AGRICULTURE AND ENVIRONMENTAL SERVICES DISCUSSION PAPER 03

FISH TO 2030

Prospects for Fisheries and Aquaculture

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IFPRI

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FOREWORD

Feeding an expected global population of 9 billion by 2050 is a daunting challenge that is engaging researchers, technical experts, and leaders the world over. A relatively unappreciated, yet promising, fact is that fish can play a major role in satisfying the palates of the world's growing middle income group while also meeting the food security needs of the poorest. Already, fish represents 16 percent of all animal protein consumed globally, and this proportion of the world's food basket is likely to increase as consumers with rising incomes seek higher-value seafood and as aquaculture steps up to meet increasing demand.

Aquaculture has grown at an impressive rate over the past decades. It has helped to produce more food fish, kept the overall price of fish down, and made fish and seafood more accessible to consumers around the world. That's why greater investment is needed in the industry—for new and safer technologies, their adaptation to local conditions, and their adoption in appropriate settings.

But supplying fish sustainably—producing it without depleting productive natural resources and without damaging the precious aquatic environment—is a huge challenge. We continue to see excessive and irresponsible harvesting in capture fisheries and in aquaculture. Disease outbreaks, among other things, have heavily impacted production—most recently with early mortality syndrome in shrimp in Asia and America.

At the World Bank, we hear from the heads of major seafood companies that they want to secure access to reliable and environmentally sustainable supply chains. Matching growing market demand with this private sector interest in reliable and sustainable sourcing presents a major opportunity for developing countries prepared to invest in improved fisheries management and environmentally sustainable aquaculture. By taking up this opportunity, countries can create jobs, help meet global demand, and achieve their own food security aspirations.

There is substantial potential for many developing countries to capitalize on the opportunity that the seafood trade provides. This study employs state-of-the-art economic models of global seafood supply and demand that can be used to analyze the trends and the extent of such opportunities. The insights gained here can inform developing and developed countries alike of the importance and urgency of improved capture fisheries and aquaculture management, so that seafood demand is met in an environmentally and economically sustainable way.

Working alongside partners like IFPRI and FAO, the World Bank can support developing countries in their efforts to manage their fish production sustainably through tailored and innovative solutions that work.

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Siwa Msangi (Senior Research Fellow, International Food Policy Research Institute) led the modeling work to add a fisheries component to IFPRI's IMPACT model and drafted the main text of the report.

Mimako Kobayashi (Natural Resources Economist, World Bank) coordinated with the IFPRI team to improve and validate model output and drafted and edited the report.

Miroslav Batka (Research Analyst, International Food Policy Research Institute) processed data that went into the model, performed model simulations, and generated figures and tables for the report.

Stefania Vannuccini (Fishery Statistician, Fishery Information and Statistics Branch, Food and Agriculture Organization of the UN) constructed the primary raw data set from which the model baseline was built and provided input into the commodity definitions.

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ACRONYMS AND ABBREVIATIONS

AFR	Sub-Saharan Africa
CAPRI	Common Agricultural Policy Regionalised Impact Modeling System
CHN	China
CobSwf	aggregate of cobia and swordfish
CSE	consumer subsidy equivalent
EAP	East Asia and the Pacific, including Mongolia and developed nations, excluding Southeast Asia, China, and Japan
ECA	Europe and Central Asia, including developed nations
EelStg	aggregate of eels and sturgeon
EEZ	exclusive economic zone
EwE	Ecopath with Ecosim
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO food and agriculture statistics
FBS	food balance sheets (produced by the FAO)
FCR	feed conversion ratio
FIPS	FAO Fisheries Information and Statistics Branch
FishStat	FAO Fisheries and Aquaculture Statistics
FPI	Fishery Performance Indicators
GAMS	General Algebraic Modeling System
GDP	gross domestic product
GDP/c	gross domestic product per capita
HS	Harmonized System
IFFO	International Fishmeal and Fish Oil Organisation
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IND	India
ISA	infectious salmon anemia
JAP	Japan
LAC	Latin America and Caribbean
MDemersals	major demersal fish
MM	marketing margin
MNA	Middle East and North Africa
MSY	maximum sustainable yield

NAM	North America (United States and Canada)
OCarp	silver, bighead, and grass carp
OECD	Organization for Economic Co-Operation and Development
OFresh	freshwater and diadromous species, excluding tilapia, *Pangasius*/catfish, carp, OCarp, and EelStg
OMarine	other marine fish
OPelagic	other pelagic species
Pangasius/catfish	*Pangasius* and other catfish
PSE	producer subsidy equivalent
ROW	rest of the world, including Greenland, Iceland, and Pacific small island states
RR	reduction ratio
SAR	South Asia, excluding India
SEA	Southeast Asia
WBG	World Bank Group
WCO	World Customs Organization
WDR	World Development Report

All tons are metric tons unless otherwise indicated.

All dollar amounts are U.S. dollars unless otherwise indicated.

EXECUTIVE SUMMARY

CONTEXT

The World Bank Group (WBG) Agriculture Action Plan 2013–15[1] summarizes critical challenges facing the global food and agriculture sector. Global population is expected to reach 9 billion by 2050, and the world food-producing sector must secure food and nutrition for the growing population through increased production and reduced waste. Production increase must occur in a context where resources necessary for food production, such as land and water, are even scarcer in a more crowded world, and thus the sector needs to be far more efficient in utilizing productive resources. Further, in the face of global climate change, the world is required to change the ways to conduct economic activities.

Fisheries and aquaculture must address many of these difficult challenges. Especially with rapidly expanding aquaculture production around the world, there is a large potential of further and rapid increases in fish supply—an important source of animal protein for human consumption. During the last three decades, capture fisheries production increased from 69 million to 93 million tons; during the same time, world aquaculture production increased from 5 million to 63 million tons (FishStat). Globally, fish[2] currently represents about 16.6 percent of animal protein supply and 6.5 percent of all protein for human consumption (FAO 2012). Fish is usually low in saturated fats, carbohydrates, and cholesterol and provides not only high-value protein but also a wide range of essential micronutrients, including various vitamins, minerals, and polyunsaturated omega-3 fatty acids (FAO 2012). Thus, even in small quantities, provision of fish can be effective in addressing food and nutritional security among the poor and vulnerable populations around the globe.

In some parts of the world and for certain species, aquaculture has expanded at the expense of natural environment (for example, shrimp aquaculture and mangrove cover) or under technology with high input requirements from capture fisheries (for example, fishmeal). However, some aquaculture can produce fish efficiently with low or no direct input. For example, bivalve species such as oysters, mussels, clams, and scallops are grown without artificial feeding; they feed on materials that occur naturally in their culture environment in the sea and lagoons. Silver carp and bighead carp are grown with planktons proliferated through fertilization and the wastes and leftover feed materials for fed species in multispecies aquaculture systems (FAO 2012). While the proportion of non-fed species in global aquaculture has declined relative to higher trophic-level species of fish and crustaceans over the past decades, these fish still represent a third of all farmed food fish production, or 20 million tons (FAO 2012). Further, production efficiency of fed species has improved. For example, the use of fishmeal and fish oil per unit of farmed fish produced has declined substantially as reflected in the steadily declining inclusion levels of average dietary fishmeal and fish oil within compound aquafeeds (Tacon and Metian 2008). Overall, a 62 percent increase in global aquaculture production was achieved when the global supply of fishmeal declined by 12 percent during the 2000–08 period (FAO 2012).

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[1] It builds on the *World Development Report* (*WDR*) 2008 and the subsequent WBG Agriculture Action Plan 2010–12. *WDR* 2008 reaffirmed that "promoting agriculture is imperative for meeting the Millennium Development Goal of halving poverty and hunger by 2015 and reducing poverty and hunger for several decades thereafter." It redefined "how agriculture can be used for development, taking account of the vastly different context of opportunities and challenges that has emerged." The subsequent WBG Agriculture Action Plan 2010–12 provided strategies to operationalize the findings of the *WDR* 2008.

[2] Throughout this report, fish is considered in a broad sense that includes finfish, mollusks, and crustaceans.

Many of the fishers and fish farmers in developing countries are smallholders. The Food and Agriculture Organization (FAO) estimates that 55 million people were engaged in capture fisheries and aquaculture in 2010, while small-scale fisheries employ over 90 percent of the world's capture fishers (FAO 2012). To these small-scale producers fish are both sources of household income and nutrients, and sustainable production and improved efficiency would contribute to improve their livelihoods and food security. Sustainably managing marine and coastal resources, including fish stock and habitat, would also help building and augmenting resilience of coastal communities in the face of climate change threats.

One important feature of this food-producing sector is that fish is highly traded in international markets. According to the FAO (2012), 38 percent of fish produced in the world was exported in 2010. This implies that there are inherent imbalances in regional supply and regional demand for fish, and international trade—through price signals in markets—provides a mechanism to resolve such imbalances (Anderson 2003). Therefore, it is important to understand the global links of supply and demand of fish to discuss production and consumption of fish in a given country or a region, while understanding the drivers of fish supply and demand in major countries and regions is essential in making inferences about global trade outcomes. Developing countries are well integrated in the global seafood trade, and flow of seafood exports from developing countries to developed countries has been increasing. In value, 67 percent of fishery exports by developing countries are now directed to developed countries (FAO 2012).

This report offers a global view of fish supply and demand. Based on trends in each country or group of countries for the production of capture fisheries and aquaculture and those for the consumption of fish, driven by income and population growth, IFPRI's newly improved International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT model) simulates outcomes of interactions across countries and regions and makes projections of global fish supply and demand into 2030. Projections are generated under different assumptions about factors considered as drivers of the global fish markets. This report reflects a collaborative work between the International Food Policy Research Institute (IFPRI), the FAO, the University of Arkansas at Pine Bluff, and the World Bank. This work builds on the publication *Fish to 2020* by Delgado and others (2003).

Throughout the report, the discussions are centered around three themes: (1) health of global capture fisheries, (2) the role of aquaculture in filling the global fish supply-demand gap and potentially reducing the pressure on capture fisheries, and (3) implications of changes in the global fish markets on fish consumption, especially in China and Sub-Saharan Africa.

FINDINGS AND IMPLICATIONS

This study employs IFPRI's IMPACT model to generate projections of global fish supply and demand. IMPACT covers the world in 115 model regions for a range of agricultural commodities, to which fish and fish products are added for this study. As is the case with most global modeling work, an important value that IMPACT brings to this study is an internally consistent framework for analyzing and organizing the underlying data. However, there are known data and methodology issues that arise from choices made by the key researchers for the purposes of maintaining computational tractability, internal analytical consistency, and overall simplicity. These are summarized in section 2.6.

BASELINE SCENARIO

After demonstrating that the model successfully approximates the dynamics of the global fish supply and demand over the 2000–08 period, the outlook of the global fish markets into 2030 is projected under the scenario considered most plausible given currently observed trends (see table E.1 for key results). The model projects that the total fish supply will increase from 154 million tons in 2011 to 186 million tons in 2030. ***Aquaculture***'s share in global supply will likely continue to expand to the point where capture fisheries and aquaculture will be contributing equal amounts by 2030. However, aquaculture is projected to supply over 60 percent of fish destined for direct human

TABLE E.1: Summary Results under Baseline Scenario (000 tons)

	TOTAL FISH SUPPLY		FOOD FISH CONSUMPTION	
	DATA 2008	PROJECTION 2030	DATA 2006	PROJECTION 2030
Capture	89,443	93,229	64,533	58,159
Aquaculture	52,843	93,612	47,164	93,612
Global total	142,285	186,842	111,697	151,771
Total broken down by region as follows				
ECA	14,564	15,796	16,290	16,735
NAM	6,064	6,472	8,151	10,674
LAC	17,427	21,829	5,246	5,200
EAP	3,724	3,956	3,866	2,943
CHN	49,224	68,950	35,291	57,361
JAP	4,912	4,702	7,485	7,447
SEA	20,009	29,092	14,623	19,327
SAR	6,815	9,975	4,940	9,331
IND	7,589	12,731	5,887	10,054
MNA	3,518	4,680	3,604	4,730
AFR	5,654	5,936	5,947	7,759
ROW	2,786	2,724	367	208

Source: IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

consumption by 2030. It is projected that aquaculture will expand substantially, but its growth will continue to slow down from a peak of 11 percent per year during the 1980s. The global production from capture fisheries will likely be stable around 93 million tons during the 2010–30 period.

Looking across regions, ***China*** will likely increasingly influence the global fish markets. According to the baseline model results, in 2030 China will account for 37 percent of total fish production (17 percent of capture production and 57 percent of aquaculture production), while accounting for 38 percent of global consumption of *food fish*.[3] Given the continued growth in production projection, China is expected to remain a net exporter of food fish (net importer of fish if fishmeal is considered). Fast supply growth is also expected from aquaculture in South Asia (including India), Southeast Asia, and Latin America.

Per capita fish ***consumption*** is projected to decline in Japan, Latin America, Europe, Central Asia, and Sub-Saharan Africa. In particular, per capita fish consumption in ***Sub-Saharan Africa*** is projected to decline at an annual rate of 1 percent to 5.6 kilograms during the 2010–30 period. However, due to rapid population growth, which is estimated at 2.3 percent annually during the 2010–30 period, total food fish consumption demand would grow substantially (by 30 percent between 2010 and 2030). On the other hand, projected production increase is only marginal. Capture production is projected to increase from an average of 5,422 thousand tons in 2007–09 to 5,472 thousand tons in 2030, while aquaculture is projected to increase from 231 thousand tons to 464 thousand tons during the same period. While the region has

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[3] Reduction into fishmeal and fish oil and inventory are the two other fish utilization categories considered in this study.

been a net importer of fish, under the baseline scenario, its fish imports in 2030 are projected to be 11 times higher than the level in 2000. As a result, the region's dependency on fish imports is expected to rise from 14 percent in 2000 to 34 percent in 2030.

Looking across species, the fastest supply growth is expected for tilapia, carp, and *Pangasius*/catfish. Global tilapia production is expected to almost double from 4.3 million tons to 7.3 million tons between 2010 and 2030.

The demand for fishmeal and fish oil will likely become stronger, given the fast expansion of the global aquaculture and sluggishness of the global capture fisheries that supply their ingredients. During the 2010–30 period, prices in real terms are expected to rise by 90 percent for fishmeal and 70 percent for fish oil. Nonetheless, with significant improvements anticipated in the efficiency of feed and management practices, the projected expansion of aquaculture will be achieved with a mere 8 percent increase in the global fishmeal supply during the 2010–30 period. In the face of higher fishmeal and fish oil prices, species substitution in production is also expected, where production of fish species that require relatively less fish-based feed is preferred.[4]

SCENARIO ANALYSIS

Besides the baseline (most plausible) scenario, six additional scenarios are implemented to investigate potential impacts of changes in the drivers of global fish markets (table E.2).

TABLE E.2: Summary Results for Year 2030 under Baseline and Alternative Scenarios

	BASELINE	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6	
		FASTER GROWTH	WASTE	DISEASE	CHINA	CAPTURE GROWTH	CC-a	CC-b
Total fish supply (million tons)	186.8	194.4	188.6	186.6	209.4	196.3	184.9	185.0
Capture supply (million tons)	93.2	93.2	93.2	93.2	93.2	105.6	90.2	90.2
Aquaculture supply (million tons)	93.6	101.2	95.4	93.4	116.2	90.7	94.7	94.8
Shrimp supply (million tons)	11.5	12.3	11.5	11.2	17.6	11.6	11.5	11.4
Salmon supply (million tons)	5.0	5.4	5.1	5.0	6.1	5.0	4.8	4.8
Tilapia supply (million tons)	7.3	9.2	7.4	7.3	7.4	7.2	7.3	7.3
Fishmeal price ($/ton; % to baseline)	1,488.0	13%	–14%	–1%	29%	–7%	2%	2%
Fish oil price ($/ton; % to baseline)	1,020.0	7%	–8%	–0%	18%	–6%	3%	3%
CHN per capita consumption (kg/capita/year)	41.0	43.3	41.5	40.9	64.6	42.2	40.7	40.7
AFR per capita consumption (kg/capita/year)	5.6	5.9	5.8	5.6	5.4	6.4	5.5	5.5

Source: IMPACT model projections.
Note: CC-a = climate change with mitigation, CC-b = climate change without drastic mitigation, CHN = China, AFR = Sub-Saharan Africa.

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[4] This substitution pattern, however, cannot be confirmed in the model results at the aggregate level. This is likely due to the fact that fishmeal-intensive species, such as shrimp and salmon, tend to have higher income elasticities of demand than low-trophic species and effects of output demand growth likely overweigh the effects of higher input costs.

Scenario 1 addresses the case where all aquaculture is able to grow faster than under the baseline scenario by 50 percent between 2011 and 2030. In particular, the scenario assumes faster technological progress such that aquaculture would be able to supply a given amount at a lower cost (supply curves would shift outward), but it assumes the same feed requirements per unit weight of aquaculture production. Technical progress may include genetic improvement, innovations in distribution, improvements in disease and other management practices, control of biological process (life cycle) for additional species, and improvements in the condition of existing production sites and expansion of new production sites. While these technical changes are implicit in the baseline parameters, this scenario accelerates the changes by 50 percent. At the global level, the model predicts that aquaculture production in 2030 would expand from 93.2 million tons under the baseline case to 101.2 million tons under this scenario. The model predicts that the faster growth in all aquaculture would stress the fishmeal market and this effect would dictate which species and which regions would grow faster than the others. Under this scenario, tilapia production in 2030 would be 30 percent higher than in the baseline case; production of mollusks, salmon, and shrimp in 2030 would be higher by more than 10 percent. As a result, relative to the baseline scenario, all fish prices in 2030 in real terms would be lower by up to 2 percent, except for the price of the other pelagic category, which is used as an ingredient of fishmeal and fish oil. Fishmeal price in 2030 would be 13 percent higher than in the baseline case, while fish oil price would be higher by 7 percent.

Scenario 2 investigates how expanded use of fish processing waste in fishmeal and fish oil production might affect the market of these fish-based products, where, in addition to the baseline countries, all countries that produce fishmeal or fish oil are now assumed to have the option to use waste in their production starting in 2011. Aquaculture expansion has relied in large part on improvements surrounding feed, including feed composition for nutrition and digestibility as well as cost effectiveness, genetics of fish, and feeding techniques and practices. While anticipated continuation of these improvements is already incorporated in the baseline parameters, this scenario addresses possible expansion of feed supply by utilizing more fish processing waste in the production of fishmeal and fish oil. The model indicates that fishmeal production in 2030 would increase by 12 percent and fishmeal price would be reduced by 14 percent relative to the 2030 results in the baseline case. This would boost the aquaculture production of freshwater and diadromous fish, salmon, and crustaceans. Although cost is involved in selection, collection, and reduction of fish waste, use of the additional feedstock represents a great opportunity to increase fishmeal and fish oil production, especially where organized fish processing is practiced. For example, 90 percent of the ingredients used in fishmeal produced in Japan come from fish waste (FAO data).[5] Globally, about 25 percent of fishmeal is produced with fish processing waste as ingredient (Shepherd 2012). Increased use of fish waste would reduce the competition for small fish between fishmeal production (that is, indirect human consumption) and direct human consumption.

Scenario 3 introduces a hypothetical major disease outbreak that would hit shrimp aquaculture in China and South and Southeast Asia and reduce their production by 35 percent in 2015. The model is used to simulate its impact on the global markets and on production in affected and unaffected countries between 2015 and 2030. Results suggest that countries unaffected by the disease would increase their shrimp production initially by 10 percent or more in response to the higher shrimp price caused by the decline in the world shrimp supply. However, since Asia accounts for 90 percent of global shrimp aquaculture, the unaffected regions would not entirely fill the supply gap. The global shrimp supply would contract by 15 percent in the year of the outbreak. However, with the simulated recovery, the projected impact of disease outbreak on the global aquaculture is negative but negligible by 2030.

Scenario 4 is a case where consumers in China expand their demand for certain fish products more aggressively than in the baseline case. The scenario is specified such that Chinese per capita consumption of high-value shrimp, crustaceans, and salmon in 2030 would be three times higher than in the baseline results for 2030 and that of mollusks double the baseline value. These are higher-value commodities

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[5] Since domestic production is insufficient, Japan imports fishmeal, mainly from Peru.

relative to other fish species and, except for mollusks, they require fishmeal in their production. Under this scenario, global aquaculture production could increase to more than 115 million tons by 2030. This scenario would benefit the producers and exporters of these high-value products, such as Southeast Asia and Latin America. While overall fish consumption in China in 2030 would be 60 percent higher relative to the baseline case, all other regions would consume less fish by 2030. For Sub-Saharan Africa, per capita fish consumption in 2030 would be reduced by 5 percent under this scenario, to 5.4 kilograms per year. Fishmeal price in 2030 in real terms would increase by 29 percent and fish oil price by 18 percent relative to the baseline case. Over 300 thousand tons more of fishmeal would be produced, by reducing additional 1 million tons of fish otherwise destined for direct human consumption.

Scenario 5 simulates the impacts of productivity increase of capture fisheries in the long run where fisheries around the globe let the fish stocks recover to the levels that permit the maximum sustainable yield (MSY). In *The Sunken Billions* (Arnason, Kelleher, and Willmann 2009), it is estimated that effectively managed global capture fisheries are assumed to sustain harvest at 10 percent above the current level. In this scenario, a gradual increase in the global harvest is assumed, achieving this augmented level in 2030. If this scenario were to be realized, the world would have 13 percent more wild-caught fish by 2030, relative to the baseline projection. In this scenario the resulting increase in the production of small pelagic and other fish for reduction into fishmeal and fish oil would reduce the pressure on the feed market, which results from the rapid expansion of aquaculture production that is expected to continue. Fishmeal price is expected to be lower by 7 percent than under the baseline case. Production in all regions would benefit from this scenario. In particular, Sub-Saharan Africa would achieve fish consumption in 2030 that is 13 percent higher than under the baseline scenario. This is because increased harvest is likely to be consumed within the region, rather than being exported. Distributional implications of the scenario would be even higher if stock recovery process is accompanied by efforts to substantially reduce inefficiency often prevalent in the harvest sector. Though confounded with losses due to lower-than-MSY yield, the cost of inefficient harvest sector is estimated to amount to $50 billion each year at the global level (Arnason, Kelleher, and Willmann 2009). On the other hand, relative abundance of fish would dampen fish prices so that aquaculture production in 2030 would be reduced by 3 million tons relative to the baseline case.

