–263
European Union 15	–76	–138	–240	–102
Eastern Europe and former Soviet Union	0	0	–6	–6
Other developed countries	–8	–15	–44	–29
Developing world	318	420	630	210
Developing world excluding China	239	297	228	–69
Developed world	–389	–465	–833	–368

Source: Calculated by authors from FAO 2002a.
Notes: Data are three-year averages centered on 1977, 1985, and 1997, respectively. Negative values indicate net imports. Tuna products are defined according to the FAO (2002a) Standard Industrial Trade Classification (SITC) categories “tuna, fresh, chilled ex. roe,” “tuna, frozen ex. roe,” and “tuna, whole or pieces, prepared, preserved.” Net exports are defined as the residual between exports and imports in a region. Global net exports do not sum to zero.

Shrimp is the principal traded fisheries commodity in value terms; it accounted for about 20 percent of world fisheries trade by value in the late 1990s (FAO 2001b). As shown by Table 7.4, it remains important in volume terms as well. The flow of trade is primarily from the developing to the developed world. The major exporters are in Southeast Asia (Thailand being the foremost world exporter), Central America, and India. The major importers are in the OECD countries; net imports of the developed world tripled by volume from the late 1970s to the late 1990s. U.S. shrimp imports currently exceed US$3 billion annually (FAO 2002a).

Freshwater fish such as Nile perch, tilapia, and catfish (including Asian varieties such as *basa*) have become significant export items from developing countries over the past 15 years, as suggested by Table 7.5, with the biggest changes occurring in Sub-Saharan Africa, where net exports have grown by 53,000 mt. Kenya, Tanzania, and Uganda have been important exporters of Nile perch fillets from Lake Victoria, and Viet Nam has rapidly expanded its *basa* exports to the U.S. markets in the past 3 years (not shown in the table).

Table 7.2 Net exports of cod products, 1977–97

Region	Net exports (thousand metric tons in processed weight)			Net change
	1977	1985	1997	1985–97
China	1	0	–249	–249
Southeast Asia	0	0	–2	–2
India	0	0	2	2
Other South Asia	0	0	0	0
Latin America	–26	–8	–21	–13
West Asia and North Africa	0	0	0	0
Sub-Saharan Africa	–12	–6	0	6
United States	–89	–28	34	62
Japan	6	–67	–26	41
European Union 15	–112	–185	–262	–77
Eastern Europe and former Soviet Union	0	0	188	188
Other developed countries	103	124	43	–81
Developing world	–35	–20	–289	–269
Developing world excluding China	–35	–20	–40	–20
Developed world	–93	–156	–23	132

Source: Calculated by authors from FAO 2002a.
Notes: Data are three-year averages centered on 1977, 1985, and 1997, respectively. Negative values indicate net imports. Cod products are defined according to the FAO (2002a) Standard Industrial Trade Classification (SITC) categories "cod, fresh, chilled ex. roe," "cod, frozen ex. roe," "cod, salted," and "cod, dried, not fillets." Net exports are defined as the residual between exports and imports in a region. Global net exports do not sum to zero.

IMPACT Commodity Groups: Historical Trends and Projections to 2020

The direction of net trade by quantity of total food fish changed dramatically from the mid-1980s to the late 1990s, as shown in Table 7.6. Developing countries as a whole went from being net importers from developed countries (over 1.2 mmt of food fish in 1985) to net exporters to developed countries (over 4 mmt in 1997). This surely must be one of the largest changes in direction of trade between developed and developing countries for any natural resource commodity.[22] The establishment of EEZs (Chapter 2) was partly responsible for this shift.

[22]A possibility of error in these tables arises through procedures used to separate biologically defined data aggregates for fish consumption into economically defined data aggregates that are consistent across production, consumption, and trade for each of the 36 country-group markets (see Appendix C). These procedures may also introduce inconsistencies with independent estimates of fish trade volumes for high- and low-value finfish (see Appendix D). FAO-calculated food balance sheets show the change in trade direction occurring earlier, though the trend and its interpretation are the same.

Table 7.3 Net exports of salmon products, 1977–97

	Net exports (thousand metric tons in processed weight)			Net change
Region	1977	1985	1997	1985–97
China	0	–1	–33	–33
Southeast Asia	0	0	–7	–7
India	0	0	0	0
Other South Asia	0	0	–1	–1
Latin America	0	1	108	107
West Asia and North Africa	0	0	–17	–17
Sub-Saharan Africa	0	0	–4	–4
United States	37	127	57	–70
Japan	–13	–107	–194	–87
European Union 15	–63	–96	–226	–130
Eastern Europe and former Soviet Union	6	4	20	15
Other developed countries	27	55	292	237
Developing world	1	–1	45	45
Developing world excluding China	1	0	78	78
Developed world	–6	–17	–52	–35

Source: Calculated by authors from FAO 2002a.

Notes: Data are three-year averages centered on 1977, 1985, and 1997. Negative values indicate net imports. Salmon products are defined according to the FAO (2002a) Standard Industrial Trade Classification (SITC) categories "salmon, frozen ex. roe," "salmon, fresh, chilled ex. roe," and "salmon, whole or pieces, prepared, preserved." Net exports are defined as the residual between exports and imports in a region. Global net exports do not sum to zero.

In absolute terms, Japan exhibited the biggest change in food fish trade over the 1985–97 period, from being one of the world's largest net exporters to being the world's largest net importer, which reflects the steep declines in Japanese catches in the 1990s. Both the European Union and the United States increased their net imports over the same period. The correspondingly large increase in net exports came from Latin America and Southeast Asia, while Sub-Saharan Africa shifted from being a major net importer to near self-sufficiency, although it is likely that a good part of this change stemmed from demand reduction.

The two rightmost columns of Table 7.6 compare the absolute aggregate change in volume of net exports from 1985 to 1997 with the change projected to 2020 under the baseline scenario described in Chapter 4. The comparison suggests a slowing and even a reversal of net export growth by developing countries. Developing countries as a whole are projected to continue as net food fish exporters in 2020 but with lower volumes than in 1997. This is driven by events in developing countries other than China, as demand for food fish is expected to

Table 7.4 Net exports of frozen shrimp products, 1977–97

	Net exports (thousand metric tons in processed weight)			Net change
Region	1977	1985	1997	1985–97
China	3	31	–14	–45
Southeast Asia	64	81	304	223
India	49	52	106	53
Other South Asia	9	35	49	14
Latin America	60	110	221	112
West Asia and North Africa	1	2	11	10
Sub-Saharan Africa	13	20	30	10
United States	–82	–140	–245	–105
Japan	–131	–189	–265	–76
European Union 15	–41	–76	–211	–136
Eastern Europe and former Soviet Union	0	0	–3	–3
Other developed countries	5	3	–21	–24
Developing world	204	338	701	363
Developing world excluding China	201	307	715	408
Developed world	–249	–401	–744	–343

Source: Calculated by authors from FAO 2002a.
Notes: Data are three-year averages centered on 1977, 1985, and 1997, respectively. Negative values indicate net imports. Frozen shrimp products are defined according to the FAO (2002a) Standard Industrial Trade Classification (SITC) category “shrimps, prawns, frozen.” Net exports are defined as the residual between exports and imports in a region. Global net exports do not sum to zero.

grow more rapidly than supply. Baseline projections indicate that world fish prices will rise; demand in developing countries will remain strong, however, because of income growth, population growth and urbanization. Similarly, the developed country groups will continue to be net importers but less so than during the 1990s.

Similar tables are presented for high- and low-value finfish used for food (Tables 7.7 and 7.8, respectively). A comparison of the two tables shows that the contribution of high- and low-value finfish to the trends discussed in the previous paragraph are quite different. Developing countries as a whole have been and are projected to remain large net importers of low-value food fish and exporters of high-value finfish. Considering developing countries without China does not significantly change this pattern. Projections indicate that China and India will become significant net exporters of low-value food fish by 2020, and India is likely to be a net importer of high-value finfish in 2020.

Crustaceans and mollusks (including squid) are other forms of high-value food fish; comparable data for their net exports are presented in Tables 7.9 and

Table 7.5 Net exports of freshwater fish products, 1977–97

	Net exports (thousand metric tons in processed weight)			Net change
Region	**1977**	**1985**	**1997**	**1985–97**
China	–31	–42	6	48
Southeast Asia	0	–1	29	30
India	0	0	1	1
Other South Asia	0	0	0	0
Latin America	0	4	–9	–12
West Asia and North Africa	0	0	1	1
Sub-Saharan Africa	1	1	54	53
United States	–20	–15	–42	–28
Japan	0	0	0	0
European Union 15	–7	–10	–45	–35
Eastern Europe and former Soviet Union	5	8	10	2
Other developed countries	8	8	5	–3
Developing world	–30	–37	83	121
Developing world excluding China	1	5	77	72
Developed world	–14	–8	–72	–64

Source: Calculated by authors from FAO 2002a.

Notes: Data are three-year averages centered on 1977, 1985, and 1997, respectively. Negative values indicate net imports. Freshwater fish products are defined according to the FAO (2002a) disaggregated trade and production data as all carp, catfish, freshwater fish, miscellaneous freshwater fish, Nile perch, perch, pike, and tilapia products. Net exports are defined as the residual between exports and imports in a region. Global net exports do not sum to zero.

7.10. The use of weight units in the table belies the high value of these items in trade compared with other fish. The net direction of trade for these categories is also from developing countries to developed countries. However, changes in net trade flows are expected through 2020. These will result primarily from rapid demand growth in some of the developing countries. China is expected to become a significant net importer of crustaceans by 2020, and Latin America and Southeast Asia are expected to increase their net exports of crustaceans. Although the conceptual framework does not specifically predict the direction of trade flows between country groups, it seems likely from these results that South–South trade will account for the majority of the trade in crustaceans in 2020.

Net exports of mollusks (including squid) from the developing to the developed world expanded rapidly in the 1980s and 1990s. Developing countries are projected to continue to be net exporters of mollusks in 2020 but at a lower annu-

Table 7.6 Total net exports of food fish, 1973–97 and 2020

	Total net exports (thousand metric tons)				Net change (thousand metric tons)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	–108	–284	181	543	465	362
Southeast Asia	–324	–145	1,131	482	1,276	–649
India	–49	–109	122	426	231	304
Other South Asia	26	–97	84	–157	181	–241
Latin America	44	480	2,435	3,047	1,955	612
West Asia and North Africa	35	–214	50	–538	264	–588
Sub-Saharan Africa	–604	–1,164	–54	–492	1,110	–438
United States	–1,153	–725	–1,106	–1,528	–381	–422
Japan	520	1,505	–3,112	–2,663	–4,617	449
European Union 15	–989	–2,141	–3,251	–2,443	–1,110	808
Eastern Europe and former Soviet Union	552	190	507	189	317	–318
Other developed countries	1,888	2,445	2,919	3,631	474	712
Developing world	–818	–1,274	4,045	2,813	5,319	–1,232
Developing world excluding China	–710	–990	3,864	2,270	4,854	–1,594
Developed world	818	1,274	–4,045	–2,813	–5,319	1,232

Sources: Actual data are calculated by authors from FAO 2002c; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).
Notes: Actual data are three-year averages centered on 1973, 1985, and 1997, respectively. Negative values indicate net imports.

al amount than at present because of increased domestic consumption within the developing countries themselves. The United States is expected to increase its net imports and Latin America its net exports, while Japan and the European Union will likely reduce their net imports significantly.

On balance, fishmeal is a net export of the developing world to the developed world (Table 7.11). China is a major net importer, and gets most of its supply from Peru—the dominant world exporter. Changes from 1997 to 2020 are expected to be of similar magnitude and direction to those from 1985 to 1997, with the exception of Japan, which went from being a net exporter of fishmeal in 1985 to being a significant net importer in 1997; the picture is likely to remain similar in 2020.

Table 7.7 Net exports of high-value finfish, 1973–97 and 2020

	Total net exports (thousand metric tons)				Net change (thousand metric tons)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	182	311	462	21	151	–441
Southeast Asia	91	315	696	594	381	–102
India	31	32	41	–286	9	–327
Other South Asia	124	37	118	6	81	–112
Latin America	424	489	1,962	2,645	1,473	683
West Asia and North Africa	47	79	184	183	105	–1
Sub-Saharan Africa	–105	–146	186	75	332	–111
United States	–1,045	–565	–901	–1,235	–336	–334
Japan	–245	–1,037	–2,073	–1,903	–1,036	170
European Union 15	–1,140	–1,231	–2,521	–2,081	–1,290	440
Eastern Europe and former Soviet Union	–122	–704	–614	–923	90	–309
Other developed countries	1,588	2,160	2,232	2,801	72	569
Developing world	964	1,377	3,877	3,341	2,500	–536
Developing world excluding China	782	1,067	3,415	3,320	2,348	–95
Developed world	–964	–1,377	–3,877	–3,341	–2,500	536

Sources: Actual data are calculated by authors from FAO 2002c; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year averages centered on 1973, 1985, and 1997, respectively. Negative values indicate net imports.

Sensitivity of Projections to Underlying Scenarios

As discussed in the methodology section of Chapter 4, the baseline model embodies a series of possibly controversial assumptions about nonprice-mediated factors likely to have a strong impact on fisheries to 2020. These are specified in advance as nonprice assumptions; the model itself focuses on price-mediated responses over time. The most uncertain of the nonprice assumptions involves the outlook for marine capture fisheries, but other major uncertainties concern the rate of technological progress in fish farming and other factors besides price that could slow down or speed up the rate of investment in both capture and aquaculture fisheries. Changes in assumptions also affect trade projections through the relative price changes they produce. The sensitivity of the net export projections to other possible scenarios (defined in Chapter 4) is presented below.

More rapid aquaculture growth increases the net food fish imports of developed countries from developing countries by 32 percent in 2020 compared with

Table 7.8 Net exports of low-value food fish, 1973–97 and 2020

	Total net exports (thousand metric tons)				Net change (thousand metric tons)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	–353	–745	–685	711	60	1,396
Southeast Asia	–546	–850	–267	–808	583	–541
India	–147	–248	–147	515	101	662
Other South Asia	–117	–179	–93	–256	86	–163
Latin America	–542	–372	–381	–908	–9	–527
West Asia and North Africa	–25	–361	–230	–795	131	–565
Sub-Saharan Africa	–516	–1,084	–313	–627	771	–314
United States	146	367	422	690	55	268
Japan	966	3,165	320	347	–2,845	27
European Union 15	324	–377	129	144	506	15
Eastern Europe and former Soviet Union	656	779	1,086	1,089	307	3
Other developed countries	268	170	376	362	206	–14
Developing world	–2,360	–4,104	–2,333	–2,633	1,771	–300
Developing world excluding China	–2,007	–3,358	–1,648	–3,344	1,710	–1,696
Developed world	2,360	4,104	2,333	2,633	–1,771	300

Sources: Actual data are calculated by authors from FAO 2002c; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year averages centered on 1973, 1985, and 1997, respectively. Negative values indicate net imports.

baseline projections; the net effects on trade in terms of total food fish (including crustaceans and mollusks) are shown in Table 7.12, while the same information for low-value food fish is contained in Table 7.13. As discussed in Chapter 4, the price impact of this scenario change is to lower world prices for low-value food fish in 2020 by 12 percent below current real levels, whereas they rise in the baseline by 6 percent over current levels (Table 4.2). Prices for high-value fish items (except mollusks) increase, but less so than under the baseline. Prices for fishmeal and fish oil shoot up three times faster than in the baseline. Food fish production (see Chapter 4) increases globally by 11 percent over the baseline result, broadly led by developing countries in percentage terms.

Net food fish imports into Sub-Saharan Africa triple under this faster aquaculture growth scenario because of the fall in the real and relative world prices of low-value fish. The matching expansion in food fish exports comes from China and India (both up by a factor of three), and lesser increases from Southeast Asia

Table 7.9 Net exports of crustaceans, 1973–97 and 2020

	Total net exports (thousand metric tons)				Net change (thousand metric tons)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	77	125	65	–570	–60	–635
Southeast Asia	116	245	534	770	289	236
India	67	93	160	120	67	–40
Other South Asia	20	45	52	87	7	35
Latin America	159	249	446	695	197	249
West Asia and North Africa	4	3	2	–11	–1	–13
Sub-Saharan Africa	17	26	57	68	31	11
United States	–187	–271	–432	–539	–161	–107
Japan	–159	–371	–712	–629	–341	83
European Union 15	–151	–293	–518	–432	–225	86
Eastern Europe and former Soviet Union	18	24	36	48	12	12
Other developed countries	7	41	252	363	211	111
Developing world	472	870	1,374	1,188	504	–186
Developing world excluding China	395	744	1,309	1,758	565	449
Developed world	–472	–870	–1,374	–1,188	–504	186

Sources: Actual data are calculated by authors from FAO 2002c; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year averages centered on 1973, 1985, and 1997, respectively. Negative values indicate net imports.

and West Asia and North Africa. The main trade-related result of this scenario is to promote production and export of low-value food fish from aquaculture in South and East Asia, and to increase fish consumption in Africa.

The net impact on world trade projections of introducing the assumptions about lower Chinese marine fish catches (the lower China production scenario) is minimal. The effects are mostly within China, and this is primarily because of the downward adjustments in Chinese consumption figures in the model scenario discussed in Chapter 4. However, relative world prices in this scenario are somewhat higher than under the baseline, mostly for crustaceans and high-value finfish, and this leads to a 6 percent overall decline in net food fish imports into developed countries from developing countries, as compared with baseline scenario projections.