Scenario 6 considers the impacts of global climate change on the productivity of marine capture fisheries. Changes in the global fish markets are simulated based on the maximum catch potentials (maximum sustainable yield, MSY) predicted by Cheung and others (2010) under two scenarios: one with mitigation measures in place so that no further climate change would occur beyond the year 2000 level and the other with continuing trend of rising ocean temperature and ocean acidification. Their mitigation scenario yields a 3 percent reduction in the global marine capture fisheries production in 2030 relative to the baseline scenario, while no-mitigation scenario would result in marginal additional harm to the capture fisheries at the global level (reduction of harvest by 0.02 percent in 2030). While the aggregate impact is negligible, distribution of the expected changes in catches widely varies across regions. In principle, high-latitude regions are expected to gain while tropical regions lose capture harvest (Cheung and others 2010). The highest gains are expected in the Europe and Central Asia (ECA) region (7 percent) and the largest losses in the Southeast Asia (SEA; 4 percent) and East Asia and Pacific (EAP; 3 percent) regions. The model predicts that market interactions will attenuate the impact of the changes in the capture harvest and its distribution. Aquaculture will likely increase its production to offset the small loss in the capture harvest. Imports and exports will likely smooth the additional supply-demand gap caused by the changes in capture harvest, and fish consumption levels in 2030 are not expected to change in any region due to climate change. The simulated loss in global catches is relatively small in part because this study provides medium-term projections into 2030, whereas climate change is a long-term phenomenon. Given the structure of the IMPACT model, many small island states were grouped together in the "rest of the world" (ROW) model region. Therefore, this simulation exercise is unable to analyze the impact of climate changes in small island states, including Pacific island countries and territories.

OVERALL LESSONS

We have developed a rigorous analytical tool that is capable of making projections on the implications of the ongoing shifts on global fish production and reallocation of fish supply through international trade. The model, though with known limitations, is successfully calibrated and employed to evaluate different policies and alternative events and to illustrate likely evolution of the global seafood economy.

From the modeling exercise and scenario analyses, it is clear that aquaculture will continue to fill the growing supply-demand gap in the face of rapidly expanding global fish demand and relatively stable capture fisheries. While total fish supply will likely be equally split between capture and aquaculture by 2030, the model predicts that 62 percent of food fish will be produced by aquaculture by 2030. Beyond 2030, aquaculture will likely dominate future global fish supply. Consequently, ensuring successful and sustainable development of global aquaculture is an imperative agenda for the global economy. Investments in aquaculture must be thoughtfully undertaken with consideration of the entire value chain of the seafood industry. Policies should provide an enabling business environment that fosters efficiency and further technological innovations in aquaculture feeds, genetics and breeding, disease management, product processing, and marketing and distribution. The same is true for capture fisheries—developing enabling environment through governance reforms and other tools represents the first step toward recovery of overharvested fish stock and sustainability of global capture fisheries.

Chapter 1: INTRODUCTION

1.1. MOTIVATIONS AND OBJECTIVE

Two notable manuscripts were published in 2003 on global fisheries, aquaculture, and seafood trade. The *Fish to 2020* study by Delgado and others (2003) provided a comprehensive global overview of the food fish supply and demand balance and trends observed during the 1970s through 1990s. These analyses formed the basis of forward-looking projections to 2020 using IFPRI's IMPACT model. The *International Seafood Trade* by Anderson (2003) drew insights into global seafood trade by discussing it in the context of broader food commodity trade. Focusing on key fish species and major players in the markets, Anderson further analyzed the factors that drove global seafood trade and prices.

Three key observations motivated these two publications: stagnant global capture fisheries, rapid expansion of aquaculture, and the rise of China in the global seafood market. Separately and using different approaches and methods, both studies analyzed these trends and their implications for the global seafood economy. Ten years later, many of these trends and the associated concerns and challenges have continued, as documented in the FAO's *State of World Fisheries and Aquaculture 2012*. According to the FAO report, since the mid-1990s, production from global capture fisheries has stabilized around 90 million tons, with marine fisheries contributing around 80 million tons. This represents a substantial increase from 18.7 million tons in 1950, of which 16.8 million tons were from marine waters, but the expansion of marine capture fisheries was achieved in part at the cost of deteriorating regional fish stocks. Since the beginning of FAO stock assessments, the proportion of overexploited stocks has steadily increased from 10 percent in 1974 to 26 percent in 1989 and, with a slowing trend, to 30 percent in 2009. Furthermore, most of the stocks of the 10 key fish species (which represent 30 percent of marine capture production) are fully harvested, and there is little prospect for significant increase in the supply of these species from capture fisheries.

In contrast, the rapid expansion of global aquaculture production has continued with no sign of peaking. During the past three decades, global aquaculture production expanded at an average annual rate of more than 8 percent, from 5.2 million tons in 1981 to 62.7 million tons in 2011 (FishStat). Aquaculture's contribution to total food fish supply grew from 9 percent in 1980 to 48 percent in 2011 (FAO 2013). The estimated number of fish farmers also grew from 3.9 million in 1990 to 16.6 million in 2010. The rapid and massive growth of aquaculture production has contributed significantly to increased production of species whose supply would be otherwise constrained given the lack of growth in capture fisheries production. As a result, the prices of these species (for example, salmon and shrimp) declined, especially during the 1990s and in the early 2000s (FAO 2012).

Seafood demand from China, the single largest market for seafood, has grown substantially, and its influence on the global fish markets and trade has intensified. China's per capita fish consumption grew to 33.1 kilograms per year in 2010, at an annual rate of 6 percent between 1990 and 2010. So far, due particularly to growth in aquaculture production, fish production in China has kept pace with the growth in consumption demand from population and income growth. While Asia accounted for 88 percent of world aquaculture production by volume in 2011, China alone accounted for 62 percent. Aquaculture now represents more than 70 percent of the total fish produced in China. With the rapid growth in production, China's share in the global fish production grew from 7 percent in 1961 to 35 percent in 2011. Notwithstanding that China consumes 34 percent of global food fish supply, it is still a net exporter of food fish. Nevertheless, China is both an importer and exporter of fish.

China became the third-largest fish-importing country by value in 2011 after Japan and the United States. Part of the fish imports is raw material to be reexported after processing. China now represents 13 percent of world fish export in value, amounting to $17.1 billion in 2011 and $18.2 billion in 2012 (FAO 2013).

Thus, the factors that that motivated Delgado and others (2003) and Anderson (2003) are still very relevant after a decade and will likely continue to shape the evolution of the global seafood economy through international trade. According to the FAO (2012), seafood is among the most heavily traded food commodities, with 38 percent of all fish produced being exported in 2010. Fish and fish products account for 10 percent of agricultural exports in value terms. Nominally, world trade of fish and fish products increased from $8 billion in 1976 to $128 billion in 2012, which in real terms translates into an average annual growth rate of 4.0 percent. Developing countries are well integrated in the global seafood trade, with more than 54 percent of all fishery exports by value and more than 60 percent by quantity (in live weight equivalent) coming from developing countries. The FAO (2012) attributes the growing participation of developing countries in the global fish trade to, at least in part, the generally low import tariffs on fish and fish products imposed by developed countries, which are dependent on fish imports (and domestic aquaculture) due to sluggish capture fisheries. Furthermore, the FAO (2012) argues, while growing demand, trade liberalization policies, globalization, and technological innovations have led to an increase in global fish trade, improvements in processing, packing, and marketing and distribution have altered the way fish products are prepared and marketed.

Given these observations, this report addresses the following suite of questions: how will global seafood trade evolve further in the next 15–20 years? In particular, to what extent and at what rate will aquaculture be able to continue to expand as fish demand growth keeps rising in China and elsewhere? How will increased fish supply from aquaculture be distributed across regions?

Along with these continuing trends, some new and renewed concerns have arisen. With the rapid growth of aquaculture, there have been major disease outbreaks within the aquaculture sector in various countries, including white-spot syndrome virus in shrimp (global), infectious myonecrotic virus in shrimp (Indonesia and Brazil), and more recently infectious salmon anemia (ISA) virus in Chile (OECD 2010). Early mortality syndrome, a disease recently found in farmed shrimp, has caused substantial losses in China, Vietnam, Malaysia, and Thailand (Leaño and Mohan 2012). These outbreaks provide a warning to other rapidly expanding aquaculture sectors of the importance of disease management and adoption of best practices (Bondad-Reantaso and others 2005). Global climate change will likely exacerbate the susceptibility of aquaculture to disease (see, for example, Leung and Bates 2013). In addition, climate change will cause further changes in the oceans and aquatic ecosystems and therefore pose threats to fish populations and the economies that depend on them (World Bank 2013b).

Despite the overall growth of fish consumption and trade that has occurred in much of the world, a decline in per capita fish consumption has been observed in some Sub-Saharan African countries, such as Gabon, Malawi, South Africa, and Liberia (FAO 2012), as well as in some developed countries, such as Japan and the United States. Per capita fish consumption in the Africa region is roughly half of the global average (FAO 2012). The decline in per capita fish consumption has far-reaching consequences for the intake of protein and micronutrients important for human growth and development (Oken and others 2008, USDA 2012).

Opportunity

In the face of these concerns and challenges, however, there has been an important and promising shift in the approach to global fisheries and aquaculture challenges. The shift is driven in part by the growing body of knowledge on the key drivers of change within the global fish markets and the understanding of management and governance of capture fisheries and aquaculture. For example, the *Sunken Billions* study by the World Bank and the FAO (Arnason, Kelleher, and Willmann 2009) endeavored to quantify, in a clear and convincing way, the extent of economic losses due to the poor management of the global marine fisheries; the estimated losses amount to $50 billion *each year*. A recent article by Costello and others (2012) illustrated how sustainable levels of stocks in marine fisheries can be regained if appropriate management changes are undertaken, especially in those fisheries that are less studied and have not been as closely monitored or assessed for their stock levels. Similarly, Gutiérrez, Hilborn, and Defeo (2011) demonstrated that community-based comanagement of aquatic resources is the only realistic solution for the majority of the world's fisheries when strong community leadership is present and is combined with effective resource management tools such as quotas and marine protected areas.

The *Fish to 2020* study raised concerns regarding environmental impacts of aquaculture expansion, including massive changes in land use, pollution of neighboring waters with effluent, and the spread of disease among fish farms. While these concerns remain today, there has been considerable discussion surrounding sustainable aquaculture (Ward and Phillips 2008, Brummett 2013). Sustainability has now been recognized as the principal goal of aquaculture governance by many governments (FAO 2012). Furthermore, the *Fish to 2020* study projected that the demand for fishmeal and fish oil would continue to increase with aquaculture expansion and that this could have serious implications for the viability and health of the capture fisheries of those species used in feed production. While it could lead to an overexploitative outcome as predicted by Delgado and others (2003), increasing demand and the associated rise in price for those fish species could also offer a remarkable opportunity for fisheries to implement appropriate management and utilize the resources profitably and sustainably. Moreover, driven by the high cost of protein, especially fishmeal, aquaculture has achieved substantial innovation in feeds and efficiency improvement in feeding practices in recent years (Rana, Siriwardena, and Hasan 2009). In trying to reduce dependence on fishmeal, research institutions and the aquaculture feed industry have conducted numerous studies, which have led to an "impressive reduction in the average inclusion of fishmeal in compound feeds for major groups of farmed species" (FAO 2012). As a result, according to FAO data, a 62 percent increase in global aquaculture production was achieved when the global supply of fishmeal declined by 12 percent during the 2000–08 period. The use of fish processing waste in fishmeal production has also increased (Chim and Pickering 2012, FAO 2012, Shepherd 2012).

Building on knowledge and lessons learned from a variety of experiences, there is considerable momentum toward combined efforts of public and private stakeholders, donors and recipients, development organizations such as the World Bank and the FAO, civil society organizations, and advanced research institutions to improve the health of the oceans and the performance and sustainability of global fisheries. For example, the Rio+20: UN Conference on Sustainable Development in June 2012 affirmed "the necessity to promote, enhance and support more sustainable agriculture, including . . . fisheries and aquaculture" and stressed "the crucial role of healthy marine ecosystems, sustainable fisheries and sustainable aquaculture for food security and nutrition and in providing for the livelihoods of millions of people."

In *Fish to 2030*

In this new and dynamic context, the *Fish to 2030* study extends the projections of the global supply, demand, and trade of fish and fish products to 2030, incorporating lessons learned in *Fish to 2020* and new developments in the global fish markets since it was published. Linking the expertise of the IMPACT modeling team at IFPRI, the sectoral knowledge of the fisheries group at the World Bank, and comprehensive data provided by the Fisheries and Aquaculture Department of the FAO, the fish component of IMPACT is substantially improved over the model version used in *Fish to 2020*. In particular, the fish species and global regions are much more disaggregated in the new version so that more targeted analyses are possible. Chapter 2 presents the details of how the model is modified and how more recent data and other information are incorporated into the analysis.

Using the model, this study generates a series of projections of fish supply, demand, and trade into 2030. The first set of results is based on the "baseline scenario" that reflects the currently observed trends of supply and demand, and thus it is deemed the "most plausible" case. These are presented in chapter 3.

Once a plausible baseline level of fish production, consumption, and trade is established out to 2030, the model is used to examine the implications of several alternative scenarios that are designed to illustrate how shocks and changes to the production or consumption side of the world fish economy trigger market responses. One scenario introduces impacts of climate change on the health and productivity of marine ecosystems, in particular through change in ocean temperatures and levels of acidity in ocean waters (Brown and others 2010, Cheung and others 2010). The results for six alternative scenarios are presented in chapter 4.

1.2. LESSONS FROM *FISH TO 2020*

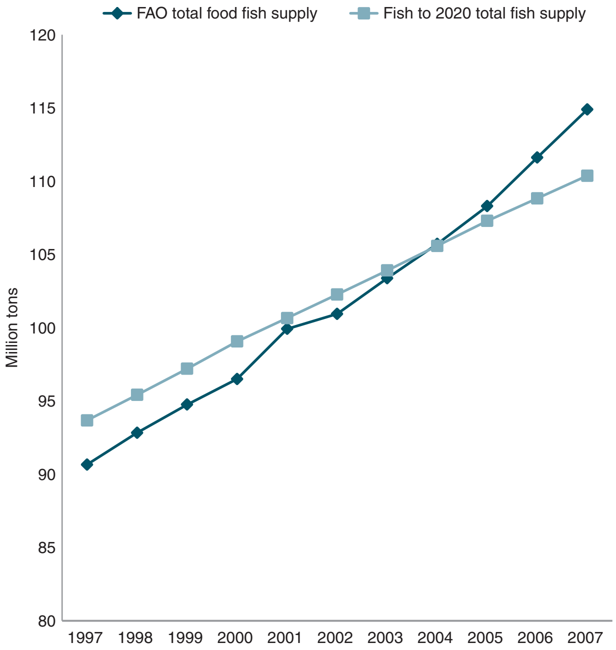
In this section, we revisit the *Fish to 2020* study (Delgado and others 2003) and review the IMPACT model's predictive power by comparing their projections to the actual evolution of global markets since it was published. Further, we summarize their key findings and discuss how the model can be improved to better address the same issues. The discussions here will lead to the two subsequent sections: the strategy to improve the IMPACT fish component (section 1.3) and the policy research questions addressed in this study (section 1.4).

Global Food Fish Production

The *Fish to 2020* study used the IMPACT model to generate projections of global food fish production, consumption, and trade for the period 1997 to 2020. The study addressed only fish destined for human consumption (food fish), and thus not all species produced by capture fisheries or aquaculture were included. Among the excluded species were those "reduced" into fishmeal and fish oil and not used for human food. The model projected that the global food fish supply would grow from 93.2 million tons in 1997 to 130.1 million tons by 2020. Of those, capture fisheries was projected to grow from 64.5 million tons in 1997 to 76.5 million tons in 2020, to represent 59 percent of the total projected supply in 2020. Aquaculture production, on the other hand, was projected to grow from 28.6 million tons in 1997 up to 53.6 million tons by 2020, representing the remaining 41 percent of the projected supply in 2020. According to the projections, by 2020 developing countries would be responsible for 79 percent of world food fish production, while 77 percent of global fish consumption would occur in developing countries.

A decade later, one can assess the quality of the *Fish to 2020* model projections by contrasting them with actual data. In figure 1.1, a reasonably close congruence is seen between the *Fish to 2020* projections and actual evolution of the global food fish supply for the first decade of the projection period (that is, 1997–2007). However, the results suggest an overprediction of capture production and an underprediction of aquaculture production (not shown in the figure). Over the 1997–2007 period, global capture fisheries were projected to grow at 0.8 percent annually, while they actually grew at the average annual rate of 0.5 percent. The projection of aquaculture growth rate in the *Fish to 2020* study was 3.4 percent a year, but in reality aquaculture grew at the rate of 7.1 percent per year on average. Given that the model incorporated the best available information, the divergence between the model projections and actual data implies that aquaculture expanded much more rapidly than the expectations of experts. A better representation of aquaculture expansion trends is warranted in the current modeling exercise in *Fish to 2030*.

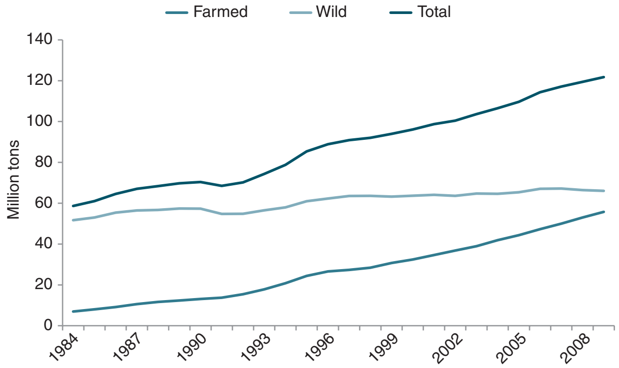
FIGURE 1.1: Comparison of *Fish to 2020* Projections and FAO Data for Global Food Fish Supply



Sources: Delgado and others 2003 and FAO Fisheries Information and Statistics Branch (FIPS) food balance sheets (FBS) data.
Note: As is detailed in section 2.3, data on global fish consumption were available through 2007 at the time of model preparation.

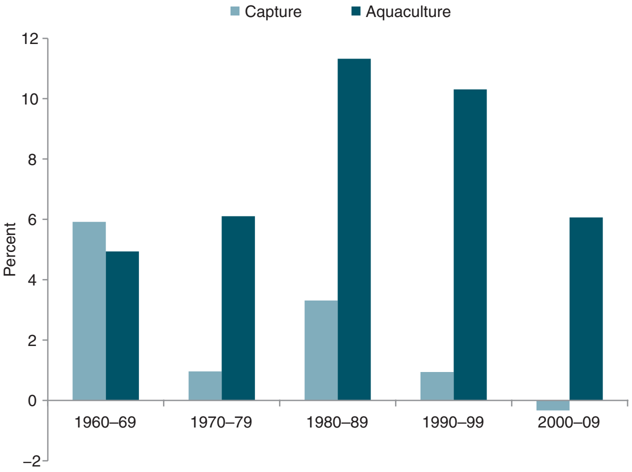
The next two figures portray the context in which *Fish to 2020* study was prepared. Figure 1.2 illustrates the evolution of the world food fish production since 1980s. The rise of aquaculture in the past three decades is clear in the figure. Aquaculture accounted for only 12 percent of world food fish production in 1984, while it accounted for 46 percent in 2009. In fact, aquaculture is one of the most rapidly growing food sectors globally (FAO 2012), which is in a sharp contrast with stagnant capture fisheries production. The stagnation of capture fisheries is also seen in figure 1.3, where even a negative growth (decline) is recorded for 2000–09. The figure also illustrates how rapidly aquaculture grew during the 1980s and 1990s. After growing at an average annual rate of more than 10 percent,

FIGURE 1.2: Evolution of World Food Fish Production, 1984–2009



Source: FishStat.

FIGURE 1.3: Average Annual Growth Rates of Capture and Aquaculture Production, 1960–2009



Source: FishStat.

growth in world aquaculture production has slowed. Nevertheless, aquaculture continued to grow at more than 6 percent annually during the 2000s. Adequately capturing this rapid growth trajectory of aquaculture constitutes one of the major objectives in the effort to improve the modeling framework in *Fish to 2030*.

Global Food Fish Consumption

The *Fish to 2020* study projected that developing countries would consume a much greater share of the world's fish in the future and that trade in fish commodities would also increase. The report projected that fish consumption in developing countries would increase by 57 percent, from 62.7 million tons in 1997 to 98.6 million tons in 2020. Rapid population growth, increasing affluence, and urbanization were considered to drive the demand for fish as well as for livestock products in developing countries. By contrast, fish consumption in developed countries was projected to increase by about only 4 percent, from 28.1 million tons in 1997 to 29.2 million tons in 2020.

The *Fish to 2020* study concluded that the projected fish consumption trajectories to 2020 could not be met by capture fisheries alone and would only be feasible if aquaculture continued to grow aggressively. Rapid expansion of aquaculture was also discussed in the context of its implications for dietary diversification and food security among the poor in developing countries. It was expected that aquaculture could augment fish supply and reduce prices, as observed for low-value freshwater fish in Asia, and could benefit poor households in food insecure parts of the world.

The report projected stagnant fish consumption in Sub-Saharan Africa and, as discussed earlier, the FAO (2012) reports declining per capita fish consumption in some Sub-Saharan African nations during the 2000s. The reported food fish consumption in Africa in 2009 was 9.1 kilograms per capita per year (FAO 2012). Whether this will grow in the future with affordable, aquaculture-sourced fish supply is an important policy research question we will keep coming back to throughout this study.

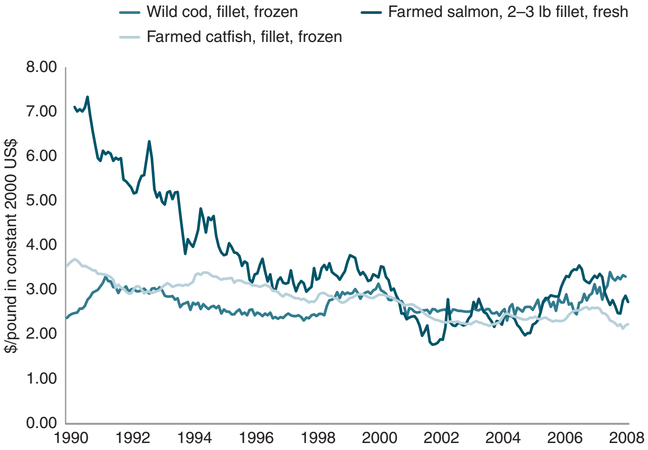
Global Food Fish Trade and Prices

One of the policy research questions addressed in the *Fish to 2020* study was whether the growth patterns for fish demand would continue along the same trends that have been observed in developed and developing regions, and how price and trade patterns would develop over time to determine fish distribution across these regions. Given the relatively stable capture fisheries production for the past decades, the only sector with the ability to grow seemed to be the aquaculture sector, even though the capacity for growth might not uniformly exist in all regions. If aquaculture were to grow to meet the growing consumption demand, what would be the implications for trade in food fish and the prices of those products? The *Fish to 2020* study projected, except under their "faster aquaculture expansion" scenario, that fish prices would rise more dynamically than prices for any other food product. This implied that there would be regional imbalances in fish supply and demand and that international trade would respond by reallocating supplies from more productive, surplus regions to those regions that tend to fall in deficit of food fish. In other words, the model projected that rising fish prices would be a catalyst to stimulate further international trade of fish to correct for regional imbalances.

The IMPACT model price projections, however, need to be interpreted with caution. As figure 22 in the *State of the World Fisheries and Aquaculture* (FAO 2012) indicates, at the aggregate level, average fish prices declined in real terms during the 1990s and, even with an increase during the 2000s, fish prices in 2010 were still lower than the 1990 levels. In general, falling prices were observed for those species that achieved rapid expansion of aquaculture production (FAO 2012), which in turn was driven by technological advances in the animal genetics and in the production and utilization of feeds (Brummett 2003). Those species with falling prices include shrimp, salmon, and some fish species farmed in freshwater.

The difficulties the IMPACT model faced in addressing species-specific trends in production and prices originated in part from their species aggregation strategy. In the *Fish to 2020* study, the species were aggregated into four commodities: low-value food fish, high-value finfish, crustaceans, and mollusks. However, more importantly, there seem to be structural limitations in the extent to which the IMPACT model could represent the dynamics of world fish prices. The IMPACT model was originally developed for commodities whose international markets are relatively more established and mature (for example, grains and meat), while aquaculture is a relatively new and far more dynamic industry, with new technological advances being made continuously for existing and new species as well as for processing, packaging, and distribution. Some aquaculture species, such as salmon, have already gone through a series of substantial technological changes and their markets have fairly matured. During the process, the production cost has been substantially reduced—and world salmon price has dropped considerably (figure 1.4). For those relatively new aquaculture species, such as tilapia and *Pangasius*, technological advances have only begun and similar downward trends of real prices are expected in the near future. Aquaculture species that are not yet commercially farmed may become commercially viable in the future, and they will likely follow similar paths of market maturity as other species (Asche 2011; Brummett 2003, 2007). If the model indeed had difficulties in incorporating such dynamisms of global aquaculture, this poses a challenge for the model improvement effort in this study as well.

FIGURE 1.4: Trends of Real Prices of Selected Seafood



Source: USDA, Urner-Barry Publications, U.S. Department of Commerce (USDC)/ National Marine Fisheries Service (NMFS). Reproduced from Anderson 2012.

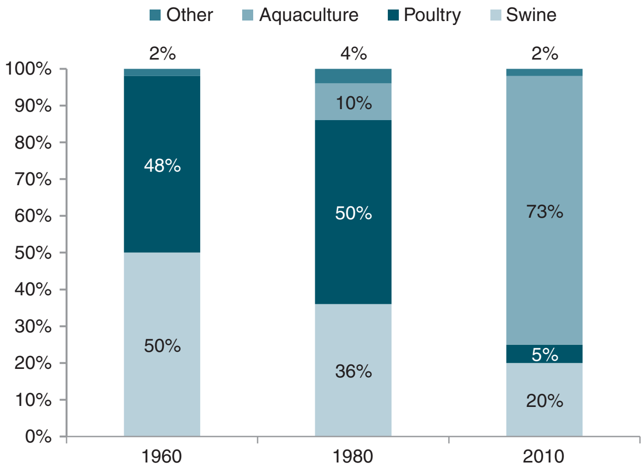
Aquaculture-Capture Interactions

The *Fish to 2020* study addressed the sustainability of marine capture fisheries in the face of rapid expansion of global aquaculture and associated strong growth in fishmeal demand. An "ecological collapse" scenario simulated the market-level impacts of a gradual but catastrophic collapse of the marine fisheries (a decline of food fish capture fisheries at the annual rate of 1 percent was applied). As expected, the results were striking in terms of price increases for fishmeal and fish oil as well as for fish commodities that use these products in production.

The study also emphasized the role of technology, especially technology to increase the efficiency with which fishmeal and fish oil are converted into farmed fish. A scenario where such feed conversion efficiency would improve twice as fast relative to the baseline scenario resulted in reduced prices of fishmeal and fish oil, but practically no change was projected for the levels of fish prices or fish supply. The latter results seem counterintuitive and warrant further investigation.

The *Fish to 2020* study has identified production and use of fishmeal and fish oil as one of the key interactions between aquaculture and capture fisheries and between fisheries (capture or aquaculture) and the natural environment. However, the study only addressed

FIGURE 1.5: Global Fishmeal Use



Source: Shepherd 2012.

food fish, and fish species that are used for production of fishmeal and fish oil were left out. Thus the scope and the depth of the analyses on the aquaculture-capture interactions through feed fish were limited. Furthermore, as illustrated in figure 1.5, the utilization of global fishmeal has evolved over the past half century. The importance of aquaculture as user of fishmeal has grown substantially as a result of the industry's rapid growth since the 1980s. From this observation, it is likely that fishmeal-intensive segments of the aquaculture industry (for example, salmon and shrimp) increasingly affect the dynamics of fishmeal and fish oil markets. In this context, modeling of demand for fishmeal and for fish oil as a function of aquaculture production seems essential.

1.3. STRATEGY OF IMPROVING MODELING FRAMEWORK IN *FISH TO 2030*

From the review of Delgado and others (2003), we have identified several directions in which the IMPACT model can be improved for use in the *Fish to 2030* analysis. In this section we summarize the strategy in adding a fisheries component to the existing IMPACT model. Detailed descriptions of the model and data are provided in chapter 2.

Expansion of Fish Product Category

The four broad classifications of fish used in the *Fish to 2020* study (low-value food fish, high-value finfish, crustaceans, and mollusks) are expanded in this study. A more disaggregated representation of fish species enables better representation of the dynamics of high-value markets, such as shrimp and salmon, and to separate them from other important and fast-growing aquaculture species, such as tilapia and *Pangasius*. The production side of the newly modified IMPACT model contains 16 fish species groups, which is aggregated into nine commodities for the modeling of consumption and trade. This disaggregation, based mainly on feeding requirements of fish species, is also much less arbitrary than the previous classification, as the same species may be of higher or lower value depending on value-added processes (for example, tuna fillets in an expensive restaurant versus canned tuna) or depending on countries and regions. For example, relatively high-value export species in Sub-Saharan Africa, such as Nile perch, were categorized as low value. Note also that the new version of the model includes production of all types of fish, including those destined for fishmeal and fish oil production as well as for direct human consumption and other uses. This makes possible the modeling of explicit links between fishmeal and fish oil production and their use in aquaculture.

Realistic Treatment of Capture Production Growth

As seen in the previous section, the *Fish to 2020* study tended to project overly optimistic growth of capture fisheries and underestimate the growth of aquaculture in relation to the actual data between 1997 and 2007. We suspect that the rising fish prices in the model, combined with capture supply that was specified overly sensitive to fish prices, drove the results. Consequently, the projected capture supply increased more than the actual data indicated, crowding out the growth of aquaculture in the model.

In response to these shortcomings, this study treats the growth of capture fisheries as entirely exogenous—that is, no supply response to price changes is modeled for capture fisheries. In terms of modeling price responses of supply, we maintain a solid focus on aquaculture. The rationale behind this decision is that, given relatively stable capture fisheries in the last decades and the fact that dynamic biological processes determine the amount of fish stock available for harvest, modeling of price-responsive capture supply in a static sense seems unrealistic. The open-access nature of many capture fisheries also further complicates the representation of fish supply behavior (Arnason, Kelleher, and Willmann 2009). Thus, rather than allowing capture supply to respond freely to increasing or decreasing fish prices, in this study we exogenously specify the behavior of capture fisheries based on the observed trends and according to alternative scenarios. However, results on the final distribution of capture fisheries production will depend on relative prices and demand in each country.

Incorporating Fishmeal and Fish Oil Markets

In the new version of IMPACT, production and utilization of fishmeal and fish oil are modeled explicitly. The utilization of lower-value, smaller pelagic and other species for "reduction" and the resulting production of fishmeal and fish oil are now endogenized in a much more complete way. That is, the supply of fishmeal and fish oil and the demand for the ingredient fish species are now determined in the model as a result of responses to the price of those commodities. The demand for the fish-based feed is also modeled as price responsive. Further, feed demand is now calculated for each species based on the biological requirements and their trends. The new treatment of fishmeal and fish oil production and utilization is entirely parallel to the way that plant-based oil and meal production and utilization have been treated in the IMPACT model, where oil-bearing crops (soybean and oilseeds) are used as input into the production of vegetable oil and the meal produced as by-product is used as input for livestock production.

In addition to small fish from capture fisheries, the newly modified IMPACT model also accounts for the use of fish processing waste in production of fishmeal and fish oil. While this is an area that is not well documented, an increase in the importance of waste use is suggested (Chim and Pickering 2012, FAO 2012, Shepherd 2012). Incorporation of fish processing waste enables a comprehensive analysis of the links of the global fish markets through fishmeal and fish oil and implicitly through fish processing.

Model Calibration

In this study, considerable effort is taken to calibrate the model projections to observed data. Such an exercise was not conducted in the *Fish to 2020* study. By ensuring that the near-term projections closely align with the most recent data, further confidence about the future projections is gained. The calibration exercise also has enabled us to appreciate the issues and problems regarding the available fisheries statistics, and, as a result, much time has been spent identifying the causes of data problems and devising ways to reconcile those problems. The exercise is detailed in section 2.4 and calibration results are presented in section 2.5 of chapter 2.

1.4. POLICY RESEARCH QUESTIONS

Using the modified IMPACT model, this study takes on the challenge of inferring the short- to medium-run picture of the global fish markets. The discussion begins with the baseline scenario, which reflects the trends that are currently observed and is deemed most plausible given the current knowledge. Subsequently, the following six illustrative scenarios are introduced:

- Scenario 1: Faster aquaculture growth
- Scenario 2: Expanded use of fish processing waste in fishmeal and fish oil production
- Scenario 3: A major disease outbreak in shrimp aquaculture in Asia
- Scenario 4: Accelerated shift of consumer preferences in China
- Scenario 5: Improvement of capture fisheries productivity
- Scenario 6: Impacts of climate change on the productivity of capture fisheries

The results from the baseline and the six scenarios are used to understand how the trends in the factors considered as key drivers of change actually drive the model output. For example, we posit that the growth of demand for fish products is based on trends in regional income and population growth. However, even without the model, we predict that the growth in regional demand for fish would not be proportional to the population growth or income growth. There will be limitations in the extent that the global fish supply can grow and fish prices will adjust to the extent that the demand grows faster than supply. Production in some countries and regions will grow faster than in others, and accordingly there will be regional gaps in fish supply and demand and the global fish trade market will balance those regional gaps. The elasticities of demand incorporated in the IMPACT model translate the strength of income growth and price changes into consumption growth for each country.

In the scenario analyses, special attention is placed on the cases of China and Sub-Saharan Africa. China is one massive market that can influence the dynamics of the global fish supply and demand. China currently accounts for 35 percent of global fish production and 30 percent of global fish consumption and is a net exporter of fish, although different commodities are imported or exported. While one scenario specifically addresses China's consumption trend (scenario 4), all other scenarios affect China's fish supply-demand balance in important ways, which in turn influences the rest of the world through the global fish markets. How such repercussions in the global markets affect fish supply balances in Sub-Saharan Africa is one of the key research questions of this study. As seen earlier, per capita fish consumption in this region is on a declining trend. The region is a net importer of fish in volume and, with the projected population growth at an annual rate of 2.3 percent between 2010 and 2030 (UN 2011), the region's dependence on imports for fish consumption is expected to rise.

Scenarios 3 and 6 introduce supply shocks to aquaculture through disease outbreak and capture fisheries through climate change, respectively. Although the direct impacts of these shocks may be local, their impacts extend globally. Links exist at all levels of the fish sector. Though not explicitly incorporated, crucial biophysical links include the spread of fish diseases through waterways, the migration pathways of fish that determine spatial stock distributions, and any other connectedness brought about by contiguity of ocean waters. Further interconnectedness occurs through value chains of fish products and, in particular, international trade, which connects the supply of fish products with their demands in all regions of the world. Thus, none of the effects of these localized supply shocks can be completely isolated. The expected differences in the way different regions will be able to cope with such shocks are of interest to this study.

Another channel of global links in the fish markets is through fishmeal and fish oil. The rapid growth of aquaculture across various fish species leads to considerable pressure on supplies of fish-based feed. Scenario 1 directly intensifies such pressure while scenario 2 reduces it. Other scenarios also indirectly affect the supply or demand of fish-based feed. Given the fish species disaggregation in the new version of the IMPACT model, the effects of changes in fishmeal and fish oil supply on aquaculture can now be examined at the species level.

Scenario 5 offers a picture of the potential outcome of global efforts to restore capture fisheries around the world. Growing global interests in oceans agenda are expected to accelerate and scale up such global efforts and bring the state of the capture fisheries closer to their potentials as described in *The Sunken Billions* (Arnason, Kelleher, and Willmann 2009). This study offers illustrations of how each region may benefit from improved capture fisheries in terms of gains in fish production and consumption.

Chapter 2: PREPARING IMPACT MODEL FOR *FISH TO 2030*

2.1. BASICS OF IMPACT MODEL

IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade, or IMPACT (Rosegrant and others 2001) continues to serve as the "workhorse" of the analyses in this book. IMPACT is a global, multimarket, partial equilibrium economic model that covers a wide range of agricultural products, such as cereals, oilseeds, roots and tubers, pulses, livestock products, and now the new addition of fish products. While the model has undergone a number of extensions since when the *Fish to 2020* study was conducted, the basic architecture of the model has remained true to its origins. The main objective of IMPACT is to provide forward-looking projections of supply, demand, and trade for various agricultural products. Projections are typically generated under baseline specifications and under alternative scenarios.

Commodities

For the purpose of this study, as discussed in chapter 1 (section 1.3), the fish category is expanded relative to the *Fish to 2020* specification. Accordingly, a total of 17 fish products are included in the newer version of IMPACT. Some of the existing non-fish commodities are aggregated in order to reduce the overall "size" of the model and the number of variables; however, this aggregation of non-fish commodities does not change the model results in any way. This helps to make the model run faster and allows a focus on the commodities of particular interest, namely fish and fish-based products (fishmeal and fish oil). Table 2.1 summarizes the aggregated non-fish commodities that are incorporated in the current IMPACT model, while table 2.2 lists the added fish products. These cover the range of commodities that are important for global food consumption and nutrition.

TABLE 2.1: Non-Fish Commodities Included in the IMPACT Model

CATEGORIES	DESCRIPTION
Livestock products	Beef and buffalo meat All poultry meat (chicken and ducks, primarily) Sheep and goat meat (small ruminants) Pig meat Eggs All liquid and solid milk products from large and small ruminants
Cereals	Aggregate of all grains (rice, wheat, maize, and other coarse grains)
Roots and tubers	Aggregate of all roots and tuber crops (Irish and sweet potatoes, yams, cassava, and other roots/tubers)
Pulses	Principally chickpea and pigeon pea
Sugar crops	Aggregate of sugar cane and sugar beet
Soybean	Soybean, with soybean oil and meal as by-products
Temperate oilseeds	Rapeseed (canola), sunflower and safflower seeds, with their oil and meal by-products
Tropical oilseeds	Groundnut, coconut, palm, and other tropical oil-bearing crops, with their oil and meal by-products
Fruits and vegetables	Aggregate of fruit and vegetable categories
Cotton	Lint cotton
Other	Aggregate of other miscellaneous agricultural crops

The addition represents a significant expansion of the fish category from the *Fish to 2020* classification (low-value food fish, high-value finfish, crustaceans, and mollusks). In section 2.3, we will further describe the logic and data sources that underlie the choice of these fish product classifications. In brief, the consumption category is more aggregated than the production category due to lack of disaggregated consumption data. On the production side, available highly disaggregated data by species are aggregated to ensure model tractability while maintaining a sufficient level of disaggregation to allow flexibility in analysis.

Regions

The earlier version of the IMPACT model used in the *Fish to 2020* study divided the world into 36 regions. In contrast, the latest version of the IMPACT model now contains 115 regions. This is the degree of

TABLE 2.2: Fish Products Included in the IMPACT Model

CONSUMPTION CATEGORY	PRODUCTION CATEGORY		DESCRIPTION
SPECIES GROUP	SPECIES GROUP	ABBREVIATION	
Shrimp	Shrimp	Shrimp	Shrimp and prawns
Crustaceans	Crustaceans	Crustaceans	Aggregate of all other crustaceans
Mollusks	Mollusks	Mollusks	Aggregate of mollusks and other invertebrates
Salmon	Salmon	Salmon	Salmon, trout, and other salmonids
Tuna	Tuna	Tuna	Tuna
Freshwater and diadromous	Tilapia	Tilapia	Tilapia and other cichlids
	Pangasius and other catfish	*Pangasius*/catfish	*Pangasius* and other catfish
	Carp	Carp	Major carp and milkfish species
	Other carp	OCarp	Silver, bighead, and grass carp
	Eel and sturgeon	EelStg	Aggregate of eels and sturgeon
	Other freshwater and diadromous	OFresh	Aggregate of other freshwater and diadromous species
Demersals	Major demersals	MDemersal	Major demersal fish
	Mullet	Mullet	Mullet
Pelagics	Cobia and swordfish	CobSwf	Aggregate of cobia and swordfish
	Other pelagics	OPelagic	Other pelagic species
Other marine	Other marine	OMarine	Other marine fish
Fishmeal	Fishmeal	Fishmeal	Fishmeal from all species
Fish oil	Fish oil	Fish oil	Fish oil from all species

spatial disaggregation used in this study. In fact, these 115 regions are mainly countries, with some smaller nations grouped together to form regions. For the definition of the IMPACT 115 regions, see the model description by Rosegrant and the IMPACT Development Team (2012). While the IMPACT model generates results for each of the 115 regions, for the purpose of this study, results are presented for 12 aggregate regions. These 12 aggregate regions are defined in figure 2.1. Table 2.3 contains the abbreviation code for each aggregate region. Major fishing/aquaculture nations in Asia—namely China (CHN), Japan (JAP), and India (IND)—are separated from their corresponding regions to give special consideration in the analysis.

Dynamics

The IMPACT model finds a global market equilibrium in each period (typically the time step is a year) and continues sequentially over the projected time horizon. To introduce dynamics, the IMPACT model incorporates trends in the drivers of change for demand and supply, and these are specified exogenously. Key drivers of demand are income and population growth. On the supply side, exogenous drivers are those outside the supply response to price changes; they include productivity and efficiency gains in agricultural production. These drivers essentially shift the intercepts of the supply curves over time. On the other hand, changes in supply in response to price changes are treated endogenously in the model using supply functions, which embed price elasticities. In this study, exogenous trends are the only determinants of supply growth in capture fisheries production. In contrast, the growth of aquaculture supply in the model is regulated by both price responses and exogenous trends in production and efficiency surrounding feed and feeding practices.

In the *Fish to 2020* study, the model started its simulations in the year 1997 and carried out projections into 2020. In the current study, the model begins its projections in the year 2000 and carries forward to 2030. Due to data constraints for some of the existing IMPACT model components (such as land cover, irrigation maps, and some hydrology measures), the model base year is set at year 2000 even though more recent commodity data are available (see section 2.3). Nonetheless, we make use of the early years of projection as a comparison period for calibration purposes. We use those years to evaluate the fit of the model projections to the existing data so as to gain further confidence in the medium-term projections to 2030. This

FIGURE 2.1: Definition of Aggregate Regions for Results Reporting

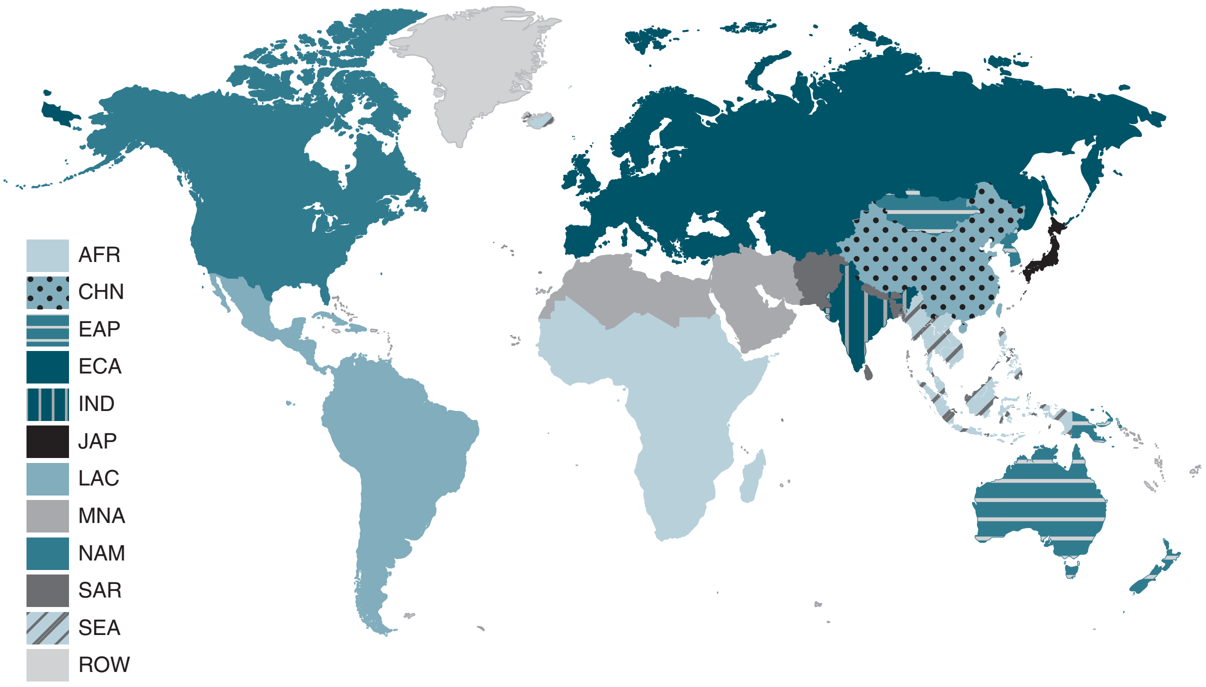


TABLE 2.3: Abbreviation Code for Aggregate Regions

REGION ABBREVIATION	NOTE
ECA	Europe and Central Asia, including developed nations
NAM	North America (United States and Canada)
LAC	Latin America and Caribbean
EAP	East Asia and the Pacific, including Mongolia and developed nations, excluding Southeast Asia, China, and Japan
CHN	China
JAP	Japan
SEA	Southeast Asia
SAR	South Asia, excluding India
IND	India
MNA	Middle East and North Africa
AFR	Sub-Saharan Africa
ROW	Rest of the world, including Greenland, Iceland, Pacific small island states

kind of comparison was not conducted explicitly in the *Fish to 2020* analysis, and this represents a significant improvement in this work.