More pessimistic assumptions about the rate of nonprice-induced investment in aquaculture, as in the slower aquaculture expansion scenario, have more signif-

Table 7.10 Net exports of mollusks, 1973–97 and 2020

	Total net exports (thousand metric tons)				Net change (thousand metric tons)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	–14	25	339	381	314	42
Southeast Asia	15	145	168	–74	23	–242
India	0	14	68	77	54	9
Other South Asia	0	0	7	6	7	–1
Latin America	3	115	408	615	293	207
West Asia and North Africa	10	65	94	85	29	–9
Sub-Saharan Africa	0	41	16	–8	–25	–24
United States	–67	–256	–195	–444	61	–249
Japan	–41	–252	–647	–478	–395	169
European Union 15	–22	–239	–341	–74	–102	267
Eastern Europe and former Soviet Union	–1	90	–1	–25	–91	–24
Other developed countries	25	74	59	105	–15	46
Developing world	106	583	1,127	917	544	–210
Developing world excluding China	120	558	788	536	230	–252
Developed world	–106	–583	–1,127	–917	–544	210

Sources: Actual data are calculated by authors from FAO 2002c; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).
Notes: Actual data are three-year averages centered on 1973, 1985, and 1997, respectively. Negative values indicate net imports.

icant impacts on world production and trade in food fish. (As described in Chapter 4, this scenario leads to across-the-board real price increases in the range of 20–25 percent for food fish items.) The main difference under this scenario is in low-value food fish, for which the real price increase is projected to be 25 percent rather than the 6 percent under the baseline. World food fish consumption declines 9 percent in 2020 compared with baseline projections, and well over half of the total decrease is concentrated in developing-country consumption of low-value food fish. Net imports of total food fish into developed countries from developing countries fall 5 percent relative to the baseline results, and low-value food fish exports from developed to developing countries increase somewhat.

The extreme pessimism underlying the ecological collapse scenario has real prices of high-value finfish and crustaceans rising approximately 70 percent relative to current world prices, low-value food fish prices rising 35 percent, and fishmeal and oil prices rising about 128 and 134 percent, respectively, to 2020. The effect on world food fish trade is similarly drastic, with net exports from develop-

Table 7.11 Net exports of fishmeal, 1977–97 and 2020

	Total net exports (thousand metric tons)				Net change (thousand metric tons)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	–109	–500	–1,031	–1,308	–531	–277
Southeast Asia	37	12	–270	–577	–282	–307
India	2	0	–9	–25	–9	–16
Other South Asia	15	–2	–4	–39	–2	–35
Latin America	705	1,588	2,312	2,915	724	603
West Asia and North Africa	–74	–160	–157	–241	3	–84
Sub-Saharan Africa	–4	–4	31	48	35	17
United States	–45	–134	33	51	167	18
Japan	–60	51	–372	–350	–423	22
European Union 15	–587	–651	–443	–316	208	127
Eastern Europe and former Soviet Union	–342	–379	–144	–137	235	7
Other developed countries	458	181	67	7	–114	–60
Developing world	575	931	859	746	–72	–113
Developing world excluding China	684	1,431	1,890	2,054	459	164
Developed world	–575	–931	–859	–746	72	113

Sources: Actual data are calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three–year averages centered on 1977, 1985, and 1997, respectively. Negative values indicate net imports.

ing to developed countries projected at only one-tenth the level forecast under the baseline scenario. The negative impact on food fish production is concentrated in developing countries and primarily in the high-value finfish and crustacean sectors. The ecological collapse scenario has a much higher relative impact on aggregate world food fish trade than on world food fish consumption. This is because higher prices induce increased aquaculture production, and effects are felt disproportionately at the higher-value end of the fisheries sector.

Reduction fish amount to about a quarter of all fish produced and a third of capture fisheries production. The sensitivity of fishmeal trade to different scenarios is shown in Table 7.14. Net fishmeal exports primarily originate in Chile and Peru, and Asian countries (China, Japan, and Taiwan) are dominant importers. Chinese net imports under the baseline scenario are equivalent to 17 percent of forecast world production in 2020. On the whole, developed countries are projected to be net importers of fishmeal, equivalent on a net basis to 9 percent of forecast world production. Fishmeal prices are very sensitive to the faster aquacul-

Table 7.12 Total projected net exports of food fish under various IMPACT scenarios, 2020

Region	Total projected net exports (thousand metric tons)					
	Most likely (baseline)	Faster aquaculture expansion	Lower China production	Fishmeal and fish oil efficiency	Slower aquaculture expansion	Ecological collapse
China	543	1,728	508	479	–790	3,219
Southeast Asia	482	604	460	492	533	–778
India	426	1,375	398	415	–211	553
Other South Asia	–157	22	–169	–159	–248	–191
Latin America	3,047	3,032	3,034	3,075	3,138	1,150
West Asia and North Africa	–538	–773	–552	–540	–338	–751
Sub-Saharan Africa	–492	–1,412	–532	–510	240	–2,371
United States	–1,528	–1,719	–1,479	–1,537	–1,377	–727
Japan	–2,663	–3,125	–2,641	–2,648	–2,293	–1,893
European Union 15	–2,443	–2,659	–2,398	–2,416	–2,291	–1,316
Eastern Europe and former Soviet Union	189	–25	224	185	366	633
Other developed countries	3,631	3,815	3,647	3,673	3,489	3,007
Developing world	2,813	3,712	2,646	2,745	2,108	295
Developing world excluding China	2,270	1,984	2,138	2,266	2,898	–2,924
Developed world	–2,813	–3,712	–2,646	–2,745	–2,108	–295

Source: Projections for 2020 are from IFPRI's IMPACT model (July 2002).
Note: See Table 4.1 for scenario descriptions.

ture expansion scenario (rising 42 percent) and the increased fishmeal efficiency scenario (falling 16 percent). The impact of scenario change on developing-country net fishmeal exports is in the range of a 10 percent increase if investment in aquaculture is higher than under the baseline, and a decrease of 13–14 percent under increased efficiency or ecological collapse.

IMPACTS OF FISHERIES TRADE ON DEVELOPING COUNTRIES

The analysis of past and projected trade trends for fisheries products suggests that the fisheries sector has become of critical importance to developing countries. This will remain the case over time, raising the issue of the net impacts of fisheries growth on developing countries, both at the macro level and directly on the poor. This issue is not fully resolved at the present time because comprehensive studies

Table 7.13 Projected net exports of low-value food fish under various IMPACT scenarios, 2020

	Projected net exports (thousand metric tons)					
Region	Most likely (baseline)	Faster aquaculture expansion	Lower China production	Fishmeal and fish oil efficiency	Slower aquaculture expansion	Ecological collapse
China	711	1,080	1,008	690	6	3,698
Southeast Asia	–808	–772	–900	–812	–702	–1,268
India	515	1,542	461	512	–180	877
Other South Asia	–256	–109	–278	–260	–326	–231
Latin America	–908	–1,037	–935	–904	–730	–1,216
West Asia and North Africa	–795	–1,021	–815	–800	–603	–901
Sub-Saharan Africa	–627	–1,506	–675	–641	73	–2,407
United States	690	853	686	696	563	665
Japan	347	261	340	361	421	200
European Union 15	144	41	138	154	232	–30
Eastern Europe and former Soviet Union	1,089	1,031	1,085	1,105	1,141	866
Other developed countries	362	321	359	369	397	225
Developing world	–2,633	–2,506	–2,609	–2,685	–2,753	–1,926
Developing world excluding China	–3,344	–3,586	–3,617	–3,375	–2,759	–5,624
Developed world	2,633	2,506	2,609	2,685	2,753	1,926

Source: Projections for 2020 are from IFPRI's IMPACT model (July 2002).
Note: See Table 4.1 for scenario descriptions.

of the impact of rising fisheries exports on welfare in developing countries largely remain to be done. This section pinpoints some relevant issues and examines the primarily anecdotal evidence available.

Impacts on the Balance of Payments

Over the years, developing countries (particularly in Asia) have imported starchy food staples from developed countries and exported fish in return. As mentioned above, the contribution of low-income food deficit countries to world fish exports was about 20 percent in the year 2000, and the equivalent of 50 percent of their import bill for food was paid by receipts for fish exports. Similarly, the contribution of Asian countries to world fish exports is around 32 percent, and these countries as a group earned enough foreign exchange from fish to finance 34 percent of their food imports in the year 2000 (FAO 2001b). This experience is not limited to China and India; in 1966, 12 developing countries had more than the

Table 7.14 Projected net exports of fishmeal under various IMPACT scenarios, 2020

	Projected net exports (thousand metric tons)					
Region	Most likely (baseline)	Faster aquaculture expansion	Lower China production	Fishmeal and fish oil efficiency	Slower aquaculture expansion	Ecological collapse
China	–1,308	–1,359	–1,417	–942	–1,266	–1,110
Southeast Asia	–577	–769	–568	–575	–433	–634
India	–25	–32	–25	–25	–20	–21
Other South Asia	–39	–32	–38	–40	–46	–30
Latin America	2,915	3,188	2,960	2,481	2,705	2,523
West Asia and North Africa	–241	–231	–237	–239	–251	–207
Sub-Saharan Africa	48	51	49	42	45	25
United States	51	74	57	51	31	77
Japan	–350	–311	–342	–354	–380	–218
European Union 15	–316	–355	–300	–247	–280	–312
Eastern Europe and former Soviet Union	–137	–102	–132	–144	–168	–77
Other developed countries	7	–95	19	24	89	5
Developing world	746	789	698	671	707	526
Developing world excluding China	2,054	2,148	2,115	1,613	1,973	1,636
Developed world	–746	–789	–698	–671	–707	–526

Source: Projections for 2020 are from IFPRI's IMPACT model (July 2002).
Note: See Table 4.1 for scenario descriptions.

equivalent of $30 million (1995 constant dollars) in fish exports per year. By 1997, 47 developing countries were surpassing that benchmark (FAO 2001b).

Impacts on Incomes and Employment

The adoption of both pond aquaculture and intensive commercial aquaculture has been widespread in Asia. Assessing the net impact of these developments on household incomes is complex. First, direct incremental income accrues to the households of farmers who operate a fish pond, and additional subsistence income results from consuming one's own fish, rather than having to buy it. Then, both landless laborers working in small-scale fish farming and employees of commercial establishments receive income from fisheries employment. Further, associated industries stimulated by the rise of fish farming and capture fisheries also provide incomes. Aquaculture has backward linkages to hatcheries, nurseries, seed gathering, reduction fish harvest, feed milling, and input distribution systems (Lewis, Wood, and Gregory 1996), while capture fisheries have backward linkages to boatbuilding, gear supply, and so on. Both fisheries sectors have forward linkages to postharvest handling, processing, and marketing, all of which absorb significant amounts of labor.

Finally, and probably most importantly in low-income countries in the early stages of development, aquaculture and capture fisheries give rise to consumption growth linkages that occur when incomes from production of a tradable good (such as fish) create additional income in rural areas with underemployed resources (typically labor). The net additions to income from fish sales are then largely spent as net increments to local consumer demand in rural areas with low effective demand for services and local goods that under-employed local resources can supply. In rural Africa, this increased spending by poor consumers has been shown to provide an additional increment to local income through re-spending of the initial income injection that is at least as large as the initial sales of tradable items that started the process (Delgado, Hopkins, and Kelly 1998). In other words, if fish can be produced and sold outside an isolated local area, the net income benefit to the area may be more than twice the value of the fish sales.

Evidence on the impact of fisheries on household income is anecdotal at best, relying either on estimates of the numbers of persons involved, or a few relatively small case studies. In terms of the former, the FAO has estimated that the number of fishers worldwide doubled between 1970 and 1990, compared with a 35 percent increase in the economically active farm population over the same period (FAO 1997c). Most of the growth occurred in Asia, where around 80 percent of the world's fishers and fish farmers live, according to the study. The total number of fish farmers and fishers for whom fishing was the primary income source was estimated at 28.5 million workers in 1990. If similar growth in fishing occurred in the 1990s, the comparable number for 2003 would be approximately 40 million. If allowance is made for the people employed in associated industries, or who derive significant income from the local expenditure of fishers, it does not seem farfetched to estimate that somewhere between 60 and 100 million workers derive their incomes from the fisheries sector at the present time. With dependents, it is conjectured that well over 200 million persons are thus dependent on fisheries for their livelihoods at the present time, overwhelmingly in Asia and overwhelmingly among the poor.

Even by the standards of developing countries, landless fish workers and artisanal fishermen are among the poorest of people in many cases (Kent 1998; Ahmed and Lorica 2002). Employment in capture fisheries on boats belonging to others is traditionally a refuge from unemployment in other sectors, in both developing and developed countries. Exclusion from the capture sector is therefore a particularly disturbing prospect for the poor in developing countries, who are often landless, without much formal schooling, without other potential sources of livelihood, and without the social safety nets more prevalent in richer countries. This raises the question of whether a rising aquaculture sector in developing countries can play a significant role in creating new livelihoods.

In this context, how has the rise of fish demand and trade affected household incomes in developing countries? A particularly careful case study of the issue—controlling for the various factors affecting overall household income and nutrition—was conducted in Bangladesh by Bouis (2000), investigating the impact of several schemes for promoting more intensified pond aquaculture. He found only modest overall net increases in household incomes from aquaculture activities but considerable potential for further increases with intensification. In a five-country survey of Asia in the 1990s, an external team reporting to the FAO found that rates of return over variable costs in pond aquaculture were 150 to 200 percent in the study countries (FAO 2001c). Overall additions to farm income thus depend on the opportunity costs of land and other fixed factors. Since even semi-intensive pond aquaculture is typically less labor-intensive than rice production in Asia, shifts of resources from rice cultivation into fish farming could lead to a reduction in demand for labor from landless people.

The overall picture that emerges in Asia is of a modestly profitable fish farming activity for small land-owners at low levels of intensification, uncertainty for landless laborers (whose position is shaky in any event as the relative profitability of rice farming declines), and a potentially highly profitable commercial activity for capital-intensive larger-scale operations with access to natural resources. The issue of the economic viability of sustainable intensification of small-scale, more capital-intensive, aquaculture under developing-country conditions has yet to be demonstrated or even fully examined (see Chapter 6).

Another way that the rise of fisheries trade might affect household incomes in developing countries is through increases in subsistence consumption of own-produced fish, both as a side effect of increased production and through its effect on the prices of food fish to poor consumers. Finally, trade may displace poor people from traditional fishing livelihoods if competition for natural resources drives them out of business. These possibilities are considered later in this chapter.

Impacts on Human Nutrition

Fish trade influences nutrition in developing countries by affecting income (as seen above), increasing the intake of micronutrient-rich foods and dense calories, and influencing relative fish prices, which potentially changes the diet and hence overall nutrient intake of the poor.

Fish provides high-quality, easily absorbable protein and a wide variety of vitamins and minerals, including phosphorus, magnesium, selenium, and iodine (from marine fish) (Thilsted, Roos, and Hassan 1997). Even a small amount of fish is an important dietary supplement for poor people who cannot easily afford animal protein, and who mainly rely on starch diets. According to the FAO (1997c), fish provides over 7 percent of animal protein in North and Central America, more than 9 percent in Europe, over 17 percent in Africa, 26 percent in Asia, and 22 percent in low-income food deficit countries, including China.

Humans extract higher amounts of minerals by weight from small fish compared with meat and large fish because the bones of small fish are easily consumable (Thilsted, Roos, and Hassan 1997). Thus, the traditional practice in much of Asia of the consumption of whole small fish is especially important to people with nutrient deficiencies. Surveys conducted in Bangladesh suggest that small fish continue to contribute larger portions of vitamin A, calcium, iron, and zinc to the diets of the rural poor than big fish (Thilsted, Roos, and Hassan 1997).

Bouis (2000), in evaluating the impact of small pond fish farming on nutrient intakes in Bangladesh, found that households adopting improved technologies for fish farming consumed the same weight of fish as previously—but in larger fish, leading to possible nutrient loss. More strikingly, Bouis found that for given income levels, fish farming households did not consume more fish than their non-fish farming counterparts but rather purchased half to two-thirds of the fish they consumed. The Bangladesh case suggests that the impact of fish trade on the prices of small fish is likely to be the key to its impact on the nutrition of the poor. Low-value fish has traditionally accounted for a disproportionately high share of the low amount of animal protein consumption by the poor in developing countries (Kent 1998).

Impacts on the Price of Fish to Poor Consumers

In his study zone in the late 1990s, Bouis (2000) reported that real fish prices had at least doubled over the previous 25 years, and the relative price to meat and vegetables had increased 50 to 75 percent. The export unit values and price series discussed in Chapter 3 suggest that on world markets, fish has become more expensive relative to other food items over the past 30 years, if only because real fish prices have not fallen, while the price of meat is half what is was in the early 1970s.

Firm prices for most fish items cannot be "blamed" on trade alone; both fish prices and trade are responding to fish demand outstripping fish supply. This demand is growing primarily in the developing countries themselves, as shown historically in Chapter 3 and in future projections to 2020. Nonetheless, it seems at least possible that the increasing globalization of fisheries and the rise of high-end fish exports (like shrimp) from poor countries is raising the price of low-value food fish beyond what it would otherwise be, through resource substitutions in production. Under increasingly interlinked world markets, this will tend to happen regardless of whether a given country or region is heavily involved in export production, because domestic prices will increasingly reflect regional and global prices. Furthermore, within developing countries, it seems reasonable to believe that rising urban demand by wealthier people will divert some local food fish production away from consumption by the poor, through rising relative fish prices.