2.2. IMPACT MODEL STRUCTURE

Here we describe the IMPACT model in more detail so that the reader can gain a deeper understanding of its structure and inner workings. Given the purpose of this report, we focus on the fish-related components of the model. Additional details on the non-fish components of the model can be found in the model description by Rosegrant and the IMPACT Development Team (2012).

Single Global Market and Single World Price

The basic modeling approach of IMPACT is a partial equilibrium representation of perfect, competitive world agricultural markets for crops, livestock, and fish. Supply and demand relationships for those commodities are linked to each other within a relatively simple representation of world trade, where all countries export to and import from a single, integrated world market for each commodity (Rosegrant Agcaoili-Sombilla and Perez 1995, Rosegrant and others 2001). The model reaches equilibrium in each market by solving for the single world price that balances the net exports and imports for all countries so that the market effectively clears globally. At the country level, the supply and demand of each commodity adjust according to price movements; the adjustment is regulated by commodity-specific price elasticities of supply and demand.[6] At the country level, there can be either a net surplus

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[6] Price elasticities represent the percentage change in demand or supply that occurs as a result of a unit percentage change in price of the good in question.

or deficit, which is to be reconciled on the global market through international trade.

Given the way the model handles international trade, in the presentation of the projection results, trade for each country or region is expressed in terms of net export. A net import is expressed in a negative value. The model structure does not permit a separate identification of countries that are both importers and exporters of a particular commodity. Neither does the model identify bilateral trade flows. While some other trade models may represent differential preferences for imported and home-produced goods, there are no explicit functions for export supply or import demand in IMPACT. In effect, each commodity in the model is assumed to be of homogenous quality. And thus it is assumed that consumer preferences differentiate commodities in terms of the broad categories described in tables 2.1 and 2.2 but not in terms of their origin.

Supply Functions

In contrast with a model that seeks to explicitly optimize the allocation of resources to the production of various goods (for example, maximizing total welfare), the IMPACT model uses reduced-form supply functions. Specified for each commodity in each country, supply functions determine the optimal amount of goods to produce given the profitability (as represented by input and output prices) and existing resource constraints.

The supply of crops and livestock products is represented as the product of yield and planted area or animal numbers. In the case of fish supply, there are two supply functions for a given fish species: one that regulates supply from capture fisheries and the other from aquaculture. The sum of the two determines the total supply in a country. Supply functions for aquaculture portray the expansion or contraction of production in response to changes in aquaculture profitability. Aquaculture profitability in the model is characterized by the price of the fish species, prices of other species, and prices of fishmeal and fish oil (critical inputs to aquaculture).[7] Accordingly, price elasticities of supply with respect to own price are positive, while those with respect to fishmeal and fish oil prices are negative. In contrast, supply of capture fisheries is assumed not to be affected by changes in profitability. Thus, no price elasticities of supply are specified for capture fisheries.

As a way to introduce dynamic trends in the supply relationships, exogenous growth rates are specified for each commodity in each country and multiplied to both capture and aquaculture supply functions. This operation is essentially equivalent to shifting supply curves to the right or left according to some exogenous trends. Typically, these exogenous growth factors represent an increase in productivity over time that comes from improvements in technology and technical efficiency so that more output is obtained at the same cost. How the growth rates are estimated for capture fisheries and aquaculture production is discussed in the next section.

Food Consumption Demand

The consumption of agricultural food commodities in a country is expressed as the product of per capita consumption and the total population. For both existing commodities and newly added fish products, reduced-form demand functions regulate per capita consumption demand in the model. Demand for a good in this model is a function of the good’s own price, prices of other food products, and the person’s income level. The own- and cross-price elasticities of demand represent the preferences for increasing consumption in response to a more favorable consumer price or for substituting toward other goods as their prices become relatively more favorable. Income elasticity of demand represents the tendency of consumers to consume more or less of a product as their incomes rise or fall. Dynamics of consumption demand in a country are introduced through exogenous trends in total population and income growth, which shift the demand curves (usually to the right) over time.

Crush/Reduction Demand for Oil Extraction and Meal Production

Another type of demand represented in the model is the demand for commodities to be used in oil extraction. In the IMPACT model, soybeans and two groups of oilseeds are “crushed” for oil extraction (table 2.1). Oil extraction from these oil-bearing crops produces byproducts (meal) that become important animal feed. As a new addition in this study, the model includes “reduction” of small pelagic and other fish for production of fishmeal and fish oil. These are also

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[7] At this point, soybean meal price is not included in the aquaculture supply functions.

important animal feed products, and the use of fish oil for direct consumption as nutritional supplements has increased in recent years (Shepherd 2012). The demand for raw commodities used for oil and meal production purposes is also represented in reduced-form demand functions. In the model, the crush/reduction demand depends on the price of the oil-bearing commodity and the prices of oil and meal. The demand decreases with higher price of the oil-bearing commodity and the demand increases with higher price of oil and meal.

For the production of fishmeal and fish oil, the model allows the use of fish processing waste, and the model includes a simple demand function for processing waste. We assume no explicit market for processing waste so the price for waste does not exist. The demand function for fish processing waste contains only fishmeal price as its argument.

The reduction demand for whole fish or processing waste has no exogenous driver of change in the model. Conversion of units from primary production (oil-bearing crops and fish) to products (oil and meal) is regulated by crush (reduction) ratios. Derivation of these ratios for fishmeal and fish oil is discussed in the next section.

Feed Demand

In livestock and aquaculture production, feed is the single most important input. Producers may choose a least-cost feed ration to achieve a certain production target, which could be represented in a model by a cost-minimization problem subject to explicit constraints, such as minimum nutrient requirements. In this study, as with supply and consumption and processing demands, we adopt a reduced-form approach that allows for price-driven adjustments in feed demand according to specified price elasticities.

A feed demand function is defined for each feed commodity. For each of the feed commodities used in aquaculture (fishmeal, fish oil, and soybean meal), two separate functions are specified: one for aquaculture production and one for livestock production. For aquaculture production, a feed demand function contains the price of the feed (fishmeal, fish oil, or soybean meal) and the levels of aquaculture production. Since the latter is determined through the supply function, feed demand is also indirectly affected by prices of fish products. Only own price enters a feed demand function for aquaculture production, thus denying the possibility of price-driven substitution among feed items.[8] Instead, substitution among aquaculture feeds (especially between fishmeal and soybean meal) is exogenously introduced in the form of trends in feed use coefficients (feed conversion ratios, or FCRs), which enter feed demand functions as parameters. Trends in FCRs also reflect feeding efficiency improvements that occur over time. In aquaculture, constant innovation in feeds and feeding practices has contributed importantly to the dramatic expansion that the sector has witnessed over the past decades (Rana, Siriwardena, and Hasan 2009). Thus, FCR trends represent an important exogenous demand shifter in the model. The definition of FCRs and their specifications are discussed in greater detail in the next section.

Other Demand

All other types of demand for fish are simply treated as an exogenous amount. While the base-year level of "other demand" is determined according to the data, it is subsequently assumed to grow in proportion to total demand.

Links of Supply and Demand

Bringing together the supply and demand relationships that we have described thus far, we can portray the way fish products are modeled in IMPACT as in figure 2.2. This parallels the way in which non-fish commodities are modeled (figure not shown). The production is differentiated between capture and aquaculture, with capture production growth being treated as completely exogenous while aquaculture supply is price responsive. On the demand side, human (direct) consumption accounts for most fish use, while lower-value species are demanded for reduction into fishmeal and fish oil. Much of the fishmeal and fish is used in aquaculture production. Thus, the capture and aquaculture segments of the sector are connected both in food fish markets and feed markets.

Price Transmission

All prices in the model are keyed to the world prices that clear global markets for each traded commodity. However, at the country level,

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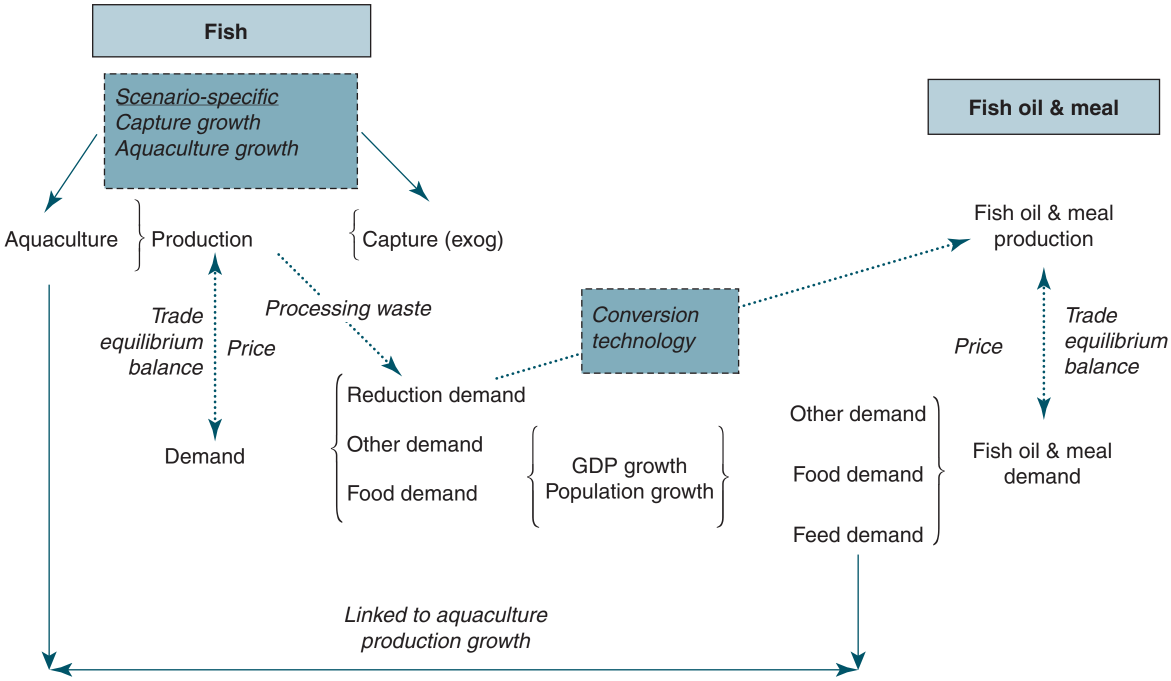
[8] Prices of other feed items enter in feed demand functions for livestock production.

FIGURE 2.2: Schematic of Links of Fish with Fishmeal and Fish Oil in the IMPACT Model



producer and consumer prices[9] are allowed to deviate from the world prices as a result of policy-driven factors (that is, subsidies and taxes) and marketing and transaction costs. Deviations from the world prices are embodied in three country-specific parameters: the subsidy equivalents for producers and consumers (PSE, CSE) and the marketing margin (MM). Marketing margins reflect a variety of infrastructural and market imperfections at the country level that add to the prices that consumers pay for imports (or what producers lose in export value).

Summary of Model Structure

Table 2.4 summarizes the key variables in the IMPACT model and indicates which variables are exogenously given and endogenously determined in the model.

Solution Procedure

In this study, the base year of 2000 is used as the starting point of the simulations. Although more recent data are available for most commodities from the FAO databases, some important data used on the crop side (such as irrigated/rain-fed area and water availability) have not yet been updated beyond year 2000. Consequently, we initiate the model in 2000 in all simulation runs while taking advantage of the period for which actual data are available in calibrating the model parameters (see section 2.5).

The code of the IMPACT model is written in the General Algebraic Modeling System (GAMS) programming language. The model is solved as a system of simultaneous equations. Exact solutions are possible because the problem is set up such that the number of equations matches the number of free variables. The current model solves for an equilibrium solution across 42,267 endogenous variables in total.

2.3. DATA USED AND PARAMETER SPECIFICATION

Given the introduction in section 2.2 of the structure of the IMPACT model and the key variables and parameters incorporated in the model, in this section we describe the data used this study. In particular, the data are important to establish a consistent picture of the global fish markets in the base (initial) year of the projection (section 2.4) as well as for calibration purposes (section 2.5). This section also describes model parameter specifications and the estimation procedure for some of the parameters. These parameter

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[9] The terms producer and consumer here are applied in relation to the prices that enter, respectively, into the supply or demand equations, for a specific product in question. For example, an aquaculture producer sees the producer price for the fish commodity, while the consumer price affects the demand for it. However, the fishmeal that is used as an input into aquaculture production enters as an intermediate price.

TABLE 2.4: Summary of Key Variables in the IMPACT Model

CROPS	LIVESTOCK	FISH	NOTES
Area	n.a.	n.a.	Price responsive with exogenous growth
Yield	n.a.	n.a.	Price responsive with exogenous growth
n.a.	Numbers	n.a.	Price responsive with exogenous growth
n.a.	Yield	n.a.	Completely exogenous
n.a.	n.a.	Total supply	Capture: completely exogenous Aquaculture: price responsive with exogenous growth
Food demand	Food demand	Food demand	Price and income responsive with exogenous growth
Crush demand	n.a.	Reduction demand	For oil-bearing crops and whole fish/fish processing waste Price responsive, no exogenous growth
Feed supply	n.a.	Feed supply	Crop: coarse grains and meals produced from oil-bearing crops Fish: fishmeal and fish oil Supply determined by crush/reduction demand multiplied by fixed crush/reduction ratios
n.a.	Feed demand	Feed demand	By livestock and aquaculture production Price responsive and dependent on livestock and aquaculture production volumes; with exogenous growth in feed conversion ratios Separate feed demand functions for livestock and aquaculture
Biofuel demand	n.a.	n.a.	With exogenous growth (according to policy scenario)
Other demand	Other demand	Other demand	Changes in strict proportion to sum of other (endogenous) demand categories
Trade			Difference between supply and demand forced to balance globally
Prices			World prices: endogenously determined to balance global trade Country prices: linked to world prices with producer/ consumer subsidy equivalents and marketing margins

Note: n.a. = not applicable.

values form the baseline scenario, whose results will be presented in chapter 3. The discussions here focus on the data and parameters for fish products that are newly added to the IMPACT model for this study. Data and parameters in the larger IMPACT model are described in the model description by Rosegrant and the IMPACT Development Team (2012).[10]

In this study, we use three broad sets of fish-related data provided by the FAO (consumption-trade, production, and fishmeal–fish oil)[11] as well as price data from multiple sources.

Consumption and Trade Data

For apparent consumption and trade data, this study relies on FAO FIPS FBS of fish and fishery products.[12] Data are available for 226 countries or areas for the following domains:

- Production (Capture + Aquaculture)
- Meals Input
- Other Non-Food Use
- Exports for Human Consumption
- Imports for Human Consumption
- Total Food Fish Supply
- Per Capita Food Fish Supply
- Stock Variation
- Population

The Meals Input series form the basis of the crush/reduction demand functions discussed in the previous section, while the Other Non-Food Use series correspond to the other demand category in IMPACT. The Stock Variation series represent the residuals between supply, demand, and trade each year for each country. Since the

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[10] Some parameters used in this study are based on the older version of IMPACT (see Rosegrant and others 2001).

[11] FAO data were received from the FIPS of the FAO Fisheries and Aquaculture Department in fall 2011.

[12] FAO FIPS is responsible for the calculation of FBS of fish and fishery products in FAO. These data are disseminated through the FAO Yearbook: Fisheries and Aquaculture Statistics and through FAOSTAT at http://faostat.fao.org/site/617/default.aspx#ancor. However, it is important to highlight that notwithstanding the same source and final results in terms of supply, data in the two domains are presented according to a different methodology related to the treatment of non-food commodities.

data on the actual level of stock are unavailable, IMPACT does not explicitly model stock-holding behavior. To accommodate the existence of this category in the dataset, the IMPACT model run is initiated with the value of stock change for the base year (2000) and progressively reducing it to zero over the first 5 to 10 years of the simulation. The correspondence of other series in the FAO FIPS FBS dataset with IMPACT variables is self-explanatory.

For fish and fishery products, the FAO calculates FBS for eight groups of similar biological characteristics.[13] In order to achieve a more consistent link between fishery trade and consumption data and production statistics for the use in the IMPACT model, the existing groups for fishery trade and consumption data have been modified through the creation of ad hoc categories. However, due to the limitation of raw trade data availability for selected species, in particular for freshwater fish, it was not possible to establish a fully comparable one-to-one link with production series. FAO fishery trade data reflect the national classifications used by the countries to collect and report their trade. These classifications are generally based on the Harmonized System (HS) classification of the World Customs Organization (WCO), which is used as a basis for the collection of customs duties and international trade statistics by more than 200 countries. Only starting with the new version, entered into force on January 1, 2012,[14] selected freshwater species, including tilapia, catfish, and carps, are identified in the HS, while in previous versions only live carps had a separate code.

In the IMPACT model, the consumption and trade series are available for nine aggregate fish commodities. In contrast, production series come in much more disaggregated categories (FishStat database, see next). Thus, these nine categories form the lowest common denominators in defining the fish product categories for this study. The nine fish commodities are shown in the consumption category in table 2.2.

The FAO FIPS series expresses the volume of various types of seafood in terms of live weight equivalent or the unit of primary production. The conversion process is a complex one and, as a result, a substantial degree of error can arise. Thus, we proceed with caution in using consumption and trade data when we seek internal balance for the IMPACT model between production, consumption, and trade for the base year (section 2.4).

At the time of model preparation, these data series were available to the team for the years 1976–2007. The fact that newer data series were not available for consumption and trade data limits the scope of calibration exercises for these variables. In the assessment of the quality of model output in section 2.5, comparisons are made between model projections and FAO FIPS data for the years 2000–06 for variables related to consumption and trade. (The data are presented in three-year moving averages. Thus the data for 1999–2007 are used in the comparisons.)

Production Data

For data on primary fish production, this study relies on the FAO fisheries databases available through FishStat.[15] The data series available in FishStat include primary production by systems (aquaculture and capture) and trade (import/export, frozen/chilled/processed).[16] All series are available in both volume (tons) and, with the exception of capture fisheries, value (in U.S. dollars). At the time of model preparation, these data were available for the years 1984–2009. Thus, for production-related series, the comparison between data and model projections is provided for the years 2000–08 in section 2.5. (Again, the data are presented in three-year moving averages, and the data for 1999–2009 are used in the comparisons.)

The primary production data in FishStat are highly disaggregated by fish species (over 2,000 species or groups of species). For tractability in the IMPACT model, the fish species are aggregated in this study. In doing so, we maintain consistency between the aggregated production series and consumption and trade data series, while allowing a certain degree of disaggregation so that some key policy

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[13] The eight groups are freshwater and diadromous fish, demersal fish, pelagic fish, marine fish unspecified, crustaceans, cephalopods, mollusks other than cephalopods, and other aquatic animals.

[14] HS 2012 reflects the FAO joint proposal to the WCO for the revision of the codes related to agriculture, forestry, and fishery products, with a resulting improved breakdown of selected fishery species.

[15] See this link for details on FishStat: http://www.fao.org/fishery/statistics/software/fishstat/en.

[16] Trade data are available in both FAO FIPS FBS and FishStat. The trade series in FishStat is measured in terms of product weight, rather than live weight equivalent as in FAO FIPS FBS. Since FAO FIPS FBS is the only source of apparent fish consumption data at the world level, which are measured in live weight equivalent, the trade series from FAO FIPS FBS are used in this study.

research questions can be addressed using the projections. The species aggregation is shown as production category in table 2.2.

When selecting the aggregation rule of fish species, special consideration was given to their diet, since it relates to the types of feed aquaculture production uses. For instance, we wished to separate those fish species that require a relatively high percentage of animal protein in their diets (for example, salmon, tuna, and demersals such as snapper, cod, halibut, and flounder) from those that can be grown mainly on a plant-based diet (for example, tilapia, *Pangasius* and other catfish, carps and other *cyprinids,* and milkfish). Furthermore, these are distinct from other species that are not usually fed directly but are grown in fertilized bonds, such as silver and grass carp, or those that live off of detritus and/or plankton, such as mollusks and other invertebrates. In the *Fish to 2020* study shrimp, prawns, and other crustaceans were combined in a single category. They are separated in this study, given that shrimp is an important commodity by itself in the world seafood market and that data of relatively good quality are available for shrimp.

Fishmeal and Fish Oil Data

The dataset for fishmeal and fish oil provided by the FAO contains series for production, imports, and exports for the years 1976–2009. The dataset is a compilation of data from FishStat, Oil World,[17] and the International Fishmeal and Fish Oil Organisation (IFFO).[18] The number of countries represented in the dataset is shown in table 2.5.

A series of data preparation tasks were necessary in order to achieve consistency between the reported volume of fishmeal and fish oil production, reported amount of whole fish used in reduction, and reported volume of fishmeal and fish oil exported by each country.

TABLE 2.5: Number of Countries Covered in FAO Fishmeal and Fish Oil Dataset, 1976–2009

	PRODUCTION	IMPORT	EXPORT
Fishmeal	86	202	159
Fish oil	54	201	143

Source: Compilation of data from FishStat, Oil World, and the IFFO.

First, table 2.5 indicates that there are more exporter countries of fishmeal/fish oil than producers in the data. Given the treatment of international trade in the IMPACT model, all fishmeal and fish oil are homogenous and trade is expressed in terms of net exports. As a result, for example, importation of a product for the purpose of reexportation or exportation after reformulation of the product composition is captured in net export only to the degree that there is a difference in the volume of importation and exportation. Accordingly, in the process of obtaining the consistent base-year picture of the global fish markets, we had to ensure that only countries that produce fishmeal or fish oil could have positive net export. The details of base-year establishment are presented in section 2.4.

Fishmeal and fish oil are produced by reducing whole fish caught for that purpose and bycatch and/or other low-value species, as well as waste from poor postharvest handling or from the processing of fish into fillets and other value-added products. It is estimated that currently about 25 percent of fishmeal produced globally uses fish processing waste as ingredient (Shepherd 2012). The FAO FIPS FBS dataset includes the series "Meals Input" that represents the volume of various types of whole fish used for reduction into fishmeal and fish oil. However, country-level data on the volume of processing waste used for reduction are not available. The use of fish processing waste is imputed for 2000, as a part of the base-year establishment. (See section 2.4 and technical appendix C to this chapter.)

Finally, since the datasets provided by the FAO do not contain series on the use of aquaculture feed (fishmeal, fish oil, and soybean meal), these are also imputed such that they balance with production and trade on a country and global level. See section 2.3's subsection *Feed Conversion Ratios and FCR Growth* and the technical appendix C to this chapter for details on the imputation procedure.

World Prices

World prices series are generated in a manner consistent with the definition of world prices specific to the IMPACT model. World prices for traded commodities are derived in three steps. First, for each commodity, a group of countries is defined that, combined, constitute the bulk of world exports (see technical appendix A to this chapter for the procedure). Second, the world price is calculated

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[17] http://www.oilworld.biz.

[18] http://www.iffo.net/.

as the weighted average of export unit value (FishStat) in each of the above countries. The weight used is the export share of each country, in live weight equivalent, in the sum of all the selected major players in the market. Third, the world prices calculated for individual fish species are aggregated to consumption category using trade volume as weight. For fishmeal and fish oil, price series provided by the IFFO are used.

Parameter Specification

Lastly, we discuss the specification of the parameters of the IMPACT model. Given the sheer number of parameters used in the model, it is not possible to describe them all here. While further explanations are provided for some of the parameters, key groups of parameters are listed in table 2.6 together with their sources.

Capture Growth

Exogenous trends of capture fisheries incorporated in the model are estimated using the time series data from the FAO FishStat database. The estimates are based on the best fit to observed data over the 2000–08 period and plausible trajectories beyond 2008.

Aquaculture Growth

More careful estimation of exogenous growth rates is conducted for aquaculture production using FAO FishStat data (1984–2009) for each commodity in each country. Three patterns are observed in the data and, for each case, the following approach is used to specify growth rates. First, when the production is trending upward, a logistic growth curve is fitted to the data using least squares method. Second, when there is a downward trend, the projection

TABLE 2.6: List of Key Parameters in the IMPACT Model and Their Sources

PARAMETER	DESCRIPTION	DATA SOURCE
ELASTICITIES		
Area elasticity	Own- and cross-price elasticities of crop area	Modified from values in Appendix B, Rosegrant and others 2001
Livestock elasticity	Own- and cross-price elasticities of livestock numbers	
Yield elasticity	Own-price elasticities of crop yield	
FoodDmd elasticity	Own- and cross-price elasticities of food demand	
IncDmd elasticity	Income elasticities of food demand	
Feed elasticity	Price elasticities of demand for feed commodities	
Fish elasticity	Own- and cross-price elasticities of aquaculture supply	From the model used in the *Fish to 2020* model (Delgado and others 2003), modified to cover additional fish categories and regions and to match the observed supply growth in the 2000–08 period
FoodDmd elasticity	[Fish] Own- and cross-price elasticities of food fish demand	
IncDmd elasticity	[Fish] Income elasticities of food fish demand	
Crush elasticity	Price elasticities for crush/reduction demand	Own estimates, adjusted in calibration process
Crush elasticity for waste	Price elasticities for reduction demand for fish processing waste	Own estimates, adjusted in calibration process
OTHERS		
PSE, CSE	Producer and consumer subsidy equivalents	From the model used in the *Fish to 2020* model (Delgado and others 2003), modified to cover additional fish categories and regions
MM	Marketing margin	
FCR (feed conversion ratio)	Amount of feed required per unit of livestock and aquaculture production (defined for each of fishmeal, fish oil, and soybean meal)	[Fish] Estimated based on Tacon and Metian 2008 (see text and technical appendix C to this chapter)
Reduction ratio	Amount of fishmeal and fish oil produced (in product weight) per unit of whole fish used (in live weight equivalent)	[Fish] Estimated based on FAO data and Jackson 2010 (see text and technical appendix C to this chapter)
Waste ratio	Amount of fish processing waste generated from a unit of whole fish (in live weight equivalent)	From various sources (see text and technical appendix C to this chapter)
EXOGENOUS GROWTH		
Population growth rate	Exogenous growth rates of human population	UN Medium Variant Population projections (UN 2011)
Income growth rate	Exogenous growth rates of income (gross domestic product, or GDP)	World Bank Global Economic Prospects projections and data (World Bank 2012)
Capture growth rate	Exogenous growth rates of capture fisheries production	Estimated using historical data (see text)
Aquaculture growth rate	Exogenous growth rates of aquaculture production	Estimated using historical data (see text)
FCR growth rate	Exogenous growth rates of feed conversion ratio	Estimated using the imputed FCRs

is fixed at the latest observation (2009) for the rest of the projection period (2010–30). Third, when the recent trend exhibits fluctuations around a stable average, a mean is calculated for the appropriate duration and used as the projected value for 2010–30.

For salmon aquaculture in Chile, to account for ISA outbreak during 2007–10, a negative growth rate of 3.9 percent per year is imposed for the 2005–10 period, after which the recovery is assumed to start at the rate estimated for the 2000–05 period from the fitted logistic curve and to continue at the subsequent rates.

Feed Conversion Ratios and FCR Growth

A feed conversion ratio (FCR) represents the quantity of feed required per unit of livestock or aquaculture production. This set of parameters is used in the model to calculate the amount of total feed used for livestock and aquaculture production. For aquaculture, we define FCR for three feed items: fishmeal, fish oil, and soybean meal. Thus, the use of the term FCR in this study is slightly different from the conventional sense in the literature, where the concept is usually applied to the *total* volume of feed used to produce unit volume of meat or fish. In this study, starting with initial FCR values in the base year (2000), they are allowed to evolve over time. Given the definition of the FCR adopted in this study, the FCR evolution implies the composite of two separate effects: (1) substitution between fish- and plant-based feedstock and (2) efficiency improvement in feed use.

As discussed earlier, there is constant innovation in the aquaculture feed industry, such that lower-cost plant-based alternatives are increasingly used in feed formulation, substituting away from higher-cost fishmeal and fish oil (Barnes and others 2012; Hardy 1996, 2003; Naylor and others 2009; Rana, Siriwardena, and Hasan 2009). The quality of feeds has also been improved in terms of their digestibility, while at the same time, efficiency has increased through better feeding methods and farm management in general (Tacon, Hasan, and Metian 2011). Therefore, the general tendency around the globe is a reduction in FCRs for fishmeal and fish oil. However, in a country where aquaculture feeds were not intensively used previously, improvement in feeding practices may imply an increase in any or all of the three FCRs.

For the purposes of this study, aquaculture FCRs and their growth rates are estimated using available information. Using the FAO production data for 2000, we estimate the most plausible amount of feed that must have been used per unit of livestock and aquaculture output produced. The process is repeated for 2009, and FCR growth rates are calculated based on the two sets of FCR estimates for fishmeal and fish oil. Except for a few cases, the calculated growth rates of fishmeal and fish oil FCRs are negative, supporting the general tendency that their usage per unit of aquaculture production is decreasing. See technical appendix C to this chapter for additional detail of the estimation process.

Reduction Ratio and Waste Ratio

Reduction ratio and waste ratio are used in the model to calculate the amount of feed produced from whole fish or fish processing waste. While waste ratios are derived from the literature (see technical appendix C to this chapter for the sources), reduction ratios are estimated in the process of establishing the base-year picture. See section 2.4 and technical appendix C to this chapter for the procedure of reduction ratio estimation.

We have described the specification of key parameters that are added in this version of the IMPACT model. In principle, these parameter values form the basis of the baseline specification of the model, whose results are presented in chapter 3. However, it must be noted here that these parameter values are further fine-tuned individually in order to achieve consistency across data series in the base year and to obtain reasonable model results under the baseline scenario. The definition of reasonable is one of expert judgment and has been subject to much discussion and adjustment in the course of constructing the baseline results for this report. Such adjustment efforts and their outcomes are presented in the next two sections.

2.4. ESTABLISHING A CONSISTENT BASE-YEAR PICTURE

In this study, all simulations are initiated in the base year of 2000. The next step in model preparation is to establish a credible picture of fish supply, demand, and trade for the base year. Since all projections for the subsequent years depend on this estimate, appropriately representing the base-year picture of the global agricultural commodity markets is extremely important in the use of the IMPACT model. In assembling a number of basic components of the model, the challenge is to obtain internal consistency in data series across those components. Since a consistent base-year picture has been established for the non-fish commodities prior to the inclusion of fish products in the model, the discussions here focus on such tasks for fish products.

Balance of Supply, Demand, and Trade at Country Level

Simply put, for each fish commodity in each country in a given year, the following condition must hold for consistency:

(1) Food Fish Demand + Reduction Demand + Other Demand + Export = Production + Import.

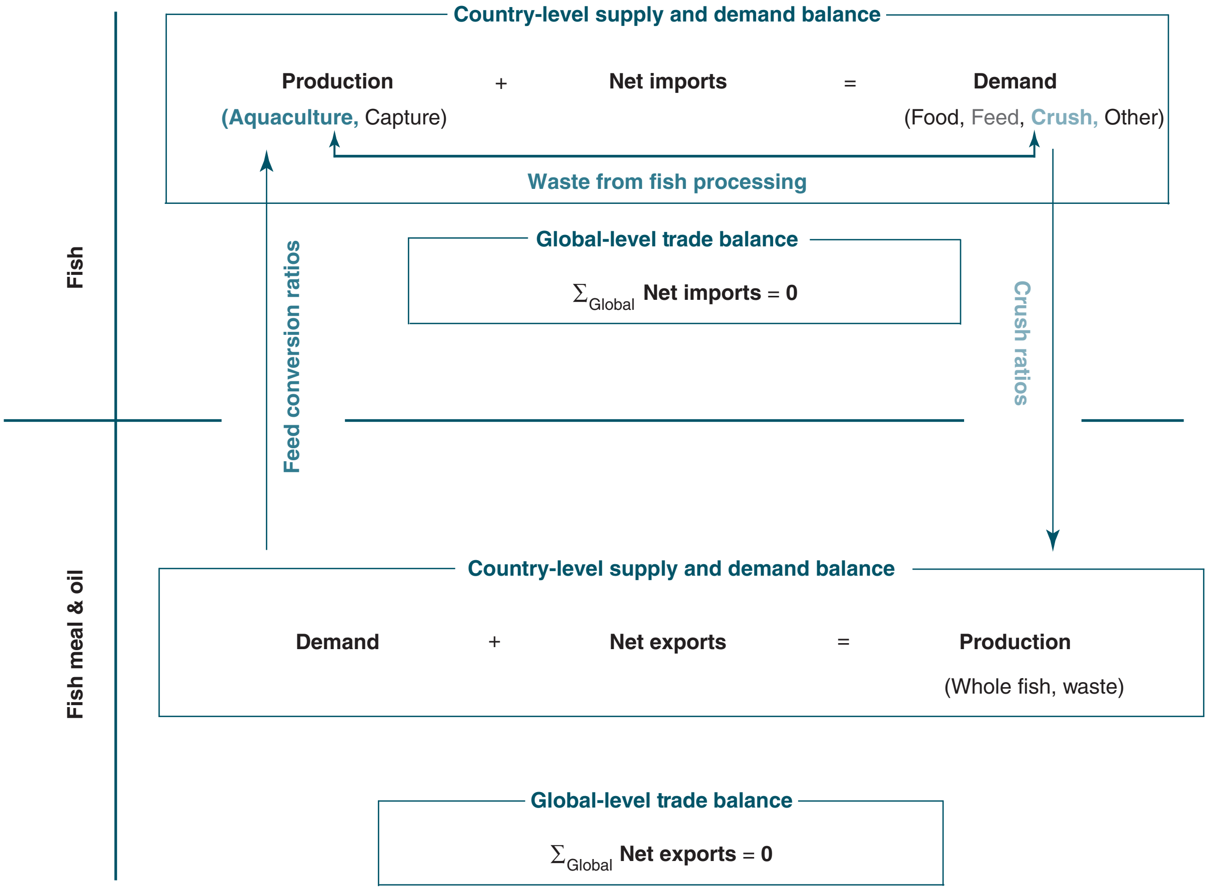
However, since production and consumption-trade data come from different datasets, this equality is not guaranteed to hold in the raw data for most country-commodity combinations.

Adding-Up Conditions at the Global Level

Due to the complex links in the model as depicted in figure 2.2, an imbalance in this relationship in a given country will be "exported" to other countries in the model, causing an imbalance elsewhere. The effect ripples through all of the price-quantity-trade relationships and throws off the balance such that the model cannot reproduce the observed data in the base year of the simulation. The difficulty in obtaining data consistency is further exacerbated in this model version by the endogenous treatment of fishmeal and fish oil production and their use in aquaculture production.

Figure 2.3 depicts the data links and the "adding-up conditions," or conditions for market clearance (equilibrium) in the fish part of the model. (See technical appendix B to this chapter for the complete set of adding-up conditions for the IMPACT model.) As a fundamental requirement, the balance of supply and demand must be reached for each commodity in each country as in equation (1). At the same time, the global sum of net trade (exports minus import flows) must equal zero for each commodity. In other words, every ton of exports from any country must be imported by some other country, with no residual left on the market.

FIGURE 2.3: Key Data Relationships Used to Balance Fish Data in IMPACT



This is the case for trade in fishmeal and fish oil as well. As a result, the link between fishmeal, fish oil, and aquaculture results in two more adding-up conditions. First, the fishmeal and fish oil demand quantities have to be consistent with the production levels of aquaculture, such that there is sufficient feed demand for fishmeal/fish oil to justify the quantities of aquaculture production. Second, the demand for whole fish for reduction (plus the imputed value of processing waste) has to be consistent with the production quantities of fishmeal and fish oil that are reflected in the data.

Inconsistency across Datasets

As discussed in section 2.3, the addition of fish products to the IMPACT model for this study relies on three FAO datasets:

- Dataset I: Contains disaggregated data for fish production data (FishStat).
- Dataset II: Contains aggregated consumption and trade data (FAO FIPS FBS).
- Dataset III: Contains fishmeal/fish oil production and trade data.

The three datasets contain data obtained from different sources and domains and are not specifically prepared for the purpose of being used together. Therefore, it is not surprising that the data series do not satisfy the adding-up conditions of figure 2.3.

Establishing a Consistent Picture for 2000

As a result, the task here is to find a set of values for the IMPACT variables that are internally consistent and satisfy the adding-up conditions for the base year. The basic strategy we take is to reconstruct a consistent picture for the year 2000 by adhering to the available data as much as possible while allowing some variables to deviate from the levels indicated by the data. Note that the data are presented in three-year moving averages. And thus we define the "base" to be the average picture of the global agricultural market for the years 1999–2001.

The data inconsistency originates mainly from the addition of fishmeal and fish oil to the model. As a result, deviations are allowed to a larger extent for variables related to fishmeal and fish oil. More specifically, establishing the base-year picture involves the following related processes.

In relation to fishmeal and fish oil production:

- By estimating reduction ratios, the levels of fish processing waste used in fishmeal and fish oil production are imputed.
- In doing so, in order to achieve internal consistency, the amount of whole fish used in fishmeal and fish oil production is allowed to deviate from "Meals Input" data series.
- As a result, the levels of food fish consumption demand and fish trade volume are also allowed to deviate from the FAO data.
- The amount of fish supplied (by capture fisheries or aquaculture) is never allowed to deviate from the data.

In relation to fishmeal and fish oil utilization:

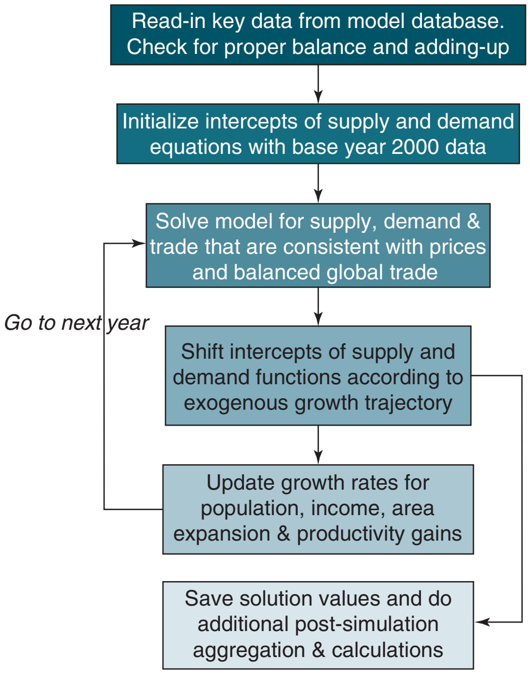
- By estimating FCRs and based on the aquaculture production data, the levels of fishmeal and fish oil use are imputed.
- In doing so, in order to achieve internal consistency, the levels of trade and production of fishmeal and fish oil are allowed to deviate from the data.

A consistent base-year picture is obtained with a help of a GAMS program developed specifically for the purposes. The program estimates reduction ratios and FCRs, while fixing the value of fish production variables to the levels indicated by data and penalizing the deviations of other variables from the data. This ensures the base-year values of production, consumption, and trade are internally consistent and as close to the original FAO data as possible. See technical appendix C to this chapter for the procedure and assumptions used in the establishment of the base-year picture of the global fish markets for 2000.

Setting the "Intercepts" of Supply and Demand Functions

Once the conditions in figure 2.3 are satisfied and a consistent picture is obtained for the base year, initial values of the "intercepts" of the supply and demand curves are determined. These intercepts regulate the position of the supply and demand curves and thus also serve to "scale" the values of model output. Since they are derived from the consistent initial values of the variables, using these intercept levels in the model result in the perfect replication of the base-year picture for 2000. For the subsequent years in the simulation, these intercept values are changed according to the exogenous growth rates specified for each of the supply and demand functions. Figure 2.4 depicts the sequence

FIGURE 2.4: Computational Steps and Sequence of the Model



of model initialization, solution, and information updating within the IMPACT model.

2.5. ASSESSING THE QUALITY OF PROJECTIONS

The final step in model preparation is to adjust parameter values so that subsequent model projections are sufficiently close to the observed data for the calibration period (2000–08 for production series and 2000–06 for consumption and trade series). Projections under the baseline scenario are used for calibration exercises. Baseline projections for the years beyond the calibration period will be discussed in chapter 3.

Calibration is implemented by sequentially and manually fine-tuning model parameters, rather than using some algorithm to calibrate all parameters at once. Adjusted parameters are mostly elasticities, but in some cases exogenous growth rates of aquaculture production are also adjusted. Exogenous growth rates for food consumption demand are never adjusted. As depicted in figures 2.2 and 2.3, the model is built on extremely complex links of supply-demand relationships for 115 model regions as well as global adding-up conditions. The issues of data quality and inconsistency across datasets are also relevant here. For these reasons, it is impossible for the model to reproduce all of the variables at the levels indicated by the data during the calibration period. The calibration objective is thus to generate projections that are closer to the actual data for relatively more important commodities for relatively more important players in those markets.

In doing so, differential priorities are assigned to series from the three datasets according to the confidence given to the series and datasets. Priorities are given to the data series for which no unit conversion is necessary. The first priority is given to the production data from FishStat (Dataset I). The series are measured in live weight, which is the common unit throughout the model. Second, we prioritize production and trade data for fishmeal and fish oil (Dataset III). These are measured in product weight. However, in the production process, fish (whole or processing waste), which is measured in live weight (or its equivalent), is converted to products, which is measured in product weight. Thus, a larger degree of discrepancy is expected for these series than for primary production. The largest discrepancy is expected for fish utilization (consumption, reduction, and other) and trade from FAO FIPS FBS (Dataset II), as these involve unit conversion of final processed consumption products back to live weight equivalent.

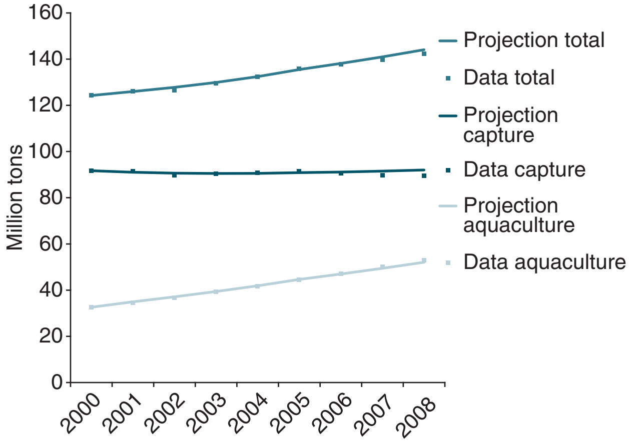
In the next subsection, we discuss the results of the calibrated model.