As argued in Chapter 6, the rise of high-value aquaculture will probably not reduce the supply of food fish for the poor by 2020, both because of substitution out of fishmeal in terrestrial livestock and because of the separate fisheries involved in low-value food fish and reduction fish. Nonetheless, the huge real price increases for fishmeal and fish oil projected to 2020 under the faster aquaculture expansion scenario make it conceivable that fishmeal and fish oil prices could rise sufficiently for entrepreneurs to begin processing the food fish of the poor into fishmeal. In fact, anecdotal evidence suggests this has already occurred in some artisanal fisheries such as the *omena* fishery in Lake Victoria (Abila and Jansen 1997). The rising cost of low-value food fish to the poor in the present, and the potential for further relative rises in the future, are real policy concerns.

Impacts on Resource Use and Sustainability

It is likely that the combination of high incentives for production, a weak regulatory environment, and the meteoric rise of aquaculture in developing countries have created conditions ripe for environmental degradation of the type discussed in Chapter 5. Lucrative trade markets for high-value commodities such as shrimp have induced large-scale aquaculture development along coastlines in Latin America and Southeast Asia, often with severe environmental impacts. In addition, public health issues have arisen from the use of polluting chemicals and the concentration of toxic agents in fish from intensive aquaculture operations (FAO 2002d). Public health issues surrounding fish consumption have direct impacts on trade, in that exporting countries will increasingly have to meet consumer demands for food safety in importing countries.

Ultimately, these conditions will have to be dealt with through legislative and administrative processes in the developing countries themselves. This has begun to happen in India and Thailand, as constituencies that benefit from fisheries trade have joined with other interest groups to help ensure the sustainability of aquaculture development. In the shorter term, rising market premiums for seafood products in Europe and Japan that are certifiable as having been sustainably produced may create incentives for changing behavior in the commercial fisheries sector. A case in point is the demonstrated desire of many fish processors and retailers in developed countries to have Marine Stewardship Council certification for their seafood products shipped from all over the world (Roheim 2002). Although support for eco-labeling has been strong in the maritime industries, it has neither been universal nor unconditional. Furthermore, some producers from developing countries have taken the position that eco-labeling in the OECD countries will discriminate against producers from developing countries, where the costs of certification are seen as too steep for any one association to bear. Other concerns in the commercial sector have arisen from rising retentions at the borders of rich importing countries on health grounds—because of chloraphenicol residues in shrimp, for example (WorldCatch 2002)—causing losses in developing countries. Together, these concerns are providing incentives for developing countries to enforce health and environmental regulations, and possibly also to rein in small-scale producers, as is discussed below.

RISING BARRIERS TO EXPORTS FROM DEVELOPING COUNTRIES

The relevance of this issue in the context of this book is to consider whether the rapid rise in fish trade from the South to the North is likely to continue. The primary reason for projecting decreasing net exports of fish from developing to developed countries is that the swelling ranks of the middle class in developing countries will increasingly wish to consume local high-value fisheries items themselves. Nonetheless, other rapidly occurring factors are also affecting fish imports into developed-country markets and could be an increasing issue for developing-country exporters. Even as trade liberalization in the sense of tariff reduction has occurred, nontariff barriers of various sorts have arisen. The net effect of the latter—as is discussed later in this chapter—may be more to displace traditional small-scale fishers in developing countries than to block developing-country exports.

Tariffs in Developed and Developing Countries and Tariff Escalation

The General Agreement on Tariffs and Trade (GATT) era under the Uruguay round of trade negotiations culminated in the launch of the World Trade Organization in late 1994 and the signing of the associated Sanitary and Phyto-Sanitary Agreements (SPS) early in 1995, just as world trade in fish was reaching its highest point to date. Two significant events with respect to fisheries were the commitment to reduce fish tariffs and the attempt to subject health-justified restrictions on trade to a predictable set of rules. In fact, tariffs on primary fish commodities have declined significantly in developed countries and have decreased even in the developing countries of Asia, where they were previously much higher than in developed countries (Tables 7.15 and 7.16).

Table 7.15 Reductions in average tariffs for fisheries imports in selected Asian countries

	Share of c.i.f. value (percent)			
Country	Tariff before WTO		Tariff after WTO	
China	1991	47	2001	11–23
Thailand	1995	60	1999	5–30
Philippines	1994	10–60	2000	3–15
India	1993–94	60	2002–03	35
Bangladesh	1991–92	59	2000–01	28

Source: Dey et al. 2002.

Table 7.16 Tariff escalation for some developed-country fisheries imports

	Share of border values c.i.f. (percent)			
	European Union		Japan	
Product	Conventional	General System of Preferences	Most Favored Nation	General System of Preferences
Skipjack				
Fresh	22	0	3.5	3.5
Canned	24	0	9.6	6.4
Mackerel				
Fresh Indian	20	0	0	0
Canned/processed Indian	25	0	9.6	7.2
Scallops				
Fresh	8	2.8	10	7.2
Processed	20	7	9.6	7.2
Crabs/lobsters				
Fresh/live	10	8.2	7	7
Processed	20	7	6.7	6.7

Source: Dey et al. 2002.

While average tariff levels have declined, it should be noted both that most fish trade is in processed products of some sort, and that developed countries generally maintain higher tariff rates on processed fish commodities than on chilled fresh fish—a case of “tariff escalation” shown in Table 7.16. Yet even the tariff rates for processed products are fairly low (compared with meat out of quota, for example), and it is not plausible that tariffs are or will be a major constraint on the growth of fish exports from developing countries. Nontariff barriers are another matter.

Technical, Sanitary, and Other Nontariff Barriers to Trade

Concerns in electorates about food safety and environmental sustainability have provoked major fish importing countries to introduce institutional innovations for controlling trade in fisheries items, including SPS measures; better process-based procedures for ensuring food safety, such as Hazard Analysis and Critical Control Points (HACCP) plans; and labeling requirements. On one hand, these measures are legitimate responses to the concerns of electorates, but on the other, many believe them to be protective. In any event, they are expected to become more stringent in the future.

Concerns about heavy metals and other contaminants in ocean-caught fish have been rising. California recently required supermarkets to post warnings that small children and women of child-bearing age should not eat swordfish, shark, king mackerel, and tilefish (Fiorillo 2003). The primary concern is mercury, but cadmium, arsenic, thallium, zinc, and polychlorinated biphenyls (PCBs) from industrial waste are also worrisome, as is rainfall bearing pollutants from industrial smoke emissions. Heavy metals and chemical residues tend to collect over time in the oily tissues of large predators. Worried consumers are found in developing countries as well as in the North. A research team from the Chinese University of Hong Kong linked high blood levels of mercury from high seafood consumption to infertility in 150 Hong Kong couples (BBC News 2002). A recent study in Thailand found that 6 out of 10 samples of shark's fin examined had concentrations of mercury above the limit for safe human consumption (BBC News 2002).

As in the case of wild fish, heavy metals and PCBs can also affect farmed salmon through fishmeal derived from waters subject to heavy metal pollution, such as off the Arctic coast of Russia (The Globe and Mail 2002). Other human health concerns associated with aquaculture include residues from use of proscribed antibiotics, such as chloramphenicol. This has been a concern in the North for shrimp imports from developing countries, particularly China. The European Union's Standing Veterinary Committee banned imports of seafood from China during part of 2002 following discovery of the banned substance in samples and in Chinese processing plants. The United States and Canada subsequently lowered their tolerance levels to the E.U. standard following similar concerns (IntraFish Media 2003).

The issue of chloramphenicol illustrates the tension between legitimate health concerns in regulating fisheries imports, and the desire of some parties to invoke health regulations to limit imports for commercial reasons. In the United States in 2002, the primary impetus for tougher chloramphenicol regulation of shrimp imports came from the Southern Association of State Departments of Agriculture, primarily composed of states with important shrimp production interests. Meanwhile, a Dutch scientific study conducted by Dr. J. C. Hanekamp concluded that most people would have to consume 40 kg of shrimp daily for a lifetime to run a risk of contracting cancer from the chloramphenicol residues typically found in Asian shrimp (McGovern 2002).

Enforcement of SPS measures—whether clearly warranted or controversial—is naturally a problem for developing-country exporters. The European Union imposed a ban on imports of fish from Tanzania and Uganda in 1999, and on shrimp from Bangladesh in 1997. These bans (which typically range from several months to over one year in duration) can have massive effects in terms of foreign exchange revenues, disruption of investment, and losses of employment. In Tanzania and Uganda, for example, the importance of Nile perch exports had grown considerably from the 1980s to the 1990s; the value of freshwater fish exports from Tanzania alone had grown from under US$1 million in 1987 to over US$51 million in 1997 (World Bank 2000). Fish exports dropped by almost 50 percent during the ban. Uganda's loss was US$37 million during the ban, while Tanzania lost about US$63 million. About 30 percent of export fish workers lost their jobs in both countries as a result of this ban (Calzadilla-Sarmiento 2002). Cato and dos Santos (2000) estimated the cost to Bangladesh as a US$65 million loss of revenue, although US$50 million could be offset from increased sales in other markets. The study also estimated that about one million people were affected either directly or indirectly through backward and forward linkages associated with the shrimp export sector.

Responding to the concerns of consumers and governments in importing countries with regard to microbial and chemical contamination of traded fish food, the Codex Alimentarius Commission (CAC) recommended adoption of HACCP as a tool for food safety management in 1993. Although the CAC has no formal enforcement mechanism for its recommendations through international law, it has been endorsed by the 1995 agreements of the WTO on SPS and Technical Barriers to Trade (TBT) (Thomas and Meyer 1997). National governments have also adopted CAC recommendations in their national policies, as in the case of the United States. In practice, therefore, exporting countries are forced to comply with HACCP norms and other CAC recommendations. As discussed below, there are cost implications to compliance that are justified by the value of the trade it permits, but that create economies of scale in exporting countries that could work to exclude the small-scale sectors in those countries.

Three significant sets of international codes of practice, agreements, and technical guidelines have been promoted to provide a degree of standardization for the protocols used to minimize the risks of diseases associated with movements of aquatic animals. These include: (a) the *Office International des Epizooties* (OIE) International Aquatic Animal Health Code and Diagnostic Manual for Aquatic Animal Diseases (OIE 2000a, 2000b), (b) the International Council for the

Exploration of the Sea (ICES) Code of Practice on the Introduction and Transfer of Marine Organisms (ICES 1995), and (c) the European Inland Fisheries Advisory Commission (EIFAC) (Turner 1988). While compliance by developing-country exporters to these standards has been mixed in the past, fisheries trade to Europe and the United States is becoming more difficult in cases where compliance cannot be demonstrated. Both compliance and improved mechanisms for the certification of compliance are soon likely to emerge as a consequence.

Besides health issues, there are other nontechnical barriers to fish trade, such as countervailing duties, anti-dumping legislation, and property rights over market names. Some of these respond to concerns of political constituencies in the importing countries, such as eco-labeling or the certification of non-use of child labor. Some are more clearly motivated by commercial concerns, such as actions by U.S. producers of farmed catfish to prevent Vietnamese *basa* from being sold as catfish in the United States. Others may arise from the administrative complexity of certifying country of origin when traceability is an issue. One recent estimate in the U.S. Federal Register estimates the net cost of implementation—due in 2003—of the new U.S. country-of-origin label law to be $2 billion (USDA 2002). It seems unlikely that all of this amount will be borne by U.S. consumers; some of it will undoubtedly be borne by developing-country exporters in the form of reduced demand for their products.

The Impact of OECD and Chinese Producer Subsidies on Fish Trade

As in the rest of agriculture, fish trade is also affected by the very large production subsidies paid by developed countries. The difference with the rest of agriculture is that China is a member of the developed-country club in this respect. A comprehensive report on the topic by Milazzo (World Bank 1998) shows that the OECD countries plus China account for three-quarters of production subsidies to fisheries, primarily in the marine capture sector. Total production support levels for fish in these countries amount to 30 to 35 percent of final price, compared with 14 percent for poultry. The size and power of the Chinese marine fleet quadrupled from 1978 to 1994, with late 1990s subsidy estimates in the range of $500 to $750 million per year—a level comparable to that of Japan and twice that of the European Union.

Although these subsidies are in the marine sector, they affect all fish prices through overcapitalization of the capture fishing effort and depressing fish prices (at least in the short term). Should the subsidies be removed, it is likely that fish prices would rise even further and that the incentives to exports from aquaculture would be even more favorable. However, the rapid rise of health and documentation requirements for high-value fish trade suggest that potent barriers are being raised to the continued participation of the small-scale sectors in fish trade, in the absence of some viable form of vertical coordination that keeps them in the loop.

RISING BARRIERS TO THE PARTICIPATION OF THE POOR

The intensification of aquaculture has been ongoing, as discussed in Chapter 6, and is likely to be accelerated by the current direction of technological change. Even environmental requirements are likely to contribute to capital-intensive production, as controlling negative externalities from aquaculture often requires expensive capital investments. If policy subsidies in developing countries follow the example of the OECD and China, capital-intensive, large-scale operations are likely to emerge in developing countries at the expense of traditional and small-scale commercial fishers. Such subsidies could include cheaper land and credit, and lower taxes and tariffs on imported inputs for larger-scale operations (Ahmed 1997). Furthermore, in many developing countries, the legal and institutional frameworks to promote or protect access rights for traditional fishers are either weak or not implemented. These issues are becoming more prominent in Asia as new land and water for fish farming is becoming scarcer.

The rapid rise in information and documentation requirements is another emerging barrier to the continued participation of small-scale and poor producers. It requires considerable experience, skill, and investment to ensure adequate documentation of safe handling, processing, and origin of fish products. The minimum installation cost in Bangladesh for a HACCP-certified plant ranges from US$270,000 to US$380,000, and annual maintenance of an average small plant costs US$35,000 to US$71,000 per year (Dey et al. 2002). Bangladesh therefore needs 9.4 percent of its one-year export sales of fish to install a HACCP plant and 1.3 percent to maintain it (Cato and dos Santos 2000).

Thailand has the most efficient HACCP processes in Asia, and the cost of processing 1 kg of fish is only US$0.10 to US$0.14 per year (Dey et al. 2002). Thus the costs of HACCP compliance are not likely to exclude countries from fish trade. They are, however, likely to make it difficult for small-scale operations to compete unless they are vertically coordinated with larger processing operations that can adequately certify the compliance of their suppliers with safe processes.

Where there are constraints, there are also opportunities. The world is moving toward skilled-labor-intensive hygiene and food safety requirements, fair labor practices, and increased consumer consciousness of environmental issues. Fish exporting countries that comply in certifiable ways should be able to capture the lucrative export market more successfully by pursuing better quality management at lower cost. There is a role for policy in favoring these outcomes. In Thailand, producers, transporters, and processors formed an all-industry organization and created a code of conduct to certify their products (Rahman 2002). Thailand now has four well-equipped inspection centers for detection of bacteria, virus, antibiotics, and heavy metals, and has developed three open auction markets. The trick for poverty reduction and inclusive development will be to find institutional means to include smaller-scale producers in these arrangements.

Chapter 8

CONCLUSIONS

Combined analysis of observed trends through the 1990s, salient issues from existing literature, baseline "best guess" projections to 2020, and other possible scenarios suggests specific answers to the research questions outlined in the beginning of this book. Quantitative projections for consumption, production, trade, and prices are the result of the simultaneous interaction of supply and demand relationships around the world. For convenience, the projections are summarized separately under the former classifications rather than the latter. However, the framework for considering broader policy conclusions for fisheries distinguishes whether the entry points for effecting change lie on the demand- or the supply-side, and whether these entry points differ between developed and developing countries. The book concludes with a list of key issues for further policy research and a synthesized perspective for a "brave new world" in fisheries in the next two decades.

THE RESEARCH QUESTIONS

Will Growth Patterns in Fish Demand in the North and South Continue?

On average, people in 2020 will be eating more fish, but the increases will accrue more slowly than in the past two decades. The baseline scenario forecasts global per capita food fish consumption to increase at an annual compound rate of 0.4 percent from 1997[23] to 2020, with aggregate consumption increasing at 1.5 percent per annum (Chapter 4). China and India lead with per capita growth

[23]Here as elsewhere, all single years in the text prior to 1999 refer to annual three-year averages centered on the year shown (1997, for example, is the annual average for 1996–98).

forecast at 1.3 and 0.9 percent per annum to 2020, respectively. Latin America and Southeast Asia hold the middle ground with 0.4 and 0.5 percent growth, respectively, while the rest of the world exhibits little or negative growth in per capita fish consumption under baseline assumptions. On average, each person in Sub-Saharan Africa is unlikely eat more fish in 2020 than is eaten today, but because of high population growth, the region's aggregate fish consumption is predicted to rise at an average rate of 2.4 percent per year under the baseline (Appendix E).

China's fish consumption has grown rapidly of late, and will continue to grow rapidly relative to other countries. Projected annual growth in aggregate Chinese food fish consumption of 2.0 percent per annum may seem high but is actually much lower than the recorded growth of 11.8 percent per annum in the FAO figures for 1985 to 1997. Baseline projections indicate that aggregate consumption growth in the developed countries will continue to stagnate; results range from a decline in Japan (–0.3 percent per annum) to small increases in the United States (0.7 percent per annum), while the European Union remains fairly constant. Except for Eastern Europe and the former Soviet Union, which had already been through a period of very rapid decline in fish consumption in the 1990s, all regions of the world are likely to exhibit lower growth rates in food fish consumption to 2020 than observed during 1985–97.

Consumers in China will continue to diversify their diets. Low-value food fish consumption is projected to grow at a lesser annual rate (1.5 percent) than total food fish consumption (2.0 percent) to 2020 under baseline assumptions, and aggregate Chinese consumption of crustaceans, mollusks, and high-value finfish is projected to grow much more rapidly, from 2.6 to 2.8 percent per annum to 2020 (Appendix E). Over time, the Chinese are projected to consume an increasing share of higher-value fisheries items, affecting both their current exports to the developed world and their imports from neighboring countries in the South.

Southeast Asia will also follow this path; it is projected to increase its total food fish consumption faster than its low-value fish consumption (1.7 versus 1.4 percent per annum). However, in South Asia, with and without India, the consumption of low-value fish is projected to increase at 2.1 percent per annum to 2020, faster than total food fish (1.9 percent per annum). In the rest of the developing world, the aggregate consumption of total food fish increases at about 0.1 percent per annum faster than low-value food fish consumption, and the overall consumption of higher value fisheries items increases faster than low-value items, a trend already observed in developed countries.

Under the various fish production scenarios investigated in Chapter 4, global per capita fish consumption in 2020 is projected to range from a low of 14.2

kg/capita under the willfully extreme ecological collapse in capture fisheries scenario, to a high of 19.0 kg/capita under the faster investment in aquaculture scenario, while the baseline scenario projects 17.1 kg/capita. For comparison, actual estimates are 15.7 kg/capita for 1997 and 11.6 kg/capita for 1973 (Chapter 3). The comparable range across all scenarios for the developing countries, excluding China, is 8.3–11.1 kg/capita in 2020, with a baseline result of 9.9 kg/capita, compared with an actual estimate of 9.2 kg/capita in 1997. In developed countries, the scenario results for fish consumption in 2020 range from 17.0 to 22.6 kg/capita, with a baseline projection of 21.5 kg/capita, compared with an actual 1997 estimate of 21.7 kg/capita.

In sum, growth in fish consumption will very likely continue, but it will be driven primarily by the developing countries. Moreover, growth will occur slightly more in high-value than in low-value items, except in India and the rest of South Asia. Most of the world's per capita consumption growth will occur in East and Southeast Asia. Overall consumption growth of food fish will overwhelmingly occur in developing countries, where the effects of population growth will combine with consumer desire for a larger, diversified food basket. These factors are no longer important in developed countries for high-value items as a whole, although they may still be important for individual high-end fisheries items like scallops and smoked salmon. Both the existing literature on past trends and the model construction for this study identify urbanization as a significant contributing factor to the growth in developing-country fish consumption.

The 1.5 percent per annum global growth rate forecast for total food fish consumption through 2020 under the baseline scenario can be compared with estimated rates for meat and milk from the same baseline projections. Meat consumption (beef, pork, poultry, and small ruminant meat combined) is projected to grow at 2.1 percent per annum worldwide, 3.0 percent per annum in developing countries, and 0.8 percent in developed countries. Comparable figures for milk are 1.7 percent per annum growth to 2020 overall, with 2.9 percent growth in developing countries and 0.6 percent in the developed world (Rosegrant et al. 2001; Delgado et al. 2002b). On the whole, fish consumption growth rates are similar across regions to meat growth rates, although they are about one-third smaller. Furthermore, proportionately, China is slightly more important in the overall growth of fisheries than it is in the growth of the meat sector.

Where Will Supply Come From?

Observed past consumption trends and future projections can be explained in part by trends in production. Most capture fisheries growth during 1985–97 came from China, though figures for the 1990s have been challenged by some (see Chapter 2). Nevertheless, China expanded its high-seas fishing capacity by a factor of four between the late 1970s and mid-1990s (Chapter 7). Furthermore, other parts of Asia and Latin America had uncontested annual production growth rates of 3 percent or more during that period. At the same time, capture food fish production in the developed world fell at a rate of 2.4 percent per annum.

Looking forward to 2020, almost all of the 1.5 percent per annum growth in total food fish production projected under the baseline scenario will come from aquaculture, and much of this from developing countries. Capture fisheries in developed countries are only expected to grow at 0.1 percent per annum through 2020; they are likely to do a little better in the developing countries, at 1.0 percent per annum both with and without China (Chapter 4 and Appendix E).

The global share of food fish production from aquaculture is projected to rise to 41 percent in 2020, up from 31 percent in 1997 (Chapter 4). Asia will continue to be the leading region in aquaculture development in absolute terms, but aquaculture development will be widespread. 13 percent of developed-country food fish production came from aquaculture in 1997, and this share is projected to rise to 19 percent in 2020. For the developing countries, excluding China, the share of food fish production from aquaculture is projected to rise from 17 percent in 1997 to 27 percent in 2020, and for China the comparable share is projected to rise from 58 percent in 1997 to 66 percent in 2020.

Growth rates for food fish production across regions illustrate a changing locus of world fish production. China's share in global food fish production was only 10 percent in 1973, but rose to 36 percent by 1997 (based on officially recorded data), and is expected to reach 41 percent by 2020 using the same data. Using the downward-adjusted data of the lower China production scenario, which is consistent with claims of some critics of the official data, the Chinese share of world food fish production in 2020 is still 37 percent. Developed countries accounted for 56 percent of global food fish production in 1973 and 27 percent in 1997; under the baseline scenario, this share is expected to fall to 21 percent by 2020. Thus, overall, world food fish production is shifting rapidly away from being primarily an activity of the North, carried out by trawlers on the high seas, toward being an activity of the South, primarily carried out by rural people in freshwater ponds in Asia.

Despite the relatively high rates of growth in capture fisheries observed in developing countries from 1985 to 1997, projection of any further growth in capture fisheries production (even at one-third the 1985–97 rate) may seem surprising, given widely held pessimism as to the sustainability of capture fisheries. Yet while sustainability concerns remain valid in many developing-country fisheries, media views in the developed countries are heavily influenced by the experience of their own countries, where the sustainability issues of ocean fisheries are especially acute. Roughly one-quarter of the world's capture fisheries are classified by the

FAO as either under-exploited or only moderately exploited, and these growth areas are entirely in the tropics (FAO 2000a). The baseline scenario assumptions concerning capture fisheries are a conservative view, deemed reasonable at the present time by the study team; nevertheless—given the notorious uncertainty of capture fisheries—both more pessimistic and more optimistic future scenarios were also modeled.

Global food fish production from capture was 56.2 mmt in 1985 and 64.5 mmt in 1997 (Chapter 3), and is projected to reach 76.5 mmt in 2020 under baseline assumptions. If the lower China production hypothesis is correct, the 2020 projection falls to 69.2 mmt; in the event of a disastrous and global ecological collapse in marine fisheries, the low-end figure is 53.4 mmt. Slower aquaculture expansion puts substantially more pressure on capture fisheries with only small production gains, for a projected total of 77.9 mmt (Chapter 4).

The implication for technology development of the production projections is that aquaculture-related technologies will become even more important in the future. Aquaculture is likely to continue to intensify, especially in those areas of the tropics where it has been relatively extensive to date. Intensifying aquaculture brings risks of increased disease and more difficult disease control within ponds or cages, unless new technologies are also introduced to deal with these risks. Pollution control will become more of a policy issue as aquaculture increasingly impinges on other activities. Competition for water will become much more acute, especially in those parts of Asia where aquaculture development is already advanced. Technologies for better dealing with these problems will be much in demand, and their divisibility in terms of economies of scale will be important to the social outcomes of aquaculture development in developing countries because present technologies may be economically infeasible for small-scale operations. Fish nutrition will become an increasingly important issue, both for pollution control and for reducing the costs associated with rapidly rising demand for fishmeal (discussed in a subsequent section).

It seems likely that even more attention will be devoted to the selective breeding of species for aquaculture production than in the past, much as the rise of intensive poultry production coincided with the development of more productive poultry grandparent stock. As noted in Chapter 6, this is a relatively new yet crucial venture for tropical finfish in view of its expanding role in world food supply, particularly for the animal protein supply of the poor. Far more public attention is likely to be devoted to the safety and quality of aquaculture products in the future, as well as the interaction between production characteristics and product quality.

The environmental sustainability of aquaculture will become more contentious over time, not less. Biotechnology will become increasingly important in aquaculture, and claims of possible dangers to the wild genetic stock from escaped fish will become more frequent. Judging from experience in the meat sector, food safety debates and trade issues will surface relating to the use of genetically modified organisms in aquafeeds and, certainly, to the cultivation of genetically modified fish.

Although capture fisheries production will not grow much overall, technology to prevent it from shrinking further in specific regions will be in considerable demand, particularly in the traditional fisheries of the North. Technologies that permit better fisheries management are foremost among these, including information technologies that permit easier, more sustainable, and more easily documented fishing. Pressure for improved bycatch-reduction strategies (through better gear and practices) will grow. As is the case for most environmental issues, solutions will be found in a combination of technologies and policies directed at the same problem. Arguably, accurate information for fisheries management and choice of fishing gear have been more extensive for the North Sea than for most developing-country fisheries, yet stocks are still depleted. Improved information serves the interests of those who have the best access to it. Since this often means large-scale private fishing operations, there is little reason to think that it will necessarily promote better management. Appropriate institutional arrangements will be necessary both to level the playing field and to facilitate use of new technologies for the purposes of the common good.

Domestic needs and pressures will help to shape institutions, policies, and technologies for resource management, especially in developed countries and in some of the large developing countries such as China and India. However, unlike the red meat sector, the main pressure for environmental sustainability and food safety in developing countries will probably not come from domestic sources. Rather, it is likely to come from trade opportunities and barriers that will create incentives for change.

What Will Happen to Trade and Fish Prices?

The data analysis in this study, which assessed trade as the residual of production minus consumption, identified the developing-country shift away from net importation of food fish toward net exportation as occurring a few years later than the separate data on fish imports and exports would indicate—that is, the mid-1980s instead of the mid-1970s (see Chapter 7). Part of the reason for confusion surrounding the shift in export flows (other than statistical anomalies) is that developing countries first extended their EEZs to the 200 nautical mile limit in the 1970s, though these areas continued to be fished under license by foreign fleets. The catch was booked to the flag country of the foreign vessel; thus actual "exports" were under-recorded. In the 1980s, developing countries began to phase out licenses, favoring their own fleets, at which time exports began to be credited to developing countries in the records.

Either way, the shift has occurred, and the rapid rise in developing-country fish exports is one of the major developing-country trade stories of the late 1980s and early 1990s. Two-thirds of developing-country net exports are high-end items like tuna, salmon, shrimp, crabs, and bivalves. The remainder is low-value finfish for food, such as canned sardines and other processed low-value products.

A key question is whether the export boom in high-value seafood items in developing countries will continue. Overall, the 2020 projections indicate that net exports will continue but at lower levels in the future than now. Net exports of high-value finfish from developing countries, which increased by 2.5 mmt between 1985 and 1997, shrink under the baseline scenario by over 0.5 mmt to 2020, and a similar pattern results for crustaceans. Net food fish exports from developing to developed countries decrease overall by more than 1.2 mmt between 1997 and 2020 under baseline assumptions, having shifted from –1.3 mmt in 1985 (that is, net imports of 1.3 mmt) to 4.0 mmt in 1997. Since production in developing countries is not forecast to decline, the primary explanation for the decrease in net exports is that demand growth is outstripping supply growth in developing countries, particularly at the high-end, and particularly in China and South and Southeast Asia.

The developing-country export boom in fisheries of the 1980s and 1990s undoubtedly kept the relative prices of high-end items down in developed countries, while increasing them in developing countries. In any event, real world prices for food fish items generally rose—or at minimum did not fall—in the past 15 years, while red meat prices have fallen by about half (Chapter 7; Delgado et al. 1999). Anecdotal evidence suggests that, if anything, real prices of low-value food fish in developing countries rose at least as fast and probably faster than those of many high-end items such as salmon and shrimp, for which rapid growth in aquaculture production depressed prices (Chapter 7).

At one extreme, fish prices abruptly tripled in real terms in many locations in West Africa from the late 1980s to the early 1990s. Highly subsidized long-distance fleets of Eastern Europe dumped low-value blocks of frozen food fish in countries along the central part of the West African coast in the 1970s and 1980s; when these fleets disappeared with the fall of the Soviet bloc, local prices in these countries may have caught up with secular increases elsewhere in the region. China is at the other end of the spectrum; the high rate of growth of freshwater aquaculture in the late 1980s and early 1990s appears to have helped keep real domestic prices for low-value food fish stable or even slightly depressed. In this case, prices were partially controlled through various government interventions.

The rise in net fish exports from developing countries is associated with the development of institutions to facilitate trade in highly perishable commodities, such as improved airfreight facilities, a more rules-based trading system under SPS, and the extension of process-based food safety assurance approaches, such as HACCP (Chapter 7). Which came first—the institutions or the increased trade—is an open issue, but the two surely interacted.

Looking forward, it seems very likely that real fish prices will increase to 2020. Short-term price changes up or down are to be anticipated and can be quite large on a transitory basis, but production or consumption changes typically ensure a reversion to a long-term trend. The methodology used in the study is appropriate for assessing long-term structural changes in supply and demand that lead to lasting realignment of relative prices. The most likely outcome in the model is for high-value finfish and crustacean prices to be about 15 percent higher in 2020, whereas the real price of low-value food fish is expected to increase a total of 6 percent. In contrast, real fishmeal and fish oil prices are expected to increase by a total of 18 percent by 2020, whereas meats and milk are expected to decline 3 and 8 percent, respectively.

Thus fish is expected to become more expensive relative to meat and other food products. Significantly, the relative prices of both fishmeal and fish oil will increase by about 20 percent compared with poultry, pig meat, and soymeal but only 3 percent compared with high-value finfish (Chapter 4). Hence fishmeal prices will probably become de-linked from soymeal prices by 2020, and these inputs will largely exit from most uses in the poultry and hog sectors, barring technical change.

Scenario analysis suggests that the real price of high-value finfish is especially sensitive to assumptions about the health of capture fisheries. In the very pessimistic ecological collapse scenario for capture fisheries, the real price of high-value finfish rises by 69 percent, an incredible amount for a long-term real price in a price-mediated model of supply and demand. This suggests that if the situation in capture fisheries becomes sufficiently dire, even hearty growth in aquaculture cannot dampen the relative price rise for high-value fish. One reason for this is that ecological collapse in capture fisheries also leads to an even more extraordinary rise in prices for fishmeal (134 percent), also a product of capture fisheries, leading to severe pressure on profit margins for carnivorous aquaculture.

Four other insights on prices come from the scenario analysis. First, the only scenario that leads to a decrease in the real price of low-value food fish is faster aquaculture expansion (that is, a higher exogenous rate of investment or productivity increase in aquaculture). Second, slower aquaculture expansion and ecological collapse lead to 25 percent and 35 percent increases, respectively, in the real price of low-value food fish. Third, the only scenarios that lead to a stable or declining real price of fishmeal are slower aquaculture expansion (0 percent real change) and higher fishmeal efficiency growth (a 16 percent real decline). Fourth, red meat prices are hardly affected by big changes in the fish sector, but poultry prices are supported marginally by higher fish prices under pessimistic scenarios. The real price of vegetable meals, however, is projected to increase 16 percent in the event of the ecological collapse of capture fisheries.

The price forecasts imply that major re-alignments of incentives within the animal protein sector are possible, depending on the outlook for capture fisheries, investment in aquaculture, and the rate of technical efficiency in fish feeding. All can be influenced by policy, but the latter two are more likely to benefit the investors concerned; thus, they are more achievable.

What are the Implications for Sustainable Use of the Oceans and Coastal Areas?

The dire forecasts to 2020 under the pessimistic scenarios, along with the analysis of the literature and issues in Chapter 5, indicate that evolving global food markets will continue to apply heavy pressures on capture fisheries, both at the high and low ends of the sector in terms of market demand. Demand shifts in favor of fish consumption play a key role here, but the supply side is also a factor. High levels of subsidies to boat construction and operation in OECD countries and China have contributed to severe overcapitalization of their fleets. This in turn has encouraged resistance by fishers to sustainable management of stocks and has led to overfishing in the grounds frequented by these fleets.

Within capture fisheries, it will be vital for governments to invest in improving the information upon which fisheries management decisions are based and to promote better governance of natural resource use. These issues have proven difficult in both developing and developed countries for similar reasons, including inherent technical difficulties, justifiable concern about the livelihoods of traditional fishers, and strong vested interests in the fishing industry. Nevertheless, adopting systems of tradable user rights or other forms of restricting access and limiting catches is ultimately unavoidable. This study supports this need, but is not well-placed to identify specific solutions.

One insight of this study is a price-mediated tradeoff between aquaculture and capture fisheries; aquaculture can relieve pressure on fishing for food fish by dampening the rise of fish prices, but at the same time it stimulates growth in the prices of reduction fish. Under current technology, the growth of aquaculture shifts fishing pressure from output fish (such as salmon) to input fish (such as capelin).

Can Aquaculture Alleviate the Pressure on Capture Fisheries?

As shown under the scenarios of faster and slower aquaculture growth, the pace of aquaculture development makes an important difference in the projected real prices of fisheries commodities to 2020. Increased aquaculture production thus provides a price-mediated tradeoff with capture fisheries, in that lower food fish prices mean lower incentives to apply capture effort in food fisheries. On the other hand, growth in carnivorous aquaculture does put pressure on reduction fisheries by 2020. Government policy has aggressively promoted this expansion in the past, as in the Gulf of Thailand during the shrimp boom of the 1990s.

Analysis of the projections shows a modest difference in capture fisheries production between the faster and slower aquaculture scenarios. However, the previous point illustrates the importance of investing in reducing the amount of fishmeal needed for aquaculture output. In the short run, returns to such an investment may not be obvious because continuing use of fishmeal in livestock feeding would initially buffer increases in the price of fishmeal. The substitution of vegetable meals for fishmeals in livestock enterprises results in a smaller relative price increase for fishmeal than would otherwise occur.