Global Projections

Figure 2.5 compares the projections of global capture and aquaculture production (represented by lines) to the FAO data (squares) over the 2000–08 period. The figure shows that, at the global level, the IMPACT model generates production projections that are very close to the actual data. Note that, since fish production series are not allowed to deviate from the data in the base-year establishment process, the projections coincide with the data for the year 2000.

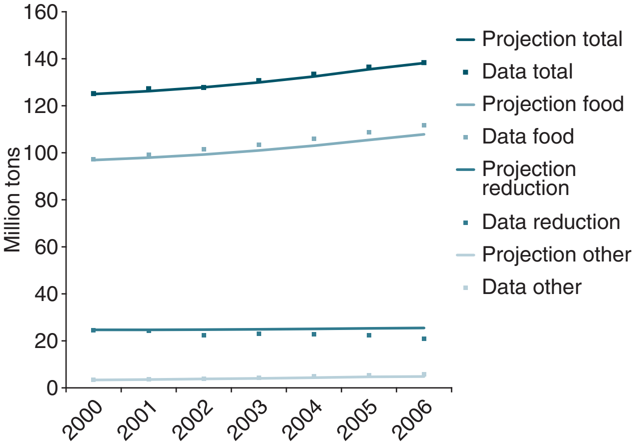
Figure 2.6 plots the projections of the three categories of fish utilization at the global level against the FAO data over the 2000–06 period. The utilization categories of food consumption, reduction, and other use are described in section 2.2, and they all add up to the total demand. The IMPACT model output for total demand matches the data very closely. In contrast, there is a slight gap between the model results and the data for the food and reduction

FIGURE 2.5: Comparison of Projections and Data for Global Fish Production, 2000–08



Sources: FishStat and IMPACT model projections.

FIGURE 2.6: Comparison of Projections and Data for Global Fish Utilization, 2000–06

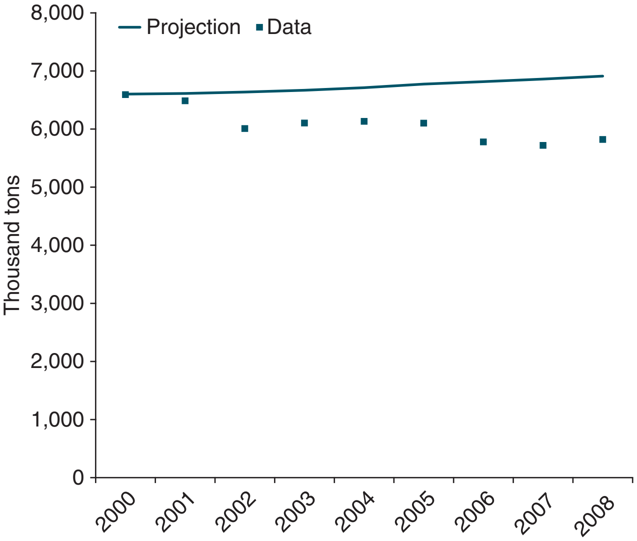


Sources: FAO FIPS FBS and IMPACT model projections.

categories. As discussed in the previous section, the projections for reduction demand, and accordingly also those for food fish consumption, are allowed to deviate from the data in order to achieve internal consistency across series for the base year. The difficulty with data inconsistency continues into the calibration period, and deviations from data are allowed according to the priority rule presented earlier. Here, deviations persist, especially for the food and reduction demand series. However the deviations for the two series balance out, and a good overall fit is obtained for total demand.

The overprojection of reduction demand is associated with the consistent overprojection of fishmeal production during the calibration period (2000–08) relative to the available data (figure 2.7). Fishmeal and fish oil demand are determined in the model as aquaculture and livestock production times the corresponding FCRs. Thus, the projected levels of aquaculture and livestock production largely drive the projections of fishmeal and fish oil supply and demand. While FCRs derived from the literature reflect biological requirements of feed in aquaculture production, in many cases fishmeal and fish oil availability in a country (production plus imports), as indicated by FAO data, is insufficient to support the observed aquaculture production levels. According to the dataset prioritization rule, therefore, fishmeal and fish oil production projections are allowed to deviate from the data, presuming that the reported feed supply is a likely underestimate of what was actually used.

FIGURE 2.7: Comparison of Projections and Data for Global Fishmeal Production, 2000–08

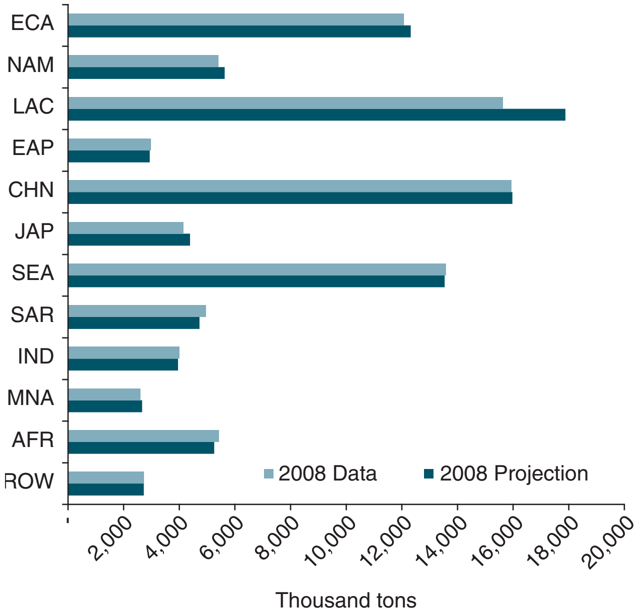


Sources: Compilation of data from FishStat, Oil World, and the IFFO and IMPACT model projections.

Projections by Region and Species

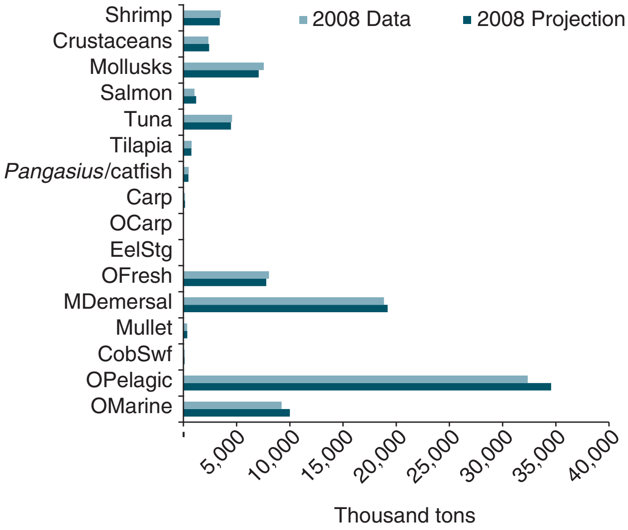
Figure 2.8 shows projections of capture fisheries production across different regions of the world against FAO data for the year 2008. The match between the two series is very close for all major regions except for the Latin America and Caribbean (LAC) region. The overprediction of LAC capture fisheries for 2008 originates from the overprediction of the reduction demand and fishmeal production.

FIGURE 2.8: Comparison of Projections and Data for Regional Capture Fisheries Production, 2008



Sources: FishStat and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

FIGURE 2.9: Comparison of Projections and Data for Capture Fisheries Production by Species, 2008



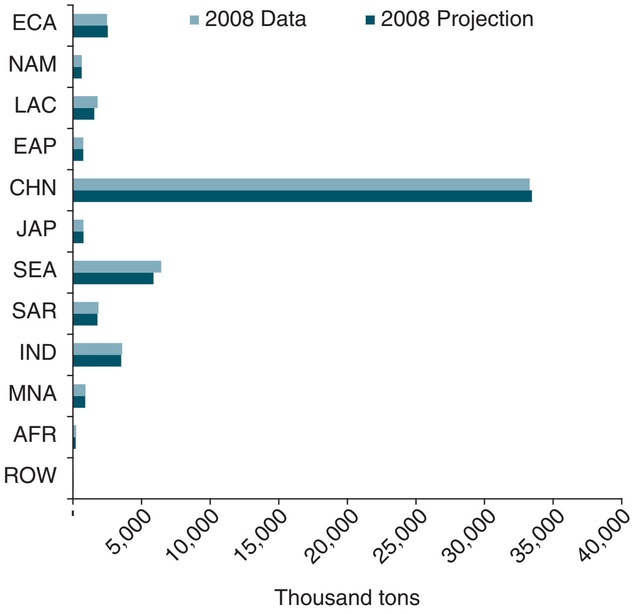
Sources: FishStat and IMPACT model projections.
Note: Pangasius/catfish = *Pangasius* and other catfish; OCarp = silver, bighead, and grass carp; EelStg = aggregate of eels and sturgeon; OFresh = freshwater and diadromous species (excluding tilapia, *Pangasius*/catfish, carp, OCarp, and EelStg); MDemersal = major demersal fish; CobSwf = aggregate of cobia and swordfish; OPelagic = other pelagic species; OMarine = other marine fish.

Since fish from capture origin (mostly other pelagic category) is the major source of fishmeal ingredients and LAC is the largest fishmeal-producing region, the discrepancy between the projection and the data is exacerbated in this region. However, one could also argue that small pelagics are subject to huge variations due to El Niño and La Niña, as well as decadal oscillations. Without explicit modeling of these oscillations, calibrated and simulated harvest behavior of small pelagics likely deviate actual observation.

We also see a good fit of projections with the data for capture production by species (figure 2.9). The fit in 2008 is fairly close for most species, with a slightly larger deviation in the OPelagic category. Again, this category of fish is most heavily used for the production of fishmeal and fish oil through reduction, and the overprojection in reduction demand and fishmeal production contributes to the overprojection of this category. For the same reason, but to a lesser degree, OMarine production is overpredicted, as they are also used for fishmeal and fish oil production.

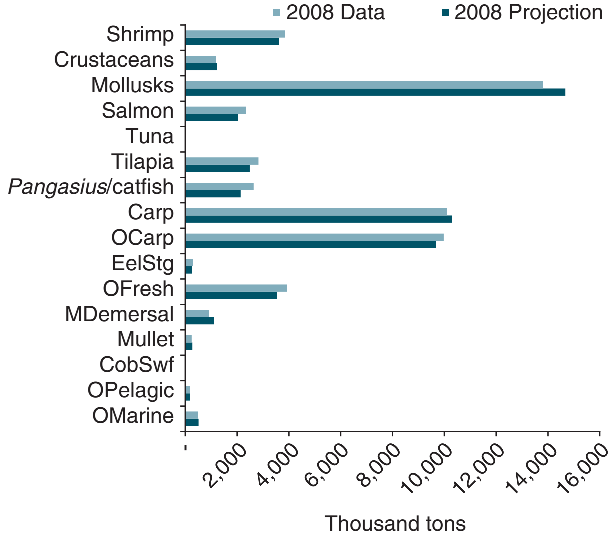
In figure 2.10, a very good fit between data and projections in 2008 is confirmed for aquaculture production across all regions.

FIGURE 2.10: Comparison of Projections and Data for Regional Aquaculture Production, 2008



Sources: FishStat and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

FIGURE 2.11: Comparison of Projections and Data for Aquaculture Production by Species, 2008



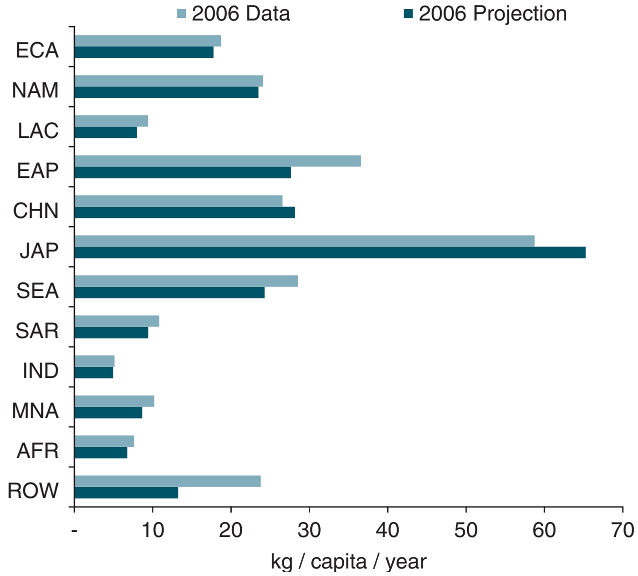
Sources: FishStat and IMPACT model projections.
Note: *Pangasius*/catfish = *Pangasius* and other catfish; OCarp = silver, bighead, and grass carp; EelStg = aggregate of eels and sturgeon; OFresh = freshwater and diadromous species (excluding tilapia, *Pangasius*/catfish, carp, OCarp, and EelStg); MDemersal = major demersal fish; CobSwf = aggregate of cobia and swordfish; OPelagic = other pelagic species; OMarine = other marine fish.

Looking across species, the overall fit of 2008 aquaculture projection to the data is fair (figure 2.11). The largest divergence is observed for MDemersal (overprediction by 22 percent) and *Pangasius*/catfish (underprediction by 19 percent). The prediction errors in 2008 for other species range between 1 and 13 percent in absolute terms.

Turning to the regional calibration of the demand side of the model, figure 2.12 shows a comparison between the model projections and FAO data for per capita food fish demand for 2006. JAP was by far the largest consumer of food fish per capita in 2006, followed by other Asian regions: EAP, SEA, and CHN. The fit of the model projections with the data in 2006 is reasonably good for most regions, with largest deviations observed for JAP (overprediction by 7 kilograms), EAP (underprediction by 9 kilograms), and ROW (overprediction of 11 kilograms).[19]

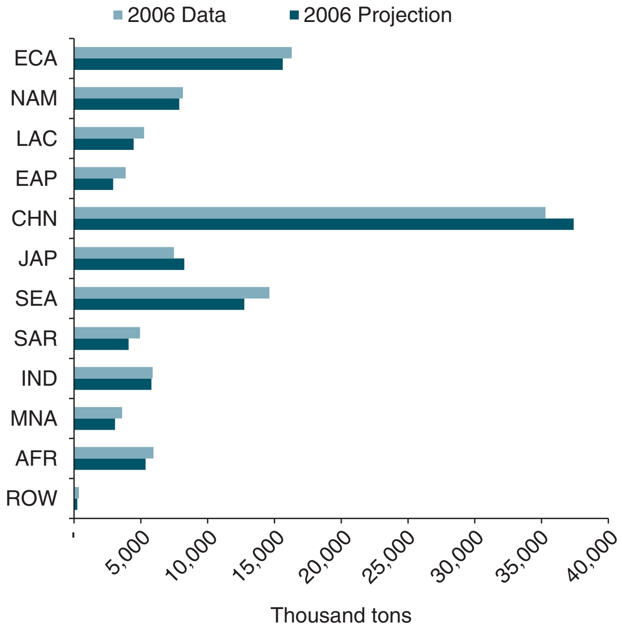
However, the deviations between projections and data in 2006 are relatively small in terms of total food fish demand obtained as per capita demand times the population (figure 2.13).

FIGURE 2.12: Comparison of Projections and Data for Regional Per Capita Food Fish Consumption, 2006



Sources: FAO FIPS FBS and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

FIGURE 2.13: Comparison of Projections and Data for Regional Total Food Fish Consumption, 2006



Sources: FAO FIPS FBS and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

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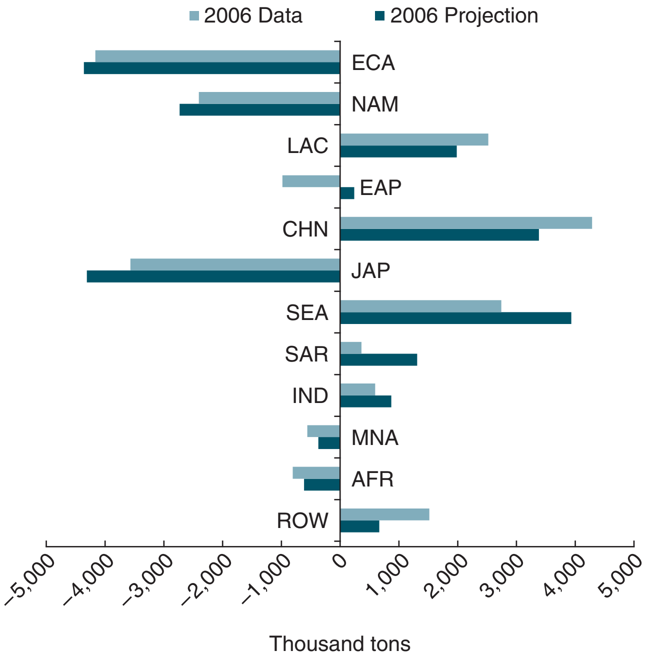
[19] ROW includes a wide range of countries and this group was not the focus of calibration exercise.

FIGURE 2.14: Comparison of Regional Projections and Data for Net Fish Export, 2006



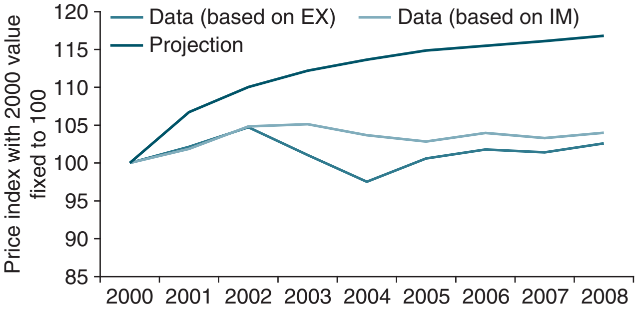
Sources: FAO FIPS FBS and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

In figure 2.14, we see a comparison between the model projections and data for regional net exports of fish. The fit between the projections and data for 2006 is fairly close for ECA and North America (NAM), but farther apart in LAC and Asian regions (EAP, CHN, JAP, SEA, SAR, and IND). The deviation results from the fact that the FAO datasets do not enforce the same balancing of trade across all species and regions as done in the IMPACT model. Following the data priority rule presented earlier, trade projections are allowed to deviate from the levels indicated by the data to a larger extent than production. Furthermore, larger deviations are allowed for trade than for consumption series. In all cases but for EAP, however, the direction of trade—that is, whether a region is an overall net fish exporter or net importer—agrees with the data.

Price Projections

We now turn to the comparison of model projections of world prices with the available data. In this study all prices are presented in real terms (price levels in constant 2000 U.S. dollars). Figure 2.15 shows aggregate prices of all nine fish commodities for which world prices are defined. Two fish price series are constructed based on trade data. Construction of the first series is based on export data and follows the procedure described in section 2.3, where the world prices of traded species in the model are determined as weighted averages of unit values faced by "dominant" exporters. The second fish price series is based on import data such that the world price of each species is constructed as weighted average of import unit value (from FishStat) by EU-15, Japan, and the United States. Construction of the latter series follows the FAO Fish Price Index, detailed in Tveterås and others (2012). The third series in the figure represents the world prices projected by the model. For each of the three series, world prices of different species are aggregated into a single fish price by weighting them according their net export volumes generated within the model. For ease of presentation, the three series are presented in the form of indices, where the price levels for 2000 are scaled to 100.

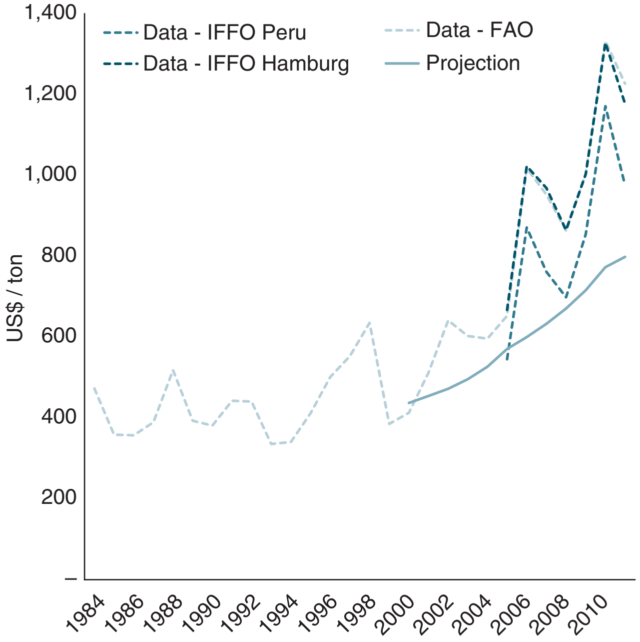
FIGURE 2.15: Comparison of Projections and Data for World Fish Prices, 2000–08



Sources: FishStat and IMPACT model projections.
Note: EX = export data; IM = import data.

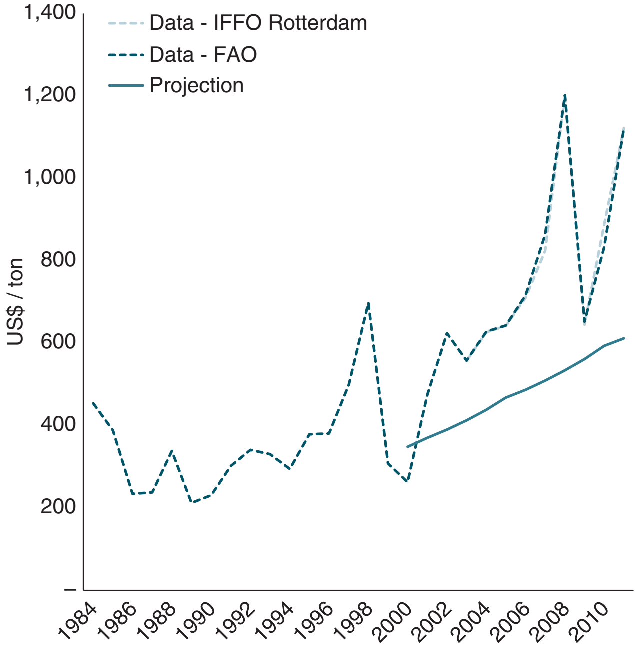
The two indices based on fish trade data indicate that the aggregate fish price fluctuated, but it rose overall some 3 to 4 percent between 2000 and 2008. On the other hand, the index based on projected price series indicates a steady increase for a total of 17 percent during the same period. The model appears to overestimate the aggregate fish price. In fact, this originates from overestimation of prices for the shrimp, crustaceans, freshwater and diadromous, and demersals categories (individual results not shown in the figure). As discussed in section 1.2, the IMPACT model seems to have structural limitations in representing the dynamics of world fish prices. The *Fish to 2020* study also overestimated fish prices relative to observed data. Throughout the rest of the study, therefore, price projections are interpreted with caution.

FIGURE 2.16: Comparison of Projections and Data for World Prices of Fishmeal, 1984–2011



Sources: Compilation of data from FishStat, Oil World, and the IFFO and IMPACT model projections.

FIGURE 2.17: Comparison of Projections and Data for World Prices of Fish Oil, 1984–2011



Sources: Compilation of data from FishStat, Oil World, and the IFFO and IMPACT model projections.

A comparison between projections and data for fishmeal world price shows a fairly close alignment, as seen in figure 2.16. While the real prices shown in the FAO and IFFO data exhibit steeper rise in the second half of 2000s, the projection reproduces the trend.

The steadily increasing trend in real world prices of fish oil is similar to that of fishmeal and is shown in figure 2.17. Again, the model underpredicts the steep rise of fish oil price after 2005.

Conclusions of Calibration Exercise

As is the case with most global modeling work, a value that IMPACT brings to the study of global fish supply and demand is an internally consistent framework for analyzing and organizing the underlying data, which is drawn from disparate and often inconsistent sources. As in many food and agriculture studies, the detailed level of understanding of what happens on the supply (production) side is often not matched on the demand side for a given country—that is, consistent links between supply, demand (across the various utilization categories), and international trade are not typically understood. Although IMPACT does represent the net flows of trade into or out of each country/region, it does not model bilateral flows that identify specific links between origins and destinations of trade. The FAO does not compile such data at the level of species detail needed for this study, and modeling bilateral trade would depend on the quality of data and the structure of model. Thus, by allowing international trade to be the mechanism that reconciles supply and demand over time, this study focuses on capturing the overall drivers of supply and demand growth.

Accordingly, the structure of world markets in IMPACT is simple and assumes a single market-clearing price for each good, across all regions. This, together with the absence of bilateral trade flows and the assumed homogeneity of quality in the goods coming from different regions, makes for only a crude approximation to how prices may actually be formed on the basis of imperfect substitution between domestic and imported goods at the country-level—that is, the classic Armington assumption (Armington 1969), or the fact that market concentration and imperfect competition might cause for a more complex process of price formation. There are classes of general and partial equilibrium multimarket models that handle these issues better than IMPACT, such as the computable general equilibrium models developed under the framework of the Global Trade Analysis

Project (GTAP) modeling consortium (Hertel 1997); the World Bank's Linkage model (van der Mensbrugghe 2005); or partial equilibrium models with spatial trade, such as the Global Biosphere Management model (Havlík and others 2011) of International Institute for Applied Systems Analysis (IIASA) or the regional Common Agricultural Policy Regionalised Impact Modelling System (CAPRI model) (Britz 2005). However, none of them can handle the detail of fish species, their feed requirements, and their links with the rest of the agricultural sector in the way we have incorporated into the model. We felt that this was a more important feature of long-term growth that should be captured in our analysis, and accepted some sacrifices on the detail brought to market structure and price links.

In this study elasticities and exogenous supply shifters were adjusted to obtain a good alignment with observed data (or to conform to expert opinion) in the projections. This is part of the normal process of calibration that many medium- and long-term projection models do—for example, OECD-FAO's AgLINK-CoSiMo or the U.S. Department of Agriculture's Partial Equilibrium Agricultural Trade Simulation (PEATSim) model (Somwaru and Dirkse 2012)—necessitated by the disparate sources of demand and supply elasticities in the literature, as elasticities are usually estimated outside of a market equilibrium framework. As observed by Blanco-Fonseca (2010) for the OECD-FAO and USDA agricultural baseline processes, the results of the first runs of the models are subjected to an extensive review process, in which considerable expert judgment is reflected in model adjustments, until a consensus on the final set of projections is reached.[20] The revisions of the IMPACT projections on fish within the project team reflected a similar approach, although with a much smaller group of experts and much simpler iteration processes involved.

An alternative to model calibration through parameter adjustments is to do a structural estimation of model parameters, whereby the elasticities and growth rates of the model are solved simultaneously with the market equilibrium calculations and projections, such that a closest alignment with observed data (for historical data) is achieved. This is computationally intractable except for a highly simplified system and would not guarantee that projections into the future would be consistent with expert judgment. Some regional models—such as the CAPRI model (Britz 2005) that is applied to the European Union region—adjust elasticities estimated from the literature such that they are consistent with the theoretical constraints implied by the functional forms of the model and with the other parameters of the model (Jansson and Kempen 2006). Because the CAPRI model is used for static policy analysis, however, it does not have to deal with the issue of how to calibrate to observed market changes over time, as is the case with those models applied to medium- and long-term market projections.

A key issue of how models such as IMPACT can best reflect observed past (or expected future) changes in market conditions depends on the degree to which a standard market equilibrium modeling structure can endogenously adapt itself to changing micro-level market conditions and whether it can be applied to commodities that are highly dynamic in their growth and market development, as opposed to more "mature" markets—such as for grains, livestock, and other commodities that are relatively well developed and have stable market structures—for which considerable data exists on observed, past behavior. IMPACT, like other models that rely on the solution of a multicommodity, multiregion market equilibrium problem, has to predefine which regions and commodities will be analyzed throughout the projection period, and define a starting point for consumption, production, and trade patterns, from which the projected market outcomes will evolve. Gradual changes can be introduced into the model structure to account for growth in population and income or gradual improvements in production technology, which are achieved through sequential shifts in the intercepts of demand and supply curves. Gradual changes in consumption preferences can also be captured through changes in the marginal expenditure propensities (that is, elasticities) according to patterns that have been observed to occur in consumption of well-known commodities. More dramatic market transformations, however, present a challenge to market

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[20] In the case of the OECD-FAO process, there are a series of annual questionnaires that are sent to participating countries and are translated into the AgLink database by country experts within the OECD secretariat. These are then combined with projections from the country modules managed by the FAO within the CoSiMo model such that a common baseline can be produced. The results are further reviewed by staff at both institutions as well as by country experts at the OECD commodity working group (Adenäuer 2008).

equilibrium models, given that they may entail the introduction (or disappearance) of production or consumption of commodities in regions for which the model was initialized, and entails the introduction (or removal) of equations and variables from the model structure in the middle of the simulation horizon. One of the well-known properties of the Armington (1969) approach to modeling trade is that it is not possible to introduce new trade flows into the model solution that did not exist at the initialization of the simulations (Plassmann 2004, Jansson and Kempen 2006). This presents a problem when dealing with fast-developing markets for fish species such as tilapia, which saw a tenfold increase in exports over 10 years and which we observed to change very rapidly even over the first five to six years of the IMPACT model calibration period. Enormous growth in tilapia production has been observed in mainland China (dwarfing Taiwan, China), and new producers, such as Ecuador, have emerged. Even though we prepared the model structure such that it could allow for this rapid growth during the calibration period, it is not possible for the model to create new growth where it does not already exist for any period after that initial calibration window. This is a problem that is inherent in the current approaches to multicommodity, multiregional market equilibrium models, and will continue to present a challenge when trying to model fish markets at the level of species detail that we have done. An obvious solution to this problem would be to adopt a higher level of commodity aggregation, as is done for the OECD-FAO analysis of aquaculture. But this would come at the expense of being unable to undertake a detailed analysis at a more disaggregate species level, which we see as a key advancement of our approach.

In general, we have focused more on the quantities of supply and demand, compared to the prices, in obtaining a close fit between projections and available data. Given that prices observed in the data are the result of interactions and processes that occur within a much more complicated value chain than the one captured in this simplified model, we are not able to obtain as close a fit for price data as for quantity data. As a result, more confidence is given to the quantity projections that come from the model than to the price projections. In this study, only qualitative interpretations are provided for price projections, as an indication of whether future market pressures will result in an overall upward or a downward trend in prices.

2.6. ISSUES AND DISCUSSIONS

In this section, issues in the data and methodology are summarized. This study relies on data compiled and made available by different groups within the FAO. While these data are widely used in fisheries analyses, it is known that availability and quality of data are the major constraint to any modeling exercise of global fish supply or demand. The following list summarizes the data issues encountered in the present modeling exercise:

- No single source of data or database exists for fish production, consumption, and trade (import and export) for countries/regions represented in the model.
- Since data are drawn from disparate sources, for a given country, the data on fish production, the consumption and trade of fish, and the production and trade of fishmeal and fish oil are typically inconsistent. This is a common challenge that also arises when modeling other agricultural markets and commodities besides fish.
- Fish production data are available in much more detail in terms of species disaggregation than fish consumption or trade data, so detailed information on fish production is lost in the process of species aggregation.
- FAO data on bilateral fish trade are unavailable at the preferred species disaggregation level or in the unit used in study (live weight equivalent).
- Trade volume and value are well documented, but the correctness of conversion factors for processed fish into live weight equivalent is uncertain (for example, whole crab versus crab meat).
- Trade data do not capture exports of processed products based on imported raw material.
- Consumption data used in this study are based on the difference between production, non-food uses, and trade, and thus the quality of consumption data depends on the quality of each of the original components.
- Production, apparent consumption (use), and trade data for fishmeal and fish oil are even less reliable and they are inconsistent with production data for small pelagic and other fish from which fishmeal and fish oil are produced.
- No data exist on the amount of fish (in whole or chopped) directly used as feed in fish farming.

Further, even for production series, which are considered more reliable than consumption or trade data series, the following issues are well known:

- For capture fisheries, overall catch levels are underestimated due to unreliable data on bycatch, discards, and illegal, unreported, and unregulated (IUU) fishing.
- Catch data are organized by flag states of fishing vessels, and they do not necessarily reflect the catch levels in waters of each coastal states.

Therefore, any sophisticated model of the global seafood market is constrained in its construction by data availability; one must interpret model results with caution, with these constraints and data quality issues in mind. Availability and quality of data dictate quality of conclusions and decisions made based on them. IMPACT is no exception. Much of the modeling effort in the present *Fish to 2030* study focused on organizing available data from multiple sources and reconciling across them in order to obtain a consistent picture of the global seafood market. It became clear to us that in order for these predictive models to generate definitive conclusions, higher-quality data are necessary. Investment in fisheries and aquaculture data—from collection to compilation across various stages and aspects of the market—should be promoted. Collaboration with private sector players in the seafood value chain may be an effective direction for improving data collection and compilation.

Besides data issues, application of IMPACT model to the global fisheries and aquaculture sector involved several challenges that lead to rigidity and limitation in the capacity of the model:

- IMPACT does not model bilateral trade flows, so specific links between origins and destinations of trade cannot be analyzed. This also implies that IMPACT assumes homogenous quality of imported and exported commodities (that is, they are treated as perfect substitutes).
- Instead, the structure of world markets in IMPACT is simple and assumes a single market-clearing price for each good across all regions. This leads to simplified representation of price formation, which in reality may be influenced by a range of factors, including commodity stock/inventory, price expectations, and imperfections in market structure such as market concentration and the power exerted by large firms.
- IMPACT modeling is based on historical data; it predicts changes in the production and consumption of various commodities in countries that are already producing or consuming the specific commodities. In other words, the model does not predict emergence of new participants—producers or consumers—in the market. This poses a limitation to the model's applicability in highly dynamic markets, such as those for fisheries and especially aquaculture, where continual technological innovations allow farming of new species and create new market opportunities.
- Given the focus of the IMPACT model on agricultural markets, several small island states and regions such as Greenland and Iceland are grouped together in a "rest of the world" (ROW) model region, as these areas are neither major producers nor major consumers of agricultural products. Some countries in the ROW group are, however, key actors in fisheries and aquaculture. Nevertheless, the model structure does not allow for changing of the makeup of the model regions for different commodities.

Further, several issues with model parameter specifications can be summarized as follows:

- With 115 model regions (individual and grouped countries) represented in IMPACT, the sheer size of the model prevented us from examining every input parameter and every output variable for each country. Use of country-specific information from existing country studies and microdata would improve the quality of model output.
- For the most part, model parameters are drawn from the relevant literature and existing data. However, future trends of parameters, which need to be specified by the researcher, are an additional source of error. A set of most important trend parameters are exogenous growth parameters for aquaculture, which reflect anticipated technological change in aquaculture, especially in feed efficiency. Rigorous analysis to predict the extent and the timing of technological innovations for various aquaculture fish species is beyond the scope of this study.

Given these observations, the model does not precisely replicate the realized outcomes of the global fish markets represented in multiple (and inconsistent) series of data. Nonetheless, substantial efforts were made to fine-tune the model to make its projections as close as possible to the observed data. In doing so, we focused on the data series to which we give more confidence (for example, capture harvest and aquaculture production series) rather than those for which the accuracy is known to be limited (for example, consumption series). We also focused our calibration efforts on countries and regions that are important fish producers, and some important aquaculture species (for example, salmon, shrimp, tilapia, and *Pangasius*/catfish) received special attention.

The following is a summary observation on the general quality of model output.

- The model closely replicates aggregate fish supply trends at the global level for 2000–08.
- Confidence on model results declines as one examines fish supply results at the country level,[21] especially for smaller countries. However, when the results are aggregated at the regional level, the fit between model output and data is fairly close.
- For supply of small pelagic fish in Latin America, there is a gap between model projections and corresponding data. These are major input used for fishmeal production. The deviation occurs because fishmeal requirements are calculated in the model for each aquaculture species based on the coefficients found in the literature and the calculated global fishmeal requirements are larger than what the data indicate on global fishmeal use. As a result, model forecasts more small fish to be destined for fishmeal production than the data indicate, and parameters are adjusted so that small pelagic fish production in Latin America picks up much of the difference. However, the harvest of small pelagic fish is subject to huge variations because of El Niño and La Niña as well as decadal oscillations, and calibration to data from particular years is probably not appropriate.
- Even at the regional level, model results for per capita fish consumption, and accordingly total fish consumption, exhibit deviation from available data in the 2000s. The deviation for per capita consumption is largest in Japan, East Asia and the Pacific, Southeast Asia, and ROW (a group of small countries that are not categorized in any region in IMPACT). The deviation for total consumption (per capita consumption times the population) is largest in China and Southeast Asia. Note that, however, as the accuracy of fish consumption data mainly relies on the quality of the original data from which they derive, as discussed earlier, perfect adherence of model output to consumption data is infeasible.
- Finally, we place least confidence on model output for world fish prices. In general, the dynamics of the global fish and seafood market is such that the price of major farmed species has declined and fish has become more affordable. However, due to the overly simplified representation of the international trade markets in IMPACT, the model cannot replicate such fish price trends.

Nevertheless, the study represents a careful examination of data and parameters and rigorous modeling of fish supply and demand. To our knowledge, the present model is the most comprehensive economic model of global fish and seafood market in terms of the treatment of fish species, countries and regions, and activities related to fisheries and aquaculture production, utilization, and trade.

TECHNICAL APPENDIX

A. Definition of Major Market Players for Deriving World Prices

The groups of major market players are selected according to a combination of approaches.

- Largest exporters indicated in FishStat for the 1999–2001 time period
- Expert opinion
- For each commodity, the combined exports of the selected countries must add up to at least 75 percent of total world exports in the year 2000.

Note that silver, bighead, and grass carp are considered non-traded goods as the vast majority is consumed domestically in China and no sizable international market exists. Therefore, no world price is calculated for this commodity. Table 2.7 lists the major market players for individual species and their combined share in the global market.

B. Adding-up Conditions for the IMPACT Model

The complete set of adding-up conditions for the IMPACT Model is as follows:

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[21] There are other multicommodity fish sector models (for example, the AsiaFish model) that work better for country-specific fish supply and demand projections (Dey, Briones, and Ahmed 2005; Dey and others 2008).

TABLE 2.7: List of Countries Used to Define World Prices for Base Year

PRODUCTION CATEGORY	COUNTRY (MAJOR MARKET PLAYER)	COMBINED SHARE IN GLOBAL TRADE
Shrimp	Thailand, China, Denmark, India, Indonesia, Netherlands, Norway, Vietnam, Greenland, Canada, Iceland, Malaysia, Mexico, United Kingdom	75%
Crustaceans	China, Canada, Thailand, United States, Indonesia, Russian Federation, United Kingdom, Myanmar, Vietnam, Australia, India, Denmark, Mexico, Ireland, Republic of Korea	76%
Mollusks	China, Republic of Korea, Argentina, Spain, Thailand, New Zealand, Morocco, United States, Vietnam, Netherlands, Denmark, United Kingdom, Taiwan Province of China, Canada, Italy	75%
Salmon	Norway, Chile, Denmark, United States, Canada	77%
Tuna	Thailand, Taiwan Province of China, Spain, France, Indonesia, Philippines, Ecuador, Côte d'Ivoire, Republic of Korea, Colombia, Seychelles	76%
Tilapia	Taiwan Province of China, Honduras, United States	99%
Pangasius and other catfish	Taiwan Province of China, United States	100%
Carp	Czech Republic, Taiwan Province of China, China, Belgium, Hungary	78%
Other carp	n.a.	n.a.
Eel and sturgeon	China, Taiwan Province of China	89%
Other freshwater and diadromous	Tanzania, Indonesia, Uganda, Kenya, Belgium, Canada, Netherlands	75%
Major demersals	Norway, Russian Federation, United States, Iceland, Denmark, Germany, Netherlands, New Zealand, Canada, Spain, Argentina, Republic of Korea, United Kingdom	77%
Mullet	United States, New Zealand, Taiwan Province of China	100%
Cobia and swordfish	Taiwan Province of China, Spain, Portugal	89%
Other pelagic	Norway, Russian Federation, United Kingdom, Netherlands, Chile, Denmark, Namibia, Spain, United States, Sweden, Germany, Morocco, Ireland, Latvia, Thailand, Poland, Canada	78%
Other marine	China, Thailand, Russian Federation, India, Indonesia, Argentina, Sweden, Namibia, Vietnam, United States, Chile, Ecuador, China, Hong Kong SAR, Japan, Ukraine, Senegal, Denmark, South Africa, Pakistan, Canada, Myanmar, Spain	78%

Source: Own calculations based on FishStat.
Note: n.a. = not applicable.

- All irrigated and rain-fed crop areas must add up to the total crop harvested area reflected in FAO data. Where these areas are disaggregated to subnational spatial definitions, these must all add up to the national FAO totals.
- In the case of fish, all aquaculture and capture production (inland/freshwater and marine) must add up to the total fish production quantities indicated in FAO data.
- Area times yield must equal the FAO production levels.
- All types of demand (food, feed, crush/reduction, biofuels, and other) must add up to FAO total demand $Q^{Total}_{Demd} = Q^{food}_{Demd} + Q^{feed}_{Demd} + Q^{crush}_{Demd} + Q^{biofuel}_{Demd} + Q^{other}_{Demd}$.
- Within each country, the relationship $Q_{prodn} = Q_{Demd} + Q_{NetExport} + \Delta S$ must hold, where $Q_{prodn}, Q_{Demd}, Q_{NetExport}$ are the quantities of production, demand, and net export, respectively, and represents the amount being added to stocks.
- Across all countries, for a given commodity, the relationship $\sum_{reg} Q^{reg}_{NetExport} = 0$ must hold for all 115 model regions, such that trade is balanced globally.
- Quantities of meal and oil production must be consistent with the crush/reduction demand from the feedstock commodities (either fish or oil-bearing crops) such that $Q^{oil,meal}_{Prodn} = RR^{oil,meal} Q^{crush}_{Demd}$, where the unit conversion of feedstock to oil or meal is given by the parameter $RR^{oil,meal}$.
- The feed relationships must achieve a balance between the animals (including fish) fed, and the quantities of feed demand that are reflected in the data such that $Q^{feed}_{Demd} = \sum_{anim} FCR^{anim} Q^{anim}_{Prodn}$, where FCR^{anim} is the amount of feed that is required per unit of animal production.

C. Details of Establishing the Consistent Base-Year Picture

Maximum Entropy Estimation

An optimization approach is adopted in the program to obtain the consistent base-year picture. The process involves estimation of two sets of parameters, reduction ratios (RRs) and feed conversion ratios (FCRs), as well as imputing associated variables (production and use of feed). This is done by fixing some variables at the levels indicated by the data and penalizing deviations from the data for the variables that are allowed to deviate. The objective criterion is to minimize the “distance” between the “target values” and the solution values of the parameters (RRs and FCRs) that satisfy the constraints. In this case, the constraints are the adding-up conditions that are employed in the IMPACT model (see technical appendix B to this chapter). To put into a simple mathematical expression, the essential problem that we are trying to solve is the following:

$$min_{RR,FCR} \sum_i \sum_k \left\| RR_{ik} - \widetilde{RR}_{ik} \right\| + \sum_i \sum_j \sum_k \left\| FCR_{ijk2000} - \widetilde{FCR}_{ijk2000} \right\|$$

subject to the adding-up conditions, including

$$feed^{prodn}_{ik2000} = RR_{ik} * \sum_j \left(Q^{redctn}_{jk2000} + Q^{waste}_{jk2000} \right) \text{ and}$$

$$\sum_k feed^{prodn}_{ik2000} = \sum_j \sum_k Q^{aquaprodn}_{jk2000} FCR_{ijk2000},$$

where

- RR_{ik} denotes RR for feed item ***i*** in country ***k***, $\widetilde{RR}_{ik}$ its target value
- FCR_{ijkt} FCR for feed item ***i***, for species ***j***, in country ***k***, and in year ***t***, $\widetilde{FCR}_{ijkt}$ its target value
- $feed^{prodn}_{ikt}$ the total feed produced of item ***i*** in country ***k*** in year ***t***
- Q^{redctn}_{jkt} the reduction demand for species ***j*** in country ***k*** in year ***t***
- Q^{waste}_{jkt} the demand for fish processing waste from species ***j*** to be used in fishmeal/fish oil production in country ***k*** in year ***t***
- $Q^{aquaprodn}_{jkt}$ the aquaculture production of species ***j*** in country ***k*** in year ***t***.

Note that RRs do not vary across fish species or over time (see next). Note also that data for Q^{waste}_{jk2000} are unavailable and this variable is imputed internally in the process (see next).