On the other hand, analysis in Chapter 5 showed that farmers of carnivorous fish (including shrimp) have generally more inelastic demand for fishmeal and fish oil than do farmers of terrestrial animals, for reasons of fish biology. This more inelastic demand over time coupled with growing aquaculture production will shift the use of fishmeal and fish oil out of livestock and poultry production. Furthermore—and this is key—this combination will tend to make the price of fishmeal even more volatile than in the past. Fishmeal prices are already notoriously volatile across years because of variable climatic factors that affect harvests of reduction fish. If fish are eating a larger share of total fishmeal output over time, then the increasingly inelastic fishmeal demand and its unpredictable supply will make the price of fishmeal extremely unstable, potentially harming the profitability of carnivorous aquaculture operations at short notice. This also implies the periodic potential to "make a killing" in fishmeal at the very time that it is most harmful to be literally killing remaining stocks.

The key to allowing aquaculture to achieve its potential of alleviating pressure on ocean fisheries is to concentrate resources on noncarnivorous forms of aquaculture, and to promote improvements in fishmeal efficiency for the carnivorous species that are farmed. Some of this scientific research will be on feed, as discussed in Chapter 6, while some will be on the output fish themselves. The main environmental message of this study is that much more needs to be done to reduce the average global amount of fishmeal used per unit of fish output, and that this is a long-term issue of critical importance where the immediate market return may not be great. This effort is a reasonable candidate for classification as a global public good.

What are the Implications for the Poor?

Review of the few studies available that link fish to the food security of the poor suggest that the outlook is not especially good. Capture fisheries are not likely to provide increasing sources of employment on any significant scale, and competition for crowded resources is likely to intensify. Aquaculture in developing countries will provide expanding employment to many; however, the net effect on employment is still not clear in land- and water-constrained areas, such as most of Asia. Fish ponds typically require less labor input per hectare than the rice paddies they supplant. Land owners are likely to experience higher incomes, especially if fish prices rise relative to other items, and this argues for targeting public-sector aquaculture development funds to small-scale fish pond development with non-carnivorous species.

On the consumption side, it seems likely that over time the poor who used to get small amounts of animal protein from small fish are likely to substitute milk and meat, as meat and milk calories become cheaper relative to fish. The nutritional impact of this is not known, but at minimum it will be necessary for the poor in question to increase their total consumption of animal protein despite rising prices for fish.

The net effect on poverty of the global fish trends outlined above could go either way. On the positive side, regional income effects of fisheries development will stimulate a great deal of local economic activity in services, local handicrafts, food sales, and so on. This will be especially true in remoter areas where underemployed local resources are available to create these products but insufficient local demand for them exists. An activity such as fish production that can bring income into the local area from outside will lead to substantial extra net income in remote areas (Chapter 7). Conversely, it seems likely that intensification of aquaculture will end up displacing many poor and landless families in developing countries from their former low-wage employment as agricultural laborers. On balance, the more remote and sparsely populated the area, the more favorable the poverty-reduction impact of aquaculture is likely to be.

Another area for policy concern is that aquaculture operations in developing countries will likely scale upward in individual size, particularly in export operations. Significant economies of scale are present in environmentally friendly technologies that have been developed primarily to fit the needs of capital-intensive aquaculture. HACCP-enabled supply chains typically also involve larger-scale producers in the absence of institutional development cutting the costs and risks of dealing with a large number of small suppliers. It is plausible, however, to assume that institutions of collective action within a market-oriented framework could capture some of these economies of scale for small-scale fishers—akin to contract farming in livestock operations—but methods of accomplishing this on a widespread basis in fisheries have yet to be documented.

ENTRY POINTS FOR POLICY ACTION

The premises outlined in Chapter 1, which have on the whole proven to be correct, and the specific conclusions outlined above, suggest a range of entry-points for policy action to improve poverty-reduction and sustainability outcomes in developing-country fisheries. Most of the dynamic policy issues apply to aquaculture situations, although coastal and marine resource management issues will continue to loom large in coastal areas.

Supply-Side Entry Points

On the supply side, issues for developing counties are not very different from those in developed countries. The partial list below applies to both.

- Facilitating institutions that can improve the governance of marine and costal resources.
- Facilitating institutions that can improve the governance of freshwater fisheries resource management, including conversion of inland water and land to aquaculture production, integrated crop-fish development, and sequential use of water.
- Developing transparent and process-based food safety systems for consumers.
- Focusing environmental and food-safety attention on the sources of pollution in fisheries that most endanger human health and sustainability (and that originate outside the fisheries sector but accumulate in fish over time).
- Developing technologies to reduce the production costs of small-scale noncarnivorous pond aquaculture outputs.
- Adopting science-based policies on genetically modified organisms and their use in aquaculture production.
- Developing enforcement mechanisms for sustainable aquaculture codes of conduct, and creating certification systems for compliance (such as ecolabeling) that allow private-sector agents to reap the benefits of sustainable behavior in the market.

- Promoting market information, certification, and extension systems for small-scale aquaculture.
- Developing an adapted legal code for participatory institutions of collective action for small-scale fisheries, such as marketing and input supply cooperatives.
- Redirecting subsidies currently going to increase marine fishing operations to improving resource management and information systems.
- Creating a fisheries policy monitoring and planning function within ministries of finance or prime ministerial offices (not just in ministries of fisheries), to ensure that the sector gets the policy attention it will deserve.

Demand-Side Entry Points

From the standpoint of improving policy outcomes in developing countries, distinct differences arise between the developed countries and the developing countries on the demand side. For developed countries, the priorities are as follows.

- Rationalizing food safety systems for seafood imports such that safety is promoted and purely protective nontariff barriers are removed.
- Harmonizing and modernizing tariff classifications across countries to fit the modern realities of fish trade in processed tropical products.
- Eliminating tariff escalation on fisheries imports.
- Providing technical assistance to associations of small-scale developing-country fish exporters in achieving and maintaining fair trade and eco-labeling certification.
- Providing technical assistance to associations of small-scale developing-country fish exporters in setting up and maintaining credible process-based food safety plans such as HACCP along their export chains.

The focus of demand-side policies in developing countries should be to facilitate South–South trade, which will grow rapidly in the next 20 years; to provide public goods in assuring domestic food safety; and to help ensure that fish products reach those in developing countries who need them the most from a nutritional standpoint. The developing-country priorities are as follows.

- Adhering to a rationalized, rule-based system of fisheries trade that protects food safety but does not create artificial barriers to imports from other developing countries.

- Using aquaculture as a development vehicle for the poor in regional development projects.
- Monitoring and evaluating the impact of such projects and how they can be improved.
- Monitoring the nutritional status of poor people in fish-producing areas and exploring cost-effective ways of improving outcomes using locally produced fish.

PRIORITIES FOR FURTHER POLICY RESEARCH

Developing a sustainable fish sector that benefits poor people will require researchers to address a number of questions that arise from the preceding analysis:

- What is happening to the industrial organization of fish production and processing in developing countries (with particular emphasis on factors promoting scaling-up of the average size of individual operations) and why?
- How does the changing structure of international fish markets affect the opportunities and constraints for developing-country exporters, specifically small-scale and poor producers? In particular, what has been the impact of eco-labeling, fair trade, organic, and food safety regulations?
- How has the fish export boom of the late 1980s and 1990s affected incomes and nutrition of the poor in developing countries, and what can be done to improve outcomes?
- How should participatory institutions of collective action be designed and facilitated to allow small-scale fishers and farmers to participate in growing fish markets subject to increasing economies of scale arising from growing environmental and health restrictions?
- How should participatory and market-oriented institutions be designed and facilitated to improve the governance of resources critical to the maintenance and expansion of fish production?
- How can research on reducing use of fishmeal in world fisheries be promoted, and how can cost recovery for that research be improved?
- What are the constraints and opportunities in terms of the expansion of South–South trade in fisheries, and what are the options for improving outcomes for poverty reduction and improving environmental sustainability?

- At what point will world fishmeal prices become de-linked from soymeal prices, and what are the implications of this for the industry and for consumers?

A BRAVE NEW WORLD IN FISHERIES

In concluding this assessment of the outlook for fisheries to 2020, five major structural shifts can be predicted for global fisheries in relation to developing countries, aquaculture development, poverty alleviation, and environmental sustainability. These "sea changes" (in the full sense) are already underway, although they are more visible in some cases than in others; by 2020, they will be pervasive. Forward-looking policy discourse, research, and technology development addressing the above issues should focus on these changes.

First, developing countries, particularly in Asia, will dominate production systems; aquaculture development is central to this shift, but it will become more apparent in capture fisheries as well. The remaining quarter of world marine capture fisheries that are not fully exploited (and which are all in the tropics, largely within the EEZs of developing countries) will become more heavily fished.

Second, the source of net fisheries exports on a global scale has already shifted from the North to the South, and South–South trade will become increasingly important with the further emergence of urban middle classes. Developed countries will continue to be large net importers, and their domestic producers will continue to gradually exit the sector. Over time, it is likely that public policy in the North will increasingly favor import-friendly regimes for fish. On the other hand, it is quite possible that trade wars—perhaps based on both real and spurious food safety claims—will become more prominent in the South. Fish will become an increasingly high-value food commodity in relative terms, and trade is likely to continue to shift from low-grade and frozen whole fish to fresh fillets and the like.

Third, environmental controversy will continue in the fisheries sector but will change focus. Overfishing in marine areas will remain a huge concern. Sustainability-motivated environmental regulations and institutions will rapidly become more prominent, starting in the developed countries and then spreading to developing countries. Relatively more attention will be devoted to the exploitation of reduction fisheries and of the stocks preyed on by traditional marine food fish. It seems likely that the relationship between pollution and food safety in fisheries will be given much more attention in both the North and the South. If problems become worse, and as the consumer base for fish becomes larger and more wealthy, more attention will be given to sources of pollution such as dioxins, PCBs, and heavy metal residues that accumulate in food fish, directly affecting capture fisheries and both directly and indirectly affecting aquaculture (through reduction fish). These pollution sources are outside the fisheries sector (via run-offs from agricultural chemicals, industrial dumping of heavy metals, chemical-laden rain, and so on), and the interests behind the activities causing the pollution have typically been stronger than the constituency worried about the pollution's effects on fisheries—but this will change.

Fourth, the importance and focus of fisheries technology development will also shift to meet new challenges. Technology to profitably reduce the fishmeal and fish oil requirements for carnivorous aquaculture are key, and efforts will be expanded by private-sector interests. Some efforts will be focused on fish, others on synthetic feeds, and still others on modification of crops used in aquafeeds. Private-sector technology development will also continue to find ways to lessen the negative environmental impacts of intensifying large-scale aquaculture, through the design of relatively capital-intensive innovations. In the public arena, interest will increase in finding technological solutions to mitigate the negative environmental externalities associated with progressive intensification of small-scale pond aquaculture under tropical conditions, where, to date, technological solutions to environmental problems have not been forthcoming. Environmental and food-safety regulations that require capital-intensive approaches to compliance will receive increased scrutiny. In capture fisheries, information technologies for improved management will become increasingly important both in the North and the South but will pay off for public purposes only where the right form of institutional development accompanies use of the technology.

Fifth and finally, the issue of institutional development in fisheries will be a necessary condition for poverty reduction through fisheries development, as it is for improving environmental sustainability and food safety. The outlook for traditional fishers in developing countries in the absence of such institutional innovation is not bright. Both capture and culture fisheries are scaling-up and becoming more capital-intensive, and increased focus on food safety and environmental externalities under current technologies is likely to further this tendency. Food safety certification will become important to the survival of all fishers in the next two decades, and eco-labeling will become important to most. The world has not yet found a way to deliver such certifications cost-effectively and credibly to large numbers of small-scale fish producers, but the stakes are increasingly clear.

Appendix A

REGIONAL CLASSIFICATION OF COUNTRIES

The 36 IMPACT country groups include 184 countries, representing over 99 percent of the world's human population and 99 percent of the world's production of IMPACT fisheries commodities from 1996–98. Countries excluded from the model produced approximately 1 mmt, or less than 1 percent, of the global production total for IMPACT commodity groups for the base year of 1997. In this book, "global" refers to the 36 IMPACT commodity groups. Regional groupings were chosen based on Delgado et al. (1999). Data from some small countries were not available in all series in all years. Missing values for very small countries are ignored without note. The following list shows the countries aggregated into the groupings reported in the tables.

China	Mainland China, Taiwan, and Hong Kong
Eastern Europe and former Soviet Union	Albania, Armenia, Azerbaijan, Belarus, Bosnia–Herzegovina, Bulgaria, Croatia, Czech Republic, Czechoslovakia, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russian Federation, Slovakia, Slovenia, Tajikistan, Turkmenistan, Ukraine, former Soviet Union, Uzbekistan, Yugoslavia, and former Yugoslavia
European Union 15	Austria, Belgium/Luxembourg, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom
India	India

Japan	Japan
Latin America	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Dominica, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Lucia, St. Kitts and Nevis, St. Vincent and Grenadines, Suriname, Trinidad and Tobago, Uruguay, and Venezuela
Other developed countries	Australia, Canada, Iceland, Israel, Malta, New Zealand, Norway, South Africa, Switzerland
Other South Asia	Afghanistan, Bangladesh, Maldives, Nepal, Pakistan, and Sri Lanka
Southeast Asia	Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, and Vietnam
Sub-Saharan Africa	Angola, Botswana, Burkina Faso, Benin, Burundi, Cameroon, Central African Republic, Chad, Comoros Islands, Democratic Republic of the Congo, Cote d'Ivoire, Djibouti, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Republic of the Congo, Reunion, Rwanda, Sao-Tome and Principe, Senegal, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe
United States	United States of America
Western Asia and North Africa	Algeria, Cyprus, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Saudi Arabia, Syria, Tunisia, Turkey, United Arab Emirates, and Yemen

Developed world	European Union 15, Japan, Other developed countries, and the United States
Developing world	China, India, Latin America, Other South Asia, Southeast Asia, Sub-Saharan Africa, West Asia and North Africa, Cape Verde, Fiji, French Polynesia, Kiribati, Macao, Mongolia, New Caledonia, North Korea, Papua New Guinea, Seychelles, South Korea, and Vanuatu
World	Developed world and Developing world

Appendix B

COMMODITY GROUPS

IMPACT commodity groups were aggregated using the FAO coding system called the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP). Effort was made to include only fish, crustaceans (with the exception of krill), and mollusks. Excluded fisheries products include reptiles, marine mammals, aquatic plants, and other miscellaneous aquatic organisms. Production of the excluded ISSCAAP categories in the 36 IMPACT country groups totaled 9.5 mmt in the base year of 1997, or 7 percent of overall aquatic production, over 90 percent of which consisted of seaweeds and other aquatic plants (FAO 2002a).[24] Table B.1 shows the IMPACT categories with their component ISSCAAP groups, along with a list of excluded ISSCAAP groups.

The category "low-value food fish" includes freshwater fish such as carp, and small marine fish such as anchovies, sardines, and jacks. Fish specified as miscellaneous in ISSCAAP groupings are assigned to low-value food fish. The category "high-value finfish" includes marine fish such as salmon, snappers, cod, tuna, and flatfishes, as well as high-value freshwater fish such as trout. "Crustaceans" represents all crustaceans with the exception of krill (plankton) and includes products ranging from prawns to lobsters. "Mollusks" includes shelled bivalves such as clams and oysters and also includes cephalopods like squid and octopuses. In this report, the terms "fisheries products," "food fish," and "seafood" refer to the IMPACT commodity groups.

[24]Blue-whales and fin-whales; crocodiles and alligators; eared seals, hair seals, and walruses; and sperm-whales and pilot-whales are excluded from the total because the units of measure for these categories are not comparable.

Table B.1—IMPACT fisheries commodity categories and component ISSCAAP groups

Low-value finfish	High-value finfish	Crustaceans	Mollusks
Carps, barbels, and other cyprinids	Cods, hakes, haddocks	Freshwater crustaceans	Abalones, winkles, conchs
Herrings, sardines, anchovies	Flounders, halibuts, soles	Horseshoe crabs and other arachnoids	Clams, cockles, arkshells
Jacks, mullets, sauries	Redfishes, basses, congers	Lobsters, spiny rock lobsters	Freshwater mollusks
Mackerels, snoeks, cutlassfishes	Salmons, trouts, smelts	Miscellaneous marine crustaceans	Miscellaneous marine mollusks
Miscellaneous freshwater fishes	Sharks, rays, chimaeras	Sea-spiders, crabs	Mussels
Miscellaneous diadromous fishes	Sturgeons, paddlefishes	Shrimps, prawns	Oysters
Miscellaneous marine fishes	Tunas, bonitos, billfishes	Squat-lobsters	Scallops, pectens
River eels			Squids, cuttlefishes, octopuses
Shads			
Tilapias and other cichlids			
ISSCAAP groups not included in IMPACT			
Blue-whales, fin-whales	Eared seals, haired seals, walruses	Miscellaneous aquatic mammals	Sea-squirts and other tunicates
Brown seaweeds	Frogs and other amphibians	Miscellaneous aquatic invertebrates	Sea-urchins and other echinoderms
Corals	Green seaweeds	Miscellaneous aquatic plants	Sperm-whales, pilot-whales
Crocodiles and alligators	Krill, planktonic crustaceans	Pearls, mother-of-pearl, shells	Sponges
	Red seaweeds	Turtles	

Appendix C

COMMODITY AGGREGATION AND BALANCING PROCEDURES

This section describes the steps involved in creating the IMPACT fisheries commodity groups described in Appendix B, and the subsequent balancing of production, consumption, and trade among the 36 IMPACT country groups. It should be noted that production data were held constant because they mapped directly into IMPACT categories, while consumption and trade data were adjusted so that their IMPACT aggregations would be consistent with the production aggregations.

The first step was to create the four IMPACT fisheries commodity categories from the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) groupings found in Fishstat Plus (FAO 2002a). Because consumption and trade data are not available in ISSCAAP categories, we took these from noncomparable categories in FAO's "Balance Sheet Data: Non-Primary Livestock and Products" and "Food Supply: Non-Primary Livestock and Products" (FAO 2002c).

The FAO aggregates consumption and trade data into eight commodity groups, six of which map almost directly into IMPACT categories. "Demersal fish" were assigned to high-value finfish; "marine fish unspecified" were assigned to low-value food fish; "crustaceans" mapped directly to crustaceans; and "cephalopods" and "molluscs other" were each assigned to mollusks. "Freshwater fish" and "pelagic fish," however, each contain species from more than one IMPACT category. Data from these two categories were initially assigned to IMPACT categories using rules based on geography and trade patterns (Delgado et al. 2000). Fish consumed in or imported to developed countries was classified as high-value finfish, while fish consumed in or imported to developing countries was classified as low-value food fish. This procedure created inevitable errors that were addressed in later steps. Fish used for feed were classified temporarily as low-value food fish, to be subsequently removed.

Three-year averages centered on 1973, 1985, and 1997, respectively, were created for all data. “Error” in a region was defined as production minus human consumption, net exports, and other uses for a given year. At this stage, considerable error arose in each region, much of which, it is assumed, came from a misallocation of shares of freshwater and pelagic fish into IMPACT categories. Consequently, in cases where a low-value food fish error was of the opposite sign to a high-value finfish error, net exports and human consumption were appropriately adjusted so that the error in each category was reduced by an amount that eliminated the smaller of the two errors.

With this stage complete, leftover error still remained in instances where both high-value finfish and low-value food fish errors were of the same sign, and in the previously unaddressed errors in the crustaceans and mollusks categories. A category’s “share” in a given region for a given commodity was defined as that category divided by the sum of imports, exports, human consumption, and other uses. Remaining error in the four IMPACT categories was eliminated by adjusting imports, exports, human consumption, and other uses, each by its proportionate share.

For each commodity, global net exports were then brought to zero by subtracting the global quantity of net exports multiplied by each region’s share in the absolute value of net exports. The resulting error in each region was eliminated by apportioning it among human consumption and other uses according to the shares of each in total availability. As a result, no further error remained, though some categories had been overcorrected (indicated by negative quantities). Overcorrected values were reverted to their original values, and error was brought to zero by adjusting imports, exports, or consumption as appropriate. These changes threw global trade out of balance, so the deficit in global net exports was spread proportionately among all other regions to maintain global net exports at zero, and error in these regions was kept at zero by subtracting the same amount from human consumption.

This process provided consistent 1997 base-year values for production, consumption, trade, and other uses for all the IMPACT categories, with the exception of low-value food fish, which still included reduction fish. Reduction fish production data (“fishmeal inputs”) were taken from FAO’s “fishery: derived” datasets (FAO 2002b). These data were assigned to 36 IMPACT country groups. Reduction fish data were only available through 1997, so 1998 reduction fish data were estimated by applying the percentage change in fishmeal production from 1997 to 1998 in each region to 1997 fishmeal input data. Three-year averages centered on 1997 were then created for all country groups.

In each region, reduction fish was removed from “low-value food fish from capture” totals by subtracting fishmeal inputs. The difference between the global total for fishmeal inputs and the global low-value food fish total for feed use was added to or subtracted from human consumption, as appropriate, proportionately by region. The above procedures were repeated to eliminate the resulting error and bring global net exports to zero. Final production, consumption, and trade data for low-value food fish, high-value finfish, crustaceans, and mollusks were passed into the IMPACT model.

Fishmeal was defined according to the Standard Industrial Trade Classification (SITC) group "flour etc. fish, animal feed" from Fishstat Plus (FAO 2002a). Fish oil was defined by the SITC group "fat, oil, of fish, other" from Fishstat Plus. Production, import, and export data for fishmeal and fish oil were collected for 1976-98 for 36 IMPACT country groups from Fishstat Plus. Three-year averages centered on 1973, 1985, and 1997 were created for all data.

Total fishmeal and fish oil consumption data were calculated for each region by subtracting net exports from production. For each commodity, global net exports were then brought to zero by subtracting the global quantity of net exports multiplied by each region's share in the absolute value of net exports. The resulting error in each region was eliminated by adjusting consumption. Resulting negative consumption values were set to zero, and net exports were adjusted by the same amount. The deficit in global net exports was spread proportionately among all other regions to keep global net exports at zero, and error in these regions was kept at zero by subtracting the same amount from human consumption.

Consumption of fish oil was assigned to aquafeed, human consumption, and other uses by employing the estimates of Tacon (2001) regarding distribution of fish oil end-uses. Fish oil feed consumption was distributed according to fixed ratios that take into account aquaculture production in each region. In cases where this procedure resulted in feed use exceeding overall use, feed use was equated with overall use. The amount by which feed use was diminished in these cases was proportionately added to feed use in the other regions. Food and other uses of fish oil were proportionately distributed among the regions with remaining unaccounted-for fish oil consumption. Final fishmeal and fish oil production, consumption, and trade data were passed into the IMPACT model.

Appendix D

HANDLING FISHERIES TRADE DATA IN IMPACT

The IMPACT model, like most international datasets, does not analyze trade flows between specific countries. Instead, it estimates net trade with a disembodied "world market," which is the difference between domestic production and consumption at domestic prices within each country group. Net trade that is positive is called "net exports" and negative net trade is "net imports." Resulting trade flows occur in the model until domestic supply (production plus net imports) equals domestic demand at prevailing domestic prices. The latter are simultaneously influenced by trade flows, and the iteration stops when a set of group-specific prices for 36 countries for each commodity are in balance across all markets for a given year, and net trade sums to zero globally for each commodity. Prices for the same commodity can differ in a given year across country groups and with world prices because of country group-specific price wedges specified as production subsidy equivalents in percentage terms.

Imposing this framework on the model requires that the baseline data for 1996–98, on which subsequent forecasts are based, have consistent series for production, consumption, and trade figures for each country and commodity group, as is discussed in Appendix C. This means that considerable effort was devoted to getting consistent estimates of production, consumption, and net trade in the model after reaggregation into IMPACT categories. Production data after reaggregation are held as the starting point, and consumption and trade estimates are jointly and proportionately adjusted to achieve balance, following the procedures described in Appendix C.

Comparison of projected trends for net trade with past trends also necessitates adjusting live weight data from FAO 2002b (including trade data) for earlier years into comparable IMPACT market-defined categories, such as low-value food fish, for IMPACT country aggregates, again using the approach and datasets detailed in Appendix C.

The question then arises as to how these historical estimates of trade for IMPACT categories actually compare with direct data on historical trade flows for fish. The best independent trade data for comparative purposes come from the "trade and production" database within FishStat Plus (FAO 2002a), which reports highly disaggregated processed-weight trade data as exports and imports by country. It was therefore possible to individually assign each trade commodity to an appropriate IMPACT category. However, to make the series more comparable with the IMPACT category series arising from the procedures in Appendix C, an unknown adjustment would have to be made to convert processed weight to live-weight equivalents. Furthermore, there is no reason why this conversion would be constant across years or countries, as the true conversion will differ by processed product and fish species, and the mix of these in broad aggregates changes across years and countries. Therefore the independent estimates of historical trade flows would need to remain in processed weight, and could be expected to be substantially smaller (but not in a systematic way) than our live-weight estimates. Finally, the commodities in the fisheries trade and production dataset may not be comprehensive with regard to the live-weight fisheries production totals.

There are two other reasons why the independent processed-weight trade data might differ from re-aggregation using the procedures in Appendix C of historical fisheries trade data. First, imperfections in the assignment of FAO live-weight commodities to IMPACT categories using Appendix C procedures will inevitably introduce some error, for which there is no solution. This is judged to be an unavoidable outcome of the worthwhile process of aggregating fisheries commodities into market-based categories. Second, and perhaps more importantly, the FAO processed-weight trade data are collected and reported separately for each nation. Global net exports do not sum to zero, as global consistency is not imposed.[26]

A comparison of the trends shown by our re-aggregations in live weight to those derived from processed-weight totals from FishStat Plus is given for IMPACT categories in Table D.1. This table reports the net change in annual food fish trade between 1985 and 1997, where these years are three-year averages centered on the year indicated. Results are largely as expected, and are largely consistent, with only one major discrepancy. The discrepancy concerns low-value food fish in the developed world. The processed-weight dataset shows net exports increasing between the two periods, whereas our procedure shows net exports of

[26]Nor should it be for this type of dataset, which serves as an independent estimate country by country.

Table D.1 Change in net exports from different sources, 1985–97

		Net exports (thousand metric tons)	
Commodity	Region	Processed weight (FAO)	Live weight (IMPACT)
Low-value food fish	Developed world	469	–1,771
	Developing world	680	1,771
	Developing world excl. China	579	1,710
High-value finfish	Developed world	–1,453	–2,500
	Developing world	377	2,500
	Developing world excl. China	266	2,348
Crustaceans	Developed world	–352	–504
	Developing world	304	504
	Developing world excl. China	363	565
Mollusks	Developed world	–309	–544
	Developing world	603	544
	Developing world excl. China	463	230
Total food fish	Developed world	–1,645	–5,319
	Developing world	1,964	5,319
	Developing world excl. China	1,671	4,854

Sources: FAO processed weight data are taken from FAO (2002a); IMPACT live weight data are calculated by authors from FAO (2002b).

Notes: Data are calculated from three-year averages centered on 1985 and 1997. Positive numbers indicate increasing net exports from 1985 to 1997; negative numbers indicate the reverse. Commodity and region definitions are from IMPACT. For the processed weight values, disaggregated commodities from the trade and production database in FAO (2002b) were aggregated into appropriate IMPACT categories according to the definitions in Appendix B. For processed weight figures, global net exports do not sum to zero. IMPACT figures are in live weight, and global net exports sum to zero by construction. Net exports are defined as the residual between exports and imports in a region.

low-value food fish declining substantially from developed countries. The main reason for this discrepancy is probably that global net exports for the processed weight dataset sum to over 1 million metric tons (not shown in table), while by construction they sum to zero in the IMPACT dataset, as in the real world they must. The imbalance in global net exports of processed-weight totals can be seen in the table, for example, in the simultaneous increase in net exports of low-value food fish by both the developing and developed countries from 1985 to 1997.

Appendix E

SUPPLEMENTARY TABLES

Table E.1 Total production of food fish, 1973–97 and 2020

	Total production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	**1973**	**1985**	**1997**	**2020**	**1985–97**	**1997–2020**
China	4,854	8,393	33,339	53,074	12.2	2.0
Southeast Asia	5,360	7,811	12,632	17,521	4.1	1.4
India	1,851	2,707	4,768	7,985	4.8	2.3
Other South Asia	1,172	1,243	2,056	2,999	4.3	1.7
Latin America	2,330	4,129	6,380	8,807	3.7	1.4
West Asia and North Africa	674	1,459	2,248	2,776	3.7	0.9
Sub-Saharan Africa	2,064	2,561	3,738	6,015	3.2	2.1
United States	1,839	3,841	4,423	4,927	1.2	0.5
Japan	8,216	9,048	5,188	5,172	–4.5	0.0
European Union 15	6,097	5,754	5,926	6,716	0.2	0.5
Eastern Europe and former Soviet Union	7,862	9,213	4,896	5,024	–5.1	0.1
Other developed countries	2,867	3,810	4,761	5,779	1.9	0.8
Developing world	20,704	32,619	67,973	102,495	6.3	1.8
Developing world excluding China	15,850	24,226	34,634	49,421	3.0	1.6
Developed world	26,880	31,666	25,194	27,618	–1.9	0.4
World	47,585	64,284	93,167	130,112	3.1	1.5

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.2 Production of food fish from capture, 1973–97 and 2020

	Total production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	3,849	4,956	13,852	17,952	8.9	1.1
Southeast Asia	4,958	6,867	10,353	12,399	3.5	0.8
India	1,678	2,077	2,877	3,618	2.8	1.0
Other South Asia	1,098	1,100	1,579	1,816	3.1	0.6
Latin America	2,327	4,051	5,724	7,355	2.9	1.1
West Asia and North Africa	663	1,391	2,054	2,342	3.3	0.6
Sub-Saharan Africa	2,059	2,552	3,702	5,883	3.1	2.0
United States	1,668	3,500	3,996	4,131	1.1	0.1
Japan	7,805	8,395	4,397	4,128	–5.2	–0.3
European Union 15	5,602	4,919	4,700	4,744	–0.4	0.0
Eastern Europe and former Soviet Union	7,658	8,793	4,707	4,818	–5.1	0.1
Other developed countries	2,835	3,728	4,177	4,651	1.0	0.5
Developing world	18,922	26,925	42,542	54,040	3.9	1.0
Developing world excluding China	15,073	21,969	28,690	36,088	2.2	1.0
Developed world	25,569	29,336	21,977	22,475	–2.4	0.1
World	44,491	56,261	64,520	76,515	1.1	0.7

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.3 Production of food fish from aquaculture, 1973–97 and 2020

	Total production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	1,005	3,437	19,487	35,122	15.6	2.6
Southeast Asia	403	944	2,279	5,122	7.6	3.6
India	173	631	1,891	4,367	9.6	3.7
Other South Asia	73	144	477	1,183	10.5	4.0
Latin America	3	78	656	1,452	19.4	3.5
West Asia and North Africa	11	68	194	434	9.2	3.6
Sub-Saharan Africa	5	10	36	132	11.7	5.8
United States	170	341	427	796	1.9	2.7
Japan	410	652	791	1,044	1.6	1.2
European Union 15	495	835	1,226	1,972	3.3	2.1
Eastern Europe and former Soviet Union	203	420	189	206	–6.4	0.4
Other developed countries	33	82	584	1,128	17.8	2.9
Developing world	1,783	5,693	25,431	48,455	13.3	2.8
Developing world excluding China	777	2,256	5,944	13,333	8.4	3.6
Developed world	1,311	2,330	3,217	5,143	2.7	2.1
World	3,094	8,023	28,647	53,597	11.2	2.8

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.4 Production of low-value food fish from capture, 1973–97 and 2020

	Production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	2,584	2,597	6,644	6,852	8.1	0.1
Southeast Asia	3,557	4,292	6,266	6,750	3.2	0.3
India	1,062	1,241	1,478	1,587	1.5	0.3
Other South Asia	878	876	1,087	1,158	1.8	0.3
Latin America	966	2,043	2,151	2,432	0.4	0.5
West Asia and North Africa	537	1,064	1,464	1,588	2.7	0.4
Sub-Saharan Africa	1,761	2,136	3,031	5,001	3.0	2.2
United States	226	300	236	235	–2.0	0.0
Japan	1,483	3,935	1,228	1,153	–9.2	–0.3
European Union 15	1,000	603	981	1,014	4.1	0.1
Eastern Europe and former Soviet Union	2,663	2,940	1,067	1,076	–8.1	0.0
Other developed countries	405	365	621	646	4.5	0.2
Developing world	12,871	16,552	22,942	26,235	2.8	0.6
Developing world excluding China	10,287	13,954	16,298	19,383	1.3	0.8
Developed world	5,778	8,144	4,132	4,124	–5.5	0.0
World	18,648	24,695	27,075	30,359	0.8	0.5

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.5 Production of high-value finfish from capture, 1973–97 and 2020

	Production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	556	877	2,386	3,517	8.7	1.7
Southeast Asia	819	1,471	2,545	3,695	4.7	1.6
India	402	577	982	1,465	4.5	1.8
Other South Asia	197	186	421	570	7.0	1.3
Latin America	924	1,386	2,536	3,447	5.2	1.3
West Asia and North Africa	98	224	421	558	5.4	1.2
Sub-Saharan Africa	258	327	545	722	4.3	1.2
United States	622	1,995	2,774	2,975	2.8	0.3
Japan	5,236	3,368	1,980	1,800	–4.3	–0.4
European Union 15	4,017	3,682	2,963	2,966	–1.8	0.0
Eastern Europe and former Soviet Union	4,890	5,574	3,457	3,549	–3.9	0.1
Other developed countries	2,242	2,956	2,946	3,243	0.0	0.4
Developing world	3,833	6,247	10,758	15,070	4.6	1.5
Developing world excluding China	3,277	5,369	8,372	11,553	3.8	1.4
Developed world	17,007	17,576	14,121	14,535	–1.8	0.1
World	20,840	23,823	24,879	29,605	0.4	0.8

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.6 Production of mollusks from capture, 1973–97 and 2020

	Production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	243	674	2,167	3,627	10.2	2.3
Southeast Asia	197	575	660	790	1.2	0.8
India	1	21	107	151	14.6	1.5
Other South Asia	1	0	8	9	36.6	0.5
Latin America	145	292	707	1,058	7.7	1.8
West Asia and North Africa	12	68	121	132	5.0	0.4
Sub-Saharan Africa	10	46	44	48	–0.4	0.4
United States	481	865	594	510	–3.1	–0.7
Japan	932	936	1,048	1,013	0.9	–0.1
European Union 15	415	449	534	471	1.4	–0.5
Eastern Europe and former Soviet Union	72	214	97	91	–6.4	–0.3
Other developed countries	87	152	210	230	2.7	0.4
Developing world	755	2,010	4,336	6,385	6.6	1.7
Developing world excluding China	513	1,335	2,169	2,758	4.1	1.0
Developed world	1,987	2,617	2,483	2,315	–0.4	–0.3
World	2,742	4,627	6,819	8,700	3.3	1.1

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.7 Production of crustaceans from capture, 1973–97 and 2020

	Production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	467	807	2,655	3,956	10.4	1.7
Southeast Asia	385	529	882	1,164	4.4	1.2
India	214	238	310	415	2.2	1.3
Other South Asia	23	37	63	79	4.6	1.0
Latin America	292	330	330	418	0.0	1.0
West Asia and North Africa	16	34	48	64	2.8	1.3
Sub-Saharan Africa	30	42	82	112	5.7	1.4
United States	339	340	392	411	1.2	0.2
Japan	155	156	141	162	–0.8	0.6
European Union 15	170	184	222	293	1.6	1.2
Eastern Europe and former Soviet Union	33	64	86	102	2.5	0.7
Other developed countries	101	254	400	532	3.8	1.2
Developing world	1,463	2,117	4,506	6,350	6.5	1.5
Developing world excluding China	996	1,310	1,851	2,394	2.9	1.1
Developed world	798	999	1,241	1,501	1.8	0.8
World	2,261	3,116	5,747	7,851	5.2	1.4

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.8 Production of low-value food fish from aquaculture, 1973–97 and 2020

	Production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	738	2,561	12,415	21,476	14.1	2.4
Southeast Asia	321	708	1,494	3,538	6.4	3.8
India	173	618	1,810	4,233	9.4	3.8
Other South Asia	71	132	415	1,042	10.0	4.1
Latin America	1	27	176	560	16.9	5.2
West Asia and North Africa	11	65	137	334	6.3	4.0
Sub-Saharan Africa	5	9	33	128	11.2	6.1
United States	30	146	258	540	4.9	3.3
Japan	126	219	195	215	–1.0	0.4
European Union 15	15	36	41	47	1.2	0.6
Eastern Europe and former Soviet Union	197	405	170	175	–7.0	0.1
Other developed countries	13	12	18	28	3.3	1.9
Developing world	1,321	4,129	16,511	31,367	12.2	2.8
Developing world excluding China	584	1,568	4,096	9,891	8.3	3.9
Developed world	380	817	682	1,003	–1.5	1.7
World	1,702	4,946	17,193	32,370	10.9	2.8

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.9 Production of high-value finfish from aquaculture, 1973–97 and 2020

	Production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	**1973**	**1985**	**1997**	**2020**	**1985–97**	**1997–2020**
China	0	2	13	23	17.9	2.5
Southeast Asia	0	0	4	7	28.2	2.5
India	0	0	0	0	–100.0	—
Other South Asia	0	0	0	0	—	—
Latin America	0	3	248	408	44.3	2.2
West Asia and North Africa	0	2	53	93	31.3	2.5
Sub-Saharan Africa	0	0	0	0	–100.0	—
United States	14	24	41	81	4.4	3.0
Japan	23	70	130	199	5.3	1.9
European Union 15	60	152	409	741	8.6	2.6
Eastern Europe and former Soviet Union	6	13	17	28	2.5	2.2
Other developed countries	2	42	454	897	22.0	3.0
Developing world	1	8	342	573	37.0	2.3
Developing world excluding China	1	6	329	550	39.5	2.3
Developed world	104	300	1,051	1,946	11.0	2.7
World	105	308	1,392	2,519	13.4	2.6

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.10 Production of mollusks from aquaculture, 1973–97 and 2020

	Production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	**1973**	**1985**	**1997**	**2020**	**1985–97**	**1997–2020**
China	266	794	6,704	12,825	19.5	2.9
Southeast Asia	65	128	203	366	3.9	2.6
India	0	0	0	0	—	—
Other South Asia	0	0	0	0	—	—
Latin America	1	5	35	88	16.9	4.1
West Asia and North Africa	0	0	2	4	19.2	3.1
Sub-Saharan Africa	0	0	0	0	–100.0	—
United States	125	136	106	153	–2.1	1.6
Japan	261	361	464	628	2.1	1.3
European Union 15	420	647	776	1,183	1.5	1.9
Eastern Europe and former Soviet Union	0	3	2	3	–1.9	1.8
Other developed countries	17	28	110	200	12.1	2.6
Developing world	438	1,301	7,297	13,823	15.5	2.8
Developing world excluding China	172	507	593	998	1.3	2.3
Developed world	824	1,175	1,458	2,166	1.8	1.7
World	1,262	2,477	8,755	15,989	11.1	2.7

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.11 Production of crustaceans from aquaculture, 1973–97 and 2020

	Production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	1	79	355	798	13.3	3.6
Southeast Asia	17	109	578	1,211	14.9	3.3
India	0	12	81	134	17.0	2.2
Other South Asia	3	12	62	141	15.0	3.6
Latin America	1	43	197	396	13.5	3.1
West Asia and North Africa	0	0	2	3	87.1	1.8
Sub-Saharan Africa	0	0	3	4	40.7	1.3
United States	2	34	22	22	–3.6	0.0
Japan	1	2	2	2	–1.0	0.0
European Union 15	0	0	0	1	–100.0	—
Eastern Europe and former Soviet Union	0	0	0	0	—	—
Other developed countries	0	0	2	3	37.4	1.8
Developing world	22	255	1,281	2,692	14.4	3.3
Developing world excluding China	21	176	926	1,894	14.9	3.2
Developed world	3	36	26	28	–2.8	0.3
World	25	292	1,307	2,719	13.3	3.2

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.12 Production of fishmeal, 1973–97 and 2020

	Production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	3	54	542	777	21.1	1.6
Southeast Asia	173	250	458	704	5.2	1.9
India	20	32	15	20	–6.0	1.3
Other South Asia	16	33	42	50	2.0	0.8
Latin America	1,188	2,259	2,763	3,575	1.7	1.1
West Asia and North Africa	25	57	95	128	4.4	1.3
Sub-Saharan Africa	10	8	46	74	16.3	2.1
United States	289	329	300	347	–0.8	0.6
Japan	769	1,103	359	355	–8.9	0.0
European Union 15	517	540	627	830	1.3	1.2
Eastern Europe and former Soviet Union	651	769	217	228	–10.0	0.2
Other developed countries	837	602	624	771	0.3	0.9
Developing world	1,451	2,752	4,008	5,387	3.2	1.3
Developing world excluding China	1,449	2,698	3,466	4,610	2.1	1.2
Developed world	3,062	3,342	2,126	2,531	–3.7	0.8
World	4,514	6,094	6,133	7,918	0.1	1.1

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.13 Production of fish oil, 1973–97 and 2020

	Production (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	0	0	0	0	–100.0	—
Southeast Asia	1	1	0	0	–100.0	—
India	0	0	0	0	—	—
Other South Asia	0	0	0	0	—	—
Latin America	196	428	524	680	1.7	1.1
West Asia and North Africa	6	7	21	28	9.1	1.3
Sub-Saharan Africa	1	1	4	6	10.0	1.8
United States	96	150	114	132	–2.3	0.6
Japan	171	425	46	46	–16.9	0.0
European Union 15	137	129	190	252	3.2	1.2
Eastern Europe and former Soviet Union	6	5	3	3	–4.7	0.0
Other developed countries	324	280	223	277	–1.9	0.9
Developing world	205	438	549	714	1.9	1.1
Developing world excluding China	205	438	549	714	1.9	1.1
Developed world	733	991	576	710	–4.4	0.9
World	938	1,429	1,124	1,425	–2.0	1.0

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.14 Total consumption of food fish, 1973–97 and 2020

	Total consumption (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	4,947	8,675	33,151	52,520	11.8	2.0
Southeast Asia	5,396	7,853	11,288	16,736	3.1	1.7
India	1,833	2,756	4,547	7,377	4.3	2.1
Other South Asia	1,145	1,337	1,975	3,154	3.3	2.1
Latin America	2,128	3,565	3,844	5,612	0.6	1.7
West Asia and North Africa	613	1,612	2,140	3,223	2.4	1.8
Sub-Saharan Africa	2,561	3,688	3,704	6,357	0.0	2.4
United States	2,922	4,485	5,352	6,251	1.5	0.7
Japan	7,626	7,431	7,893	7,439	0.5	–0.3
European Union 15	6,285	7,294	8,829	8,807	1.6	0.0
Eastern Europe and former Soviet Union	7,300	9,011	4,385	4,827	–5.8	0.4
Other developed countries	858	1,218	1,605	1,870	2.3	0.7
Developing world	20,378	32,494	63,207	98,583	5.7	2.0
Developing world excluding China	15,431	23,819	30,056	46,063	2.0	1.9
Developed world	24,992	29,440	28,064	29,192	–0.4	0.2
World	45,370	61,934	91,271	127,776	3.3	1.5

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.15 Consumption of low-value food fish, 1973–97 and 2020

	Consumption (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	3,659	5,902	19,737	27,607	10.6	1.5
Southeast Asia	4,136	5,748	7,815	10,796	2.6	1.4
India	1,381	2,107	3,435	5,305	4.2	1.9
Other South Asia	1,066	1,185	1,596	2,456	2.5	1.9
Latin America	1,352	2,359	2,611	3,760	0.8	1.6
West Asia and North Africa	552	1,435	1,773	2,626	1.8	1.7
Sub-Saharan Africa	2,174	3,193	3,290	5,606	0.3	2.3
United States	86	63	35	41	–4.8	0.7
Japan	619	907	1,049	971	1.2	–0.3
European Union 15	348	534	721	741	2.5	0.1
Eastern Europe and former Soviet Union	2,200	2,565	150	161	–21.1	0.3
Other developed countries	69	140	135	161	–0.3	0.8
Developing world	15,481	23,610	41,231	59,422	4.8	1.6
Developing world excluding China	11,821	17,708	21,494	31,815	1.6	1.7
Developed world	3,321	4,210	2,090	2,073	–5.7	0.0
World	18,802	27,820	43,321	61,496	3.8	1.5

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.16 Consumption of high-value finfish, 1973–97 and 2020

	Consumption (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	374	568	1,937	3,518	10.8	2.6
Southeast Asia	728	1,156	1,852	3,107	4.0	2.3
India	304	485	842	1,568	4.7	2.7
Other South Asia	73	149	304	564	6.1	2.7
Latin America	500	900	821	1,210	–0.8	1.7
West Asia and North Africa	46	143	290	468	6.1	2.1
Sub-Saharan Africa	363	473	359	647	–2.3	2.6
United States	1,648	2,543	3,605	4,164	3.0	0.6
Japan	5,492	4,473	4,176	3,895	–0.6	–0.3
European Union 15	4,883	4,977	5,751	5,649	1.2	–0.1
Eastern Europe and former Soviet Union	5,012	6,279	4,084	4,493	–3.5	0.4
Other developed countries	615	785	1,080	1,241	2.7	0.6
Developing world	2,797	4,750	7,067	12,035	3.4	2.3
Developing world excluding China	2,423	4,182	5,130	8,517	1.7	2.2
Developed world	17,650	19,057	18,697	19,442	–0.2	0.2
World	20,447	23,807	25,764	31,477	0.7	0.9

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.17 Consumption of mollusks, 1973–97 and 2020

	Consumption (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	522	1,444	8,532	16,071	16.0	2.8
Southeast Asia	247	557	695	1,229	1.9	2.5
India	1	7	38	74	15.8	2.9
Other South Asia	1	0	2	2	26.6	0.0
Latin America	143	182	330	523	5.1	2.0
West Asia and North Africa	3	3	29	51	22.0	2.5
Sub-Saharan Africa	11	5	28	56	14.9	3.1
United States	663	1,234	867	1,074	–2.9	0.9
Japan	1,201	1,522	1,813	1,780	1.5	–0.1
European Union 15	734	1,305	1,617	1,691	1.8	0.2
Eastern Europe and former Soviet Union	73	126	101	118	–1.9	0.7
Other developed countries	80	80	239	297	9.6	0.9
Developing world	1,087	2,632	10,496	19,273	12.2	2.7
Developing world excluding China	565	1,188	1,964	3,202	4.3	2.1
Developed world	2,751	4,267	4,636	4,960	0.7	0.3
World	3,838	6,899	15,132	24,233	6.8	2.1

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.18 Consumption of crustaceans, 1973–97 and 2020

	Consumption (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	391	761	2,945	5,324	11.9	2.6
Southeast Asia	286	392	926	1,604	7.4	2.4
India	147	158	232	430	3.3	2.7
Other South Asia	5	3	73	132	30.9	2.6
Latin America	134	124	82	119	–3.4	1.6
West Asia and North Africa	12	31	48	78	3.6	2.1
Sub-Saharan Africa	13	16	27	48	4.2	2.5
United States	526	645	845	972	2.3	0.6
Japan	314	529	855	793	4.1	–0.3
European Union 15	321	477	740	726	3.7	–0.1
Eastern Europe and former Soviet Union	15	40	50	55	1.8	0.4
Other developed countries	94	213	151	171	–2.8	0.5
Developing world	1,013	1,503	4,413	7,853	9.4	2.5
Developing world excluding China	622	741	1,468	2,529	5.9	2.4
Developed world	1,271	1,905	2,641	2,717	2.8	0.1
World	2,284	3,408	7,054	10,570	6.3	1.8

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.19 Use of fishmeal, 1973–97 and 2020

	Use (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	112	554	1,573	2,085	9.1	1.2
Southeast Asia	135	238	728	1,281	9.8	2.5
India	17	32	25	45	–2.0	2.6
Other South Asia	1	35	47	89	2.6	2.8
Latin America	483	672	451	660	–3.3	1.7
West Asia and North Africa	99	217	252	370	1.3	1.7
Sub-Saharan Africa	15	12	14	26	1.6	2.7
United States	334	463	267	296	–4.5	0.4
Japan	828	1,052	731	705	–3.0	–0.2
European Union 15	1,104	1,191	1,070	1,146	–0.9	0.3
Eastern Europe and former Soviet Union	992	1,148	361	363	–9.2	0.0
Other developed countries	379	421	557	765	2.4	1.4
Developing world	877	1,821	3,148	4,641	4.7	1.7
Developing world excluding China	765	1,266	1,575	2,556	1.8	2.1
Developed world	3,637	4,273	2,985	3,277	–2.9	0.4
World	4,514	6,094	6,133	7,918	0.1	1.1

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.20 Use of fish oil, 1973–97 and 2020

	Use (thousand metric tons)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	0	1	13	14	20.7	0.3
Southeast Asia	1	2	7	11	10.6	2.0
India	0	0	0	0	—	—
Other South Asia	0	0	0	0	–100.0	—
Latin America	204	313	348	508	0.9	1.7
West Asia and North Africa	2	5	18	27	12.1	1.8
Sub-Saharan Africa	2	1	1	2	–2.1	3.1
United States	43	39	34	46	–1.2	1.3
Japan	79	202	105	114	–5.3	0.4
European Union 15	391	640	335	364	–5.2	0.4
Eastern Europe and former Soviet Union	9	33	3	3	–18.1	0.0
Other developed countries	202	185	252	324	2.6	1.1
Developing world	215	329	394	574	1.5	1.6
Developing world excluding China	214	328	381	560	1.3	1.7
Developed world	724	1,099	730	850	–3.4	0.7
World	938	1,429	1,124	1,425	–2.0	1.0

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.21 Per capita food fish consumption, 1997

Region	Consumption (kg/person/year)				
	Low-value food fish	High-value finfish	Mollusks	Crustaceans	Total food fish
China	15.8	1.5	6.8	2.4	26.5
Southeast Asia	15.9	3.8	1.4	1.9	23.0
India	3.6	0.9	0.0	0.2	4.7
Other South Asia	4.9	0.9	0.0	0.2	6.0
Latin America	5.3	1.7	0.7	0.2	7.8
West Asia and North Africa	5.1	0.8	0.1	0.1	6.2
Sub-Saharan Africa	5.9	0.6	0.1	0.0	6.7
United States	0.1	13.3	3.2	3.1	19.7
Japan	8.3	33.1	14.4	6.8	62.6
European Union 15	1.9	15.4	4.3	2.0	23.6
Eastern Europe and former Soviet Union	0.4	9.9	0.2	0.1	10.6
Other developed countries	1.2	9.9	2.2	1.4	14.7
Developing world	9.1	1.6	2.3	1.0	14.0
Developing world excluding China	6.6	1.6	0.6	0.5	9.2
Developed world	1.6	14.5	3.6	2.0	21.7
World	7.5	4.4	2.6	1.2	15.7

Source: Calculated by authors from FAO 2002c.

Note: Data are three-year annual averages centered on 1997.

Table E.22 Projected per capita food fish consumption, 2020

Region	Projected consumption (kg/person/year)				
	Low-value food fish	High-value finfish	Mollusks	Crustaceans	Total food fish
China	18.9	2.4	11.0	3.6	35.9
Southeast Asia	16.6	4.8	1.9	2.5	25.8
India	4.2	1.2	0.1	0.3	5.8
Other South Asia	4.8	1.1	0.0	0.3	6.1
Latin America	5.8	1.9	0.8	0.2	8.6
West Asia and North Africa	5.2	0.9	0.1	0.2	6.4
Sub-Saharan Africa	5.8	0.7	0.1	0.1	6.6
United States	0.1	13.1	3.4	3.1	19.7
Japan	7.9	31.5	14.4	6.4	60.2
European Union 15	2.0	15.2	4.6	2.0	23.7
Eastern Europe and former Soviet Union	0.4	10.8	0.3	0.1	11.6
Other developed countries	1.2	9.3	2.2	1.3	14.0
Developing world	9.7	2.0	3.2	1.3	16.2
Developing world excluding China	6.9	1.8	0.7	0.5	9.9
Developed world	1.5	14.3	3.6	2.0	21.5
World	8.2	4.2	3.2	1.4	17.1

Source: Projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Table E.23 Projected production of food fish from capture under various scenarios, 2020

Region	Projected production (thousand metric tons)					
	Most likely (baseline)	Faster aquaculture expansion	Lower China production	Fishmeal and fish oil efficiency	Slower aquaculture expansion	Ecological collapse
China	17,952	17,358	10,670	18,019	18,490	11,625
Southeast Asia	12,399	12,180	12,393	12,444	12,592	8,392
India	3,618	3,548	3,618	3,626	3,680	2,388
Other South Asia	1,816	1,779	1,812	1,822	1,847	1,272
Latin America	7,355	7,256	7,352	7,380	7,446	4,622
West Asia and North Africa	2,342	2,309	2,341	2,355	2,374	1,626
Sub-Saharan Africa	5,883	5,784	5,873	5,921	5,970	2,916
United States	4,131	4,092	4,136	4,131	4,168	3,416
Japan	4,128	4,017	4,127	4,142	4,233	3,664
European Union 15	4,744	4,681	4,746	4,756	4,803	3,950
Eastern Europe and former Soviet Union	4,818	4,764	4,821	4,828	4,863	3,985
Other developed countries	4,651	4,614	4,658	4,657	4,685	3,550
Developing world	54,040	52,826	46,737	54,249	55,136	34,870
Developing world excluding China	36,088	35,468	36,067	36,230	36,646	23,245
Developed world	22,475	22,173	22,489	22,513	22,754	18,568
World	76,515	74,998	69,227	76,762	77,889	53,438

Source: Projections for 2020 are from IFPRI's IMPACT model (July 2002).

Table E.24 Projected production of food fish from aquaculture under various scenarios, 2020

	Projected production (thousand metric tons)					
Region	Most likely (baseline)	Faster aquaculture expansion	Lower China production	Fishmeal and fish oil efficiency	Slower aquaculture expansion	Ecological collapse
China	35,122	44,313	35,019	35,281	27,583	36,035
Southeast Asia	5,122	7,282	5,118	5,191	3,567	5,136
India	4,367	6,244	4,352	4,404	3,013	4,397
Other South Asia	1,183	1,749	1,180	1,195	787	1,189
Latin America	1,452	2,104	1,452	1,487	1,009	1,445
West Asia and North Africa	434	621	433	440	300	430
Sub-Saharan Africa	132	244	132	133	71	131
United States	796	1,015	793	804	622	827
Japan	1,044	1,115	1,041	1,053	971	1,093
European Union 15	1,972	2,339	1,970	2,007	1,653	2,038
Eastern Europe and former Soviet Union	206	209	205	208	201	203
Other developed countries	1,128	1,474	1,129	1,172	852	1,144
Developing world	48,455	63,329	48,325	48,776	36,863	49,416
Developing world excluding China	13,333	19,016	13,306	13,495	9,280	13,381
Developed world	5,143	6,150	5,135	5,242	4,299	5,304
World	53,597	69,480	53,460	54,019	41,161	54,720

Source: Projections for 2020 are from IFPRI's IMPACT model (July 2002).

Table E.25 Projected total production of food fish under various scenarios, 2020

Region	Projected total production (thousand metric tons)					
	Most likely (baseline)	Faster aquaculture expansion	Lower China production	Fishmeal and fish oil efficiency	Slower aquaculture expansion	Ecological collapse
China	53,074	61,671	45,689	53,300	46,073	47,660
Southeast Asia	17,521	19,462	17,511	17,635	16,159	13,528
India	7,985	9,792	7,970	8,030	6,693	6,785
Other South Asia	2,999	3,528	2,992	3,017	2,634	2,461
Latin America	8,807	9,360	8,804	8,867	8,455	6,067
West Asia and North Africa	2,776	2,930	2,774	2,795	2,674	2,056
Sub-Saharan Africa	6,015	6,028	6,005	6,054	6,041	3,047
United States	4,927	5,107	4,929	4,935	4,790	4,243
Japan	5,172	5,132	5,168	5,195	5,204	4,757
European Union 15	6,716	7,020	6,716	6,763	6,456	5,988
Eastern Europe and former Soviet Union	5,024	4,973	5,026	5,036	5,064	4,188
Other developed countries	5,779	6,088	5,787	5,829	5,537	4,694
Developing world	102,495	116,155	95,062	103,025	91,999	84,286
Developing world excluding China	49,421	54,484	49,373	49,725	45,926	36,626
Developed world	27,618	28,323	27,624	27,755	27,053	23,872
World	130,112	144,478	122,687	130,781	119,050	108,158

Source: Projections for 2020 are from IFPRI's IMPACT model (July 2002).

Table E.26 Projected total consumption of food fish under various scenarios, 2020

Region	Projected total consumption (thousand metric tons)					
	Most likely (baseline)	Faster aquaculture expansion	Lower China production	Fishmeal and fish oil efficiency	Slower aquaculture expansion	Ecological collapse
China	52,520	59,932	45,170	52,811	46,854	44,432
Southeast Asia	16,736	18,517	16,745	16,839	15,358	14,045
India	7,377	8,230	7,391	7,431	6,723	6,100
Other South Asia	3,154	3,505	3,162	3,176	2,883	2,649
Latin America	5,612	6,161	5,622	5,644	5,181	4,788
West Asia and North Africa	3,223	3,599	3,235	3,246	2,933	2,729
Sub-Saharan Africa	6,357	7,266	6,389	6,414	5,670	5,291
United States	6,251	6,609	6,205	6,267	5,971	4,804
Japan	7,439	7,814	7,412	7,447	7,139	6,282
European Union 15	8,807	9,307	8,763	8,825	8,413	7,004
Eastern Europe and former Soviet Union	4,827	4,994	4,792	4,844	4,694	3,553
Other developed countries	1,870	1,977	1,859	1,874	1,787	1,449
Developing world	98,583	111,222	91,315	99,176	88,884	83,074
Developing world excluding China	46,063	51,290	46,145	46,365	42,030	38,642
Developed world	29,192	30,700	29,031	29,259	28,001	23,089
World	127,776	141,923	120,347	128,435	116,885	106,162

Sources: Projections for 2020 are from IFPRI's IMPACT model (July 2002).

Table E.27 Per capita consumption of low-value food fish, 1973–97 and 2020

	Consumption (kg/capita/year)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	4.1	5.5	15.8	18.9	9.2	0.8
Southeast Asia	13.5	14.5	15.9	16.6	0.8	0.2
India	2.3	2.7	3.6	4.2	2.2	0.7
Other South Asia	5.8	4.8	4.9	4.8	0.1	–0.1
Latin America	4.5	6.0	5.3	5.8	–1.0	0.4
West Asia and North Africa	3.0	5.5	5.1	5.2	–0.6	0.1
Sub-Saharan Africa	7.6	7.9	5.9	5.8	–2.4	–0.1
United States	0.4	0.3	0.1	0.1	–5.7	0.0
Japan	5.7	7.5	8.3	7.9	0.9	–0.2
European Union 15	1.0	1.5	1.9	2.0	2.2	0.2
Eastern Europe and former Soviet Union	6.1	6.5	0.4	0.4	–21.3	0.3
Other developed countries	0.9	1.5	1.2	1.2	–1.8	–0.1
Developing world	5.5	6.5	9.1	9.7	2.8	0.3
Developing world excluding China	6.2	7.0	6.6	6.9	–0.5	0.2
Developed world	3.0	3.5	1.6	1.5	–6.2	–0.3
World	4.8	5.8	7.5	8.2	2.2	0.4

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.28 Per capita consumption of high-value finfish, 1973–97 and 2020

	Consumption (kg/capita/year)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	0.4	0.5	1.5	2.4	9.4	1.9
Southeast Asia	2.4	2.9	3.8	4.8	2.2	1.0
India	0.5	0.6	0.9	1.2	2.7	1.5
Other South Asia	0.4	0.6	0.9	1.1	3.6	0.7
Latin America	1.7	2.3	1.7	1.9	–2.5	0.5
West Asia and North Africa	0.3	0.5	0.8	0.9	3.5	0.5
Sub-Saharan Africa	1.3	1.2	0.6	0.7	–4.9	0.2
United States	7.6	10.5	13.3	13.1	2.0	0.0
Japan	50.5	37.0	33.1	31.5	–0.9	–0.2
European Union 15	14.1	13.9	15.4	15.2	0.9	0.0
Eastern Europe and former Soviet Union	13.9	15.8	9.9	10.8	–3.8	0.4
Other developed countries	8.0	8.6	9.9	9.3	1.1	–0.3
Developing world	1.0	1.3	1.6	2.0	1.5	1.0
Developing world excluding China	1.3	1.6	1.6	1.8	–0.4	0.7
Developed world	15.9	15.7	14.5	14.3	–0.7	0.0
World	5.2	4.9	4.4	4.2	–0.9	–0.2

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.29 Per capita consumption of mollusks, 1973–97 and 2020

	Consumption (kg/capita/year)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	0.6	1.3	6.8	11.0	14.5	2.1
Southeast Asia	0.8	1.4	1.4	1.9	0.1	1.3
India	0.0	0.0	0.0	0.1	13.6	1.7
Other South Asia	0.0	0.0	0.0	0.0	23.7	–1.9
Latin America	0.5	0.5	0.7	0.8	3.2	0.8
West Asia and North Africa	0.0	0.0	0.1	0.1	19.2	0.8
Sub-Saharan Africa	0.0	0.0	0.1	0.1	11.9	0.6
United States	3.1	5.1	3.2	3.4	–3.8	0.3
Japan	11.1	12.6	14.4	14.4	1.1	0.0
European Union 15	2.1	3.6	4.3	4.6	1.5	0.2
Eastern Europe and former Soviet Union	0.2	0.3	0.2	0.3	–2.2	0.7
Other developed countries	1.0	0.9	2.2	2.2	7.9	0.1
Developing world	0.4	0.7	2.3	3.2	10.2	1.3
Developing world excluding China	0.3	0.5	0.6	0.7	2.1	0.6
Developed world	2.5	3.5	3.6	3.6	0.1	0.1
World	1.0	1.4	2.6	3.2	5.1	1.0

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Table E.30 Per capita consumption of crustaceans, 1973–97 and 2020

	Consumption (kg/capita/year)				Annual growth rate (percent)	
	Actual			Projected	Actual	Projected
Region	1973	1985	1997	2020	1985–97	1997–2020
China	0.4	0.7	2.4	3.6	10.5	1.9
Southeast Asia	0.9	1.0	1.9	2.5	5.5	1.2
India	0.2	0.2	0.2	0.3	1.3	1.5
Other South Asia	0.0	0.0	0.2	0.3	27.8	0.6
Latin America	0.4	0.3	0.2	0.2	–5.1	0.4
West Asia and North Africa	0.1	0.1	0.1	0.2	1.2	0.5
Sub-Saharan Africa	0.0	0.0	0.0	0.1	1.4	0.1
United States	2.4	2.7	3.1	3.1	1.3	–0.1
Japan	2.9	4.4	6.8	6.4	3.7	–0.2
European Union 15	0.9	1.3	2.0	2.0	3.4	–0.1
Eastern Europe and former Soviet Union	0.0	0.1	0.1	0.1	1.4	0.4
Other developed countries	1.2	2.3	1.4	1.3	–4.3	–0.3
Developing world	0.4	0.4	1.0	1.3	7.4	1.2
Developing world excluding China	0.3	0.3	0.5	0.5	3.7	0.8
Developed world	1.1	1.6	2.0	2.0	2.2	–0.1
World	0.6	0.7	1.2	1.4	4.6	0.7

Sources: Calculated by authors from FAO 2002a; projections for 2020 are from the baseline scenario of IFPRI's IMPACT model (July 2002).

Notes: Actual data are three-year annual averages centered on 1973. 1985, and 1997, respectively. Growth rates are exponential, compounded annually using three-year averages as endpoints.

Appendix F

ACRONYMS AND GLOSSARY

Aquaculture	The cultivation of food fish or shellfish under controlled conditions, including marine net pens, freshwater ponds, brackish-water ponds, and cages
Aquafeeds	Formulated feed provided to organisms raised in aquaculture
Baseline data	The starting dataset for economic projections, in this case a consistent set of production, consumption, and trade figures for 32 food and feed commodities in 36 country groups averaged over annual FAO observations for 1996–98
Baseline scenario	The "most likely" scenario in economic modeling, incorporating the authors' best estimate of model parameters combined with the baseline data
Benthic	Living in or on the bottom of a body of water (such as clams)
Bivalves	Mollusks with two-valved shells, such as clams or mussels
BRD	Bycatch Reduction Device
Broodstock	Captured wild organisms (such as shrimp or salmon) that are used for breeding
BSE	Bovine Spongiform Encephalopathy, commonly known as "mad cow disease," a degenerative disorder affecting the central nervous system of cattle, linked to the fatal Variant Creutzfeldt-Jacob disease in humans

Bycatch	The inadvertent catch of organisms that were not specifically targeted by a fishing operation (for example, nontarget fish species, marine mammals, seabirds) that are either discarded (see "discards") or landed for commercial sale
CAC	Codex Alimentarius Commission
Capture fisheries	Fishing operations that catch wild fish, either in freshwater or saltwater
Carnivorous aquaculture	The cultivation of aquatic organisms that require animal matter as part of their feed, such as salmon or shrimp
Cephalopods	Marine mollusks in the class Cephalopoda, such as squid and octopus
C.i.f.	Cost, insurance, and freight; the price of a traded good including transport and associated costs
Cross-price elasticity of demand	A ratio measuring the percentage change in the demand for a good, X, in response to a percentage change in the price for another good, Y
Cross-price elasticity of supply	A ratio measuring the percentage change in the supply for a good, X, in response to a percentage change in the price for another good, Y
CSE	Consumer Subsidy Equivalent
Demersal	Living near the bottom of a body of water
Diadromous	Migrating between freshwater and saltwater
Discards	Fish that are thrown away after being caught, usually because of undesirable characteristics (the wrong species, unmarketable, undersized, and so on); a subset of bycatch
Eco-labeling	The practice of certifying a product as having been produced under environmentally sustainable conditions
EEZ	Exclusive Economic Zone
Effluent	An outflow, especially of liquid waste, in this context from an aquaculture operation

El Niño/Southern Oscillation or ENSO	A linked ocean–atmosphere phenomenon that occurs quasi-periodically and results in the warming of the eastern equatorial Pacific Ocean along with various climatic anomalies
Eutrophication	The process of enrichment of a body of water by organic nutrients, causing algal growth and thus reduced dissolved oxygen content, often resulting in the deaths of other organisms
Exclusive Economic Zone	An area of the sea, typically within 200 nautical miles from the shore of a sovereign nation, in which the nation may claim the rights to exploit natural resources; defined by the United Nations Convention on the Law of the Sea
Externalities	Costs/benefits of an activity that are not borne/captured by the originating agent
FAO	Food and Agriculture Organization of the United Nations
Feed conversion efficiency	A measure of the ability to convert animal feed into animal meat, expressed as the ratio of live weight gain to feed ingested
Fish oil	Usually a byproduct of the fishmeal manufacturing process, used for pharmaceuticals, fish feeds, and for direct human consumption
Fishmeal	Cooked, pressed, dried, and milled fish, usually small pelagic fish, used for animal feeds
Fry	Juvenile fish able to obtain their own food
Gamete	Sperm (in the case of a male), or egg (in the case of a female), in this context referring to fish
GATT	General Agreement on Tariffs and Trade
GESAMP	Group of Experts on the Scientific Aspects of Marine Pollution
GIS	Geographic Information Systems
GMO	Genetically Modified Organism
Groundfish	A common name for several species of demersal finfish, particularly commercial species such as cod

HACCP	Hazard Analysis and Critical Control Points
ICES	International Council for the Exploration of the Seas
IMPACT	IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade
Income elasticity of demand	A ratio measuring the percentage change in demand for a good in response to a percentage change in income
Intensification	The process of producing more outputs from the same level of the limiting factor of production, usually by increasing the levels of other purchased inputs or factors of production, or by technological change, or both
ISSCAAP	International Standard Statistical Classification of Aquatic Animals and Plants
ITQs	Individual Transferable Quotas
IUU	Illegal, Unreported, and Unregulated fishing
Krill	Very small planktonic marine crustaceans
Mariculture	Aquaculture practiced in a marine environment
Mesopelagic	Living in the region of the ocean between depths of about 200 and 1,000 meters
Micronutrient	Nutrients, such as specific vitamins or minerals, required in very small quantities for healthy functioning
NACA	Network of Aquaculture Centers in Asia/Pacific
Nes	Not elsewhere specified (an FAO statistical term)
OECD	Organisation for Economic Co-operation and Development
Pelagic	Living in the open ocean, as opposed to near shore or on the sea bottom
Polyculture	The cultivation of several species of organism within the same system
Postlarvae	Animals (like shrimp) that have changed from the larval form to the juvenile or adult form

Price elasticity of demand	A ratio measuring the percentage change in the demand for a good, X, in response to a percentage change in the price for that good
Price elasticity of supply	A ratio measuring the percentage change in the supply of a good, X, in response to a percentage change in the price for that good
PSE	Producer Subsidy Equivalent
Reduction fish	Fish destined for processing into fishmeal and fish oil, especially small pelagic fish
Seine nets	Large nets that float vertically in the water with weighted bottoms
SPS	Sanitary and Phyto-Sanitary Agreements
SSA	Sub-Saharan Africa
Stocking density	A measure of the number of organisms in an aquaculture operation per surface area of water, or per unit volume of water
Surimi	Processed fish used for imitation seafood, often for artificial crabmeat
Tariff escalation	The maintenance of higher tariff rates on products with a higher degree of processing than on products in less processed form
TBT	Technical Barriers to Trade
TFP	Total Factor Productivity
Transgenic	Relating to the transfer of genes from one species into another
Trawling	The fishing method of dragging a net behind a boat, sometimes on the sea bottom
Trophic level	Position in the food chain
VMS	Vessel Monitoring System
WTO	World Trade Organization

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Contributors

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