The optimization program allows a difference between the parameter values that satisfy the constraints and the target values, but it puts a penalty on this deviation according to a measure of distance that is conveyed by the functions $\left\| RR_{ik} - \widetilde{RR}_{ik} \right\|$ and $\left\| FCR_{ijkt} - \widetilde{FCR}_{ijkt} \right\|$. The program also imposes penalties on deviation between the values of certain variables and corresponding data in the process of enforcing certain necessary balances (such as that of trade) at the country level, so that the market equilibrium for the base year can be reproduced in a way that is consistent within the structure of the market model.

A least-squares type of fitting approach can be used in problems like this in order to minimize distance while satisfying certain constraints. However, there is often the issue of how to satisfy several different targets simultaneously, without imposing undue weight on any particular objective criterion over another. The problem becomes particularly vexing when confronted with a relative scarcity of reliable data, which may result in a far fewer number of data points than the number of unknowns that need to be determined. This situation leads to the type of “ill-posed” problems, where the degrees of freedom are non-positive, and the problems cannot be solved by linear algebraic inversion of a data matrix with respect to a vector of variables.

In order to resolve this issue, cross-entropy-based techniques can be used, which can derive unknown distributions from fairly limited data and includes one’s own “prior” beliefs on the underlying nature of the distribution where possible (Kullback 1959, Kullback and Leibler 1951). Cross-entropy methods have been successfully used in many types of statistical analyses in the physical and social sciences and also have been used in IFPRI’s work. Examples include balancing of the social accounting matrix (SAM) of a computable general equilibrium model (Robinson, Cattaneo, and El-Said 2000) and calculation of the distribution of irrigated and rain-fed crops based on global data from a variety of (sometimes inconsistent) datasets (You and Wood 2004). The overall principle used to carry out the estimation here is that of maximum entropy (Shannon 1948a, 1948b). It uses an optimization-based approach to measuring fit based on a metric of “distance,” or deviation, which is grounded in the formalism of entropy-based econometrics and statistical methods.

Assumptions used in the maximum entropy estimation of the two sets of parameters are detailed in the following two subsections. In particular, the RRs are discussed in the context of imputation of the use of fish processing waste in fishmeal and fish oil production. The FCR estimation discussion also includes the procedure of estimating growth rates of FCRs.

Imputing the Use of Fish Processing Waste in Fishmeal and Fish Oil Production

The amount of fish processing waste used in the production of fishmeal and fish oil produced is imputed for 2000 using the following two sets of parameters.

- Reduction ratio: amount of fishmeal and fish oil produced (in product weight) per unit of fish used (in live weight equivalent)
- Waste ratio: amount of fish processing waste generated from a unit of whole fish (in live weight equivalent).

In this study, reduction ratios are defined for each country, rather than each species. By this, we implicitly assume that the quantity and quality of fishmeal and fish oil produced per unit of fish are the same across species. FAO FIPS FBS specifies which species are reduced (as whole fish) to become fishmeal and fish oil. They are shrimp, crustaceans, mollusks, freshwater and diadromous, demersals, pelagics, and other marine. Waste ratios are specified for each species (see below).

The imputation is further based on the following assumptions. First, that processing waste is not traded and that the amount of processing waste available in a country is based only on the capture and aquaculture production that occurs within the country.[22] Second, that every unit of whole fish can generate an amount of fish processing weight according to the waste ratios. Third, that each unit of fish processing waste yields the same quantity of fishmeal and fish oil as a unit of whole fish according to the reduction ratios and that there is no quality difference.

Since the IFFO estimates that fish processing waste currently contributes to 25 percent of the global fishmeal production (Shepherd 2012), we try to make the imputed values as close as possible to this number. FAO data suggest there are 10 countries that currently use fish processing waste in fishmeal production: Canada, Chile, Denmark, Iceland, Japan, Mexico, Norway, Russian Federation, Thailand, and the United States. However, in order to obtain consistency between the

- Amount of whole fish used in fishmeal production indicated by FAO FIPS FBS data,
- Country-specific reduction ratios, and
- Amount of fishmeal production indicated by the FAO data, it was decided that additional countries must have used fish processing waste. These additional countries are Argentina, Australia, Belgium-Luxembourg, Brazil, the British Isles (including Ireland), Côte d'Ivoire, France, Germany, Italy, Spain/Portugal, Uruguay, and Vietnam. Thus, in the imputed amount fish processing waste use originate from all of these countries.

The actual imputation of the volume of processing waste used in fishmeal and fish oil production is conducted in conjunction with the maximum entropy estimation of reduction ratios. As the "prior," or the target value $\widetilde{RR}_{ik}$ in the estimation process, published figures for Peru (0.23 for fishmeal and 0.06 for fish oil) are used (Jackson 2010). Table 2.8 shows the regional values of the estimated reduction ratios.

The weight of processing waste generated depends on the species, processing stage, and the technology used. Table 2.9 compiles the estimates of waste ratios from various sources. The estimates are based on the processing stage defined as "dressed head-off," where

TABLE 2.8: Estimated Reduction Ratios

	FISHMEAL	FISH OIL
Global average	**0.23**	**0.05**
ECA	0.18	0.06
NAM	0.19	0.07
LAC	0.23	0.05
EAP	0.30	0.06
CHN	0.28	0.01
JAP	0.26	0.04
SEA	0.29	0.02
SAR	0.15	0.04
IND	0.03	0.02
MNA	0.14	0.05
AFR	0.32	0.06
ROW	0.22	0.07

Source: Data based on Jackson 2010.
Note: These are regional weighted averages based on reduction demand in 2000. ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

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[22] These assumptions are made for simplicity. In reality, both fish waste trade and fish trade for processing and reexport of intermediate and final products are observed (FAO 2012).

TABLE 2.9: Waste Ratios Used in the IMPACT Model

COMMODITY	WASTE	SPECIES REPRESENTED AND METHODOLOGY NOTES
Shrimp	45%	Average of two shrimp species for "Raw Headless" processing stage (Crapo, Paust, and Babbitt 2004)
Salmon	26%	Average of five different salmon species (Crapo, Paust, and Babbitt 2004)
Tilapia	50%	Clement and Lovell 1994; Garduño-Lugo and others 2003
Pangasius/catfish	40%	Argue, Liu, and Dunham 2003; Clement and Lovell 1994; Li and others 2001; Silva and Dean 2001
Tuna	25%	Crapo, Paust, and Babbitt 2004
MDemersal	29%	Average of flounder, sole, turbot, halibut, cod, and hake (Crapo, Paust, and Babbitt 2004)
Mullet	26%	Average of wild and farmed trout (Crapo, Paust, and Babbitt 2004)
OFresh	26%	Use the same value as commodity "mullet" (Crapo, Paust, and Babbitt 2004)

the head, fins, skin, and viscera, among other parts, are removed from the fish.

Estimating FCRs

In the maximum entropy program, FCRs for the year 2000 are estimated in each country for the species that are considered to use fishmeal, fish oil, and soybean meal as input. These species are shrimp, crustaceans, salmon, tilapia, *Pangasius*/catfish, carp, OCarp, EelStg, MDemersal, mullet, CobSwf, OPelagic, and OMarine. That is, the model does not account for feeding in aquaculture of mollusks, tuna, or OFresh. While mollusks and OFresh are typically not directly fed, tuna is fed with feed fish rather than processed meal. In order to account for the cost of feeding in determining tuna supply, fishmeal and fish oil prices are included in the supply function for tuna. Livestock FCRs (poultry and hogs) are also estimated in the same program.

As the target value $\widetilde{FCR}_{ijkt}$ in the maximum entropy estimation of FCRs, we heavily rely on Tacon and Metian (2008), who compiled FCR estimates for various species and various countries from the literature. Using those values, we determined minimum, maximum, and typical values of FCR for each species. When corresponding species are not found in Tacon and Metian (2008), authors' judgments are used. These minimum, maximum, and typical FCR values are used as prior in the estimation.

In order to estimate growth rates of FCRs, the maximum entropy estimation is repeated for the year 2009. The two sets of values are used to derive FCR growth rates for fishmeal and fish oil for each species. In many cases, however, the direct calculation of growth rates generated unreasonable values and adjustments had to be made. No FCR growth rates for soybean meal are estimated this time. In implementation of the growth rates in the IMPACT model, in order to prevent unrealistically low or high levels of FCRs, lower and upper bounds of FCR values are imposed. The minimum and maximum values used as prior information in estimation are used as the bounds.

Finally, using the FCR estimates, the levels of feed use are imputed such that:

$$feed_{ikt}^{use} = \sum_j Q_{jkt}^{aquaprodn} \widetilde{FCR}_{ijkt},$$

where $feed_{ikt}^{use}$ denotes the total feed used of feed item *i* in country *k* in year *t* and $\widetilde{FCR}_{ijkt}$ the estimated values of FCR for feed item *i*, for species *j*, in country *k*, and in year *t*.

Chapter 3: IMPACT PROJECTIONS TO 2030 UNDER THE BASELINE SPECIFICATION

In this chapter, we systematically present the IMPACT model output under the baseline specifications. The baseline scenario reflects the trends of the global fish markets that are currently observed in the aggregate statistics. On the consumption demand side, we incorporate the trends in human population and income growth. On the production side, incorporated in the model are trends in the capture fisheries harvest, aquaculture production, and feed use and efficiency in aquaculture. Specifications of some of these "exogenous" trends will be modified in the next chapter. Thus, the results here provide the benchmark of what the model projects given the underlying drivers of change in global fish supply, demand, and trade.

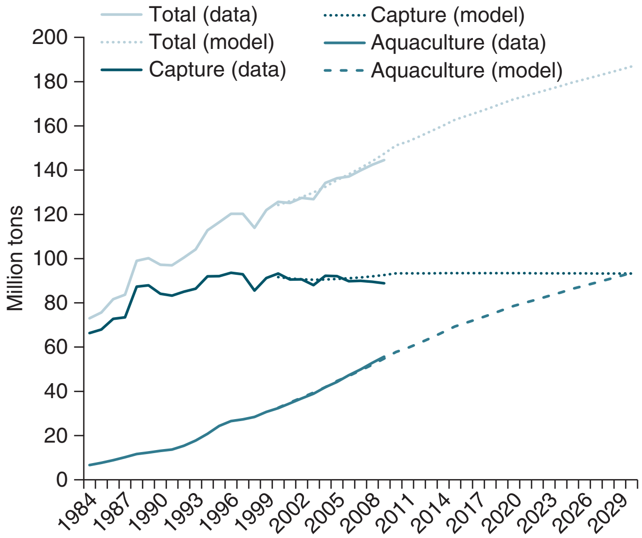
3.1. PRODUCTION

Global Trend

We begin our presentation of the baseline results with fish production at the global level. Figure 3.1 depicts the projected global fish supply to 2030 and how it is divided between capture and aquaculture production, together with their historical path. The projected capture production remains fairly stable over the 2000–30 period, as has been observed in the data. In contrast, the global aquaculture projection maintains its steady rise from historical levels, reaching the point where it equals global capture production by 2030. Global fish supply is projected to rise to 187 million tons by 2030. These projections are consistent with projections by OECD-FAO to 2021 (OECD-FAO 2012). See technical appendix to this chapter for further comparisons of our projections with those by OECD-FAO (2012).

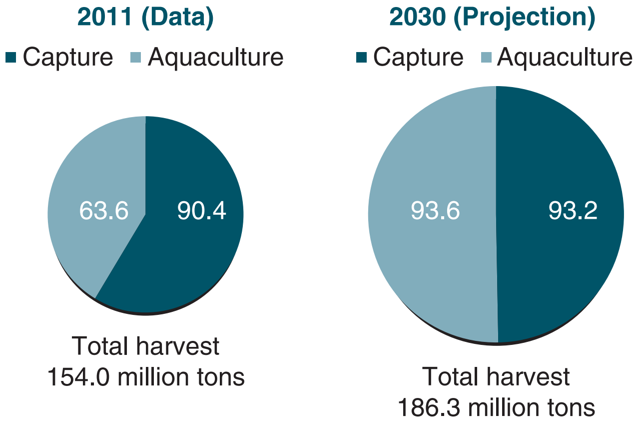
Figure 3.2 shows the breakdown of global fish supply between capture and aquaculture production. While the share of capture fisheries is nearly 60 percent of global production in 2011, it is expected

FIGURE 3.1: Global Fish Production: Data and Projections, 1984–2030



Sources: FishStat and IMPACT model projections.

FIGURE 3.2: Volume and Share of Capture and Aquaculture Production in Global Harvest

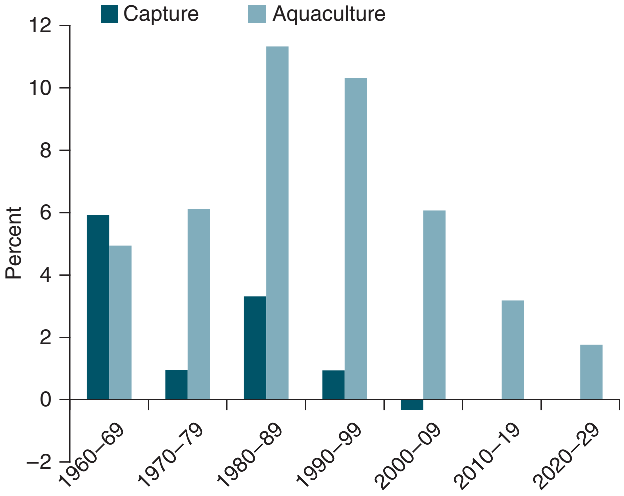


Sources: FishStat and IMPACT model projections.

to fall to exactly half by 2030, after growing only by 2.8 million tons. Aquaculture is expected to grow by 30 million tons over this same period. In terms of food fish production, the model predicts that aquaculture will contribute 62 percent of the global supply by 2030.

These results are consistent with the overview given in the introductory chapter and reinforce the importance of aquaculture in augmenting global fish supply. However, the growth of aquaculture is expected to further decelerate. Figure 3.3 extends figure 1.3 to include the projected annual growth rates for the projection periods of 2010–19 and 2020–29. For these two periods, the projected growth rate of aquaculture production is below the level in the 1960s. Nearly zero growth is projected for capture production.

FIGURE 3.3: Average Annual Growth Rates of Capture and Aquaculture Production, 1960–2029



Sources: FishStat and IMPACT model projections.

Regional Distribution

Geographically, fish production is concentrated in Asia, LAC, and ECA (table 3.1). In 2008, Asia (total of EAP, CHN, JAP, SEA, SAR, and IND) represented 65 percent of global fish production, with CHN accounting for more than a third of global production. Global fish production is expected to further concentrate in Asia toward 2030 (69 percent). IND has the largest projected growth, 60.4 percent, during 2010–30, representing 6.8 percent of global production by 2030. SEA is expected to grow 37.5 percent, and it will likely represent more than 15 percent of global production by 2030. China's fish production is expected to grow 31.4 percent, accounting for an overwhelming 36.9 percent of the world's fish production by 2030. China represented the largest and one of the fastest-growing

TABLE 3.1: Projected Total Fish Production by Region

	DATA (000 TONS)	PROJECTION (000 TONS)			SHARE IN GLOBAL TOTAL		% CHANGE
	2008	2010	2020	2030	2010 (PROJECTION)	2030 (PROJECTION)	2010–30
Global total	**142,285**	**151,129**	**172,035**	**186,842**	**100.0%**	**100.0%**	**23.6%**
ECA	14,564	14,954	15,369	15,796	9.9%	8.5%	5.6%
NAM	6,064	6,226	6,319	6,472	4.1%	3.5%	3.9%
LAC	17,427	19,743	20,957	21,829	13.1%	11.7%	10.6%
EAP	3,724	3,698	3,832	3,956	2.4%	2.1%	7.0%
CHN	49,224	52,482	62,546	68,950	34.7%	36.9%	31.4%
JAP	4,912	5,169	4,911	4,702	3.4%	2.5%	–9.0%
SEA	20,009	21,156	25,526	29,092	14.0%	15.6%	37.5%
SAR	6,815	7,548	9,210	9,975	5.0%	5.3%	32.1%
IND	7,589	7,940	10,346	12,731	5.3%	6.8%	60.4%
MNA	3,518	3,832	4,440	4,680	2.5%	2.5%	22.1%
AFR	5,654	5,682	5,865	5,936	3.8%	3.2%	4.5%
ROW	2,786	2,696	2,714	2,724	1.8%	1.5%	1.0%

Sources: FishStat and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

TABLE 3.2: Projected Aquaculture Production by Region

	DATA (000 TONS)	PROJECTION (000 TONS)			SHARE IN GLOBAL TOTAL		% CHANGE
	2008	2010	2020	2030	2010 (PROJECTION)	2030 (PROJECTION)	2010–30
Global total	**52,843**	**57,814**	**78,625**	**93,612**	**100.0%**	**100.0%**	**61.9%**
ECA	2,492	2,734	3,270	3,761	4.7%	4.0%	37.5%
NAM	655	631	728	883	1.1%	0.9%	40.0%
LAC	1,805	1,642	2,770	3,608	2.8%	3.9%	119.7%
EAP	751	795	936	1,066	1.4%	1.1%	34.0%
CHN	33,289	36,562	46,790	53,264	63.2%	56.9%	45.7%
JAP	763	765	861	985	1.3%	1.1%	28.7%
SEA	6,433	7,171	11,384	14,848	12.4%	15.9%	107.1%
SAR	1,860	2,185	3,493	4,163	3.8%	4.4%	90.5%
IND	3,585	3,885	6,232	8,588	6.7%	9.2%	121.1%
MNA	921	1,086	1,679	1,911	1.9%	2.0%	75.9%
AFR	231	302	418	464	0.5%	0.5%	53.6%
ROW	57	55	64	72	0.1%	0.1%	29.5%

Sources: FishStat and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

countries in the *Fish to 2020* assessment. Although other regions are also expected to increase fish supply, their relative contribution to the global supply will likely decline. Japan's fish production is projected to contract during this period.

Considering just aquaculture production, China's share in global production is even larger (table 3.2). In 2008, China represented 63.2 percent of global aquaculture production, and the projected share in 2030 will decline to 56.9 percent. While all regions are expected to expand their aquaculture production, the largest expansion is expected in SEA and IND. SEA is expected to represent 15.9 percent of global aquaculture production in 2030, while IND would represent 9.2 percent. LAC and South Asia (excluding India) (SAR) are also projected to experience large aquaculture growth over the 2010–30 period. Middle East and North Africa (MNA) and Sub-Saharan Africa (AFR) also show substantial expected growth over this period, but they begin from much lower production levels in 2010 compared to other regions. Given the recent aquaculture research and development efforts in these countries, the projection results are quite plausible. For example, aquaculture is considered a "sunrise sector" in India. In recent years, India has made significant achievement in aquaculture research and development, including development of improved rohu carp through selective breeding with a record of 17 percent higher growth response per generation, availability of balanced supplementary feed for different life stages for diversified cultivable species, and appropriate disease management measures (Ayyappan 2012).

Table 3.3 shows the regional distribution of fish production from capture fisheries. In contrast to aquaculture production, the distribution of capture production is more evenly spread out across regions. China, LAC, SEA, and ECA each had more than 10 percent of the share of global capture harvest in 2008. The largest growth in harvest is expected for SAR, while Japan is expected to reduce capture production by 15 percent over the 2010–30 period.

By Species

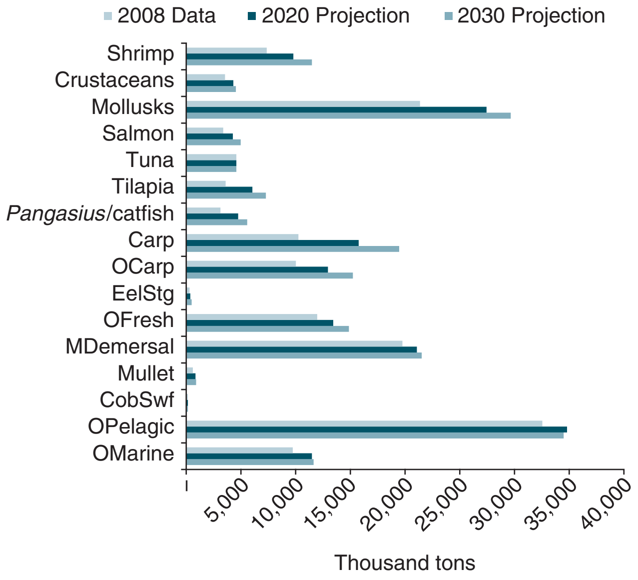
Figure 3.4 depicts the projected fish supply by species (both capture fisheries and aquaculture), while figure 3.5 shows the projected dynamics of aquaculture. Further, table 3.4 summarizes the projected change in species share over time. The fastest growth is expected for tilapia, carp, and *Pangasius*/catfish. Due to the rapid expansion of aquaculture, production of tilapia is projected to more than double between 2008 and 2030. Some high-value species (shrimp, salmon, and EelStg) are expected to grow by 50 to 60 percent over the period. Some low-value species (carp

TABLE 3.3: Projected Capture Fisheries Production by Region

	DATA (000 TONS)	PROJECTION (000 TONS)			SHARE IN GLOBAL TOTAL		% CHANGE
	2008	2010	2020	2030	2010 (PROJECTION)	2030 (PROJECTION)	2010–30
Global total	**89,443**	**93,315**	**93,410**	**93,229**	**100.0%**	**100.0%**	**–0.1%**
ECA	12,072	12,220	12,099	12,035	13.1%	12.9%	–1.5%
NAM	5,409	5,596	5,591	5,589	6.0%	6.0%	–0.1%
LAC	15,621	18,101	18,187	18,221	19.4%	19.5%	0.7%
EAP	2,973	2,903	2,896	2,890	3.1%	3.1%	–0.4%
CHN	15,935	15,920	15,756	15,686	17.1%	16.8%	–1.5%
JAP	4,149	4,403	4,050	3,717	4.7%	4.0%	–15.6%
SEA	13,575	13,986	14,142	14,244	15.0%	15.3%	1.8%
SAR	4,955	5,363	5,717	5,811	5.7%	6.2%	8.4%
IND	4,004	4,055	4,114	4,143	4.3%	4.4%	2.2%
MNA	2,597	2,746	2,761	2,769	2.9%	3.0%	0.8%
AFR	5,422	5,380	5,447	5,472	5.8%	5.9%	1.7%
ROW	2,729	2,641	2,649	2,652	2.8%	2.8%	0.4%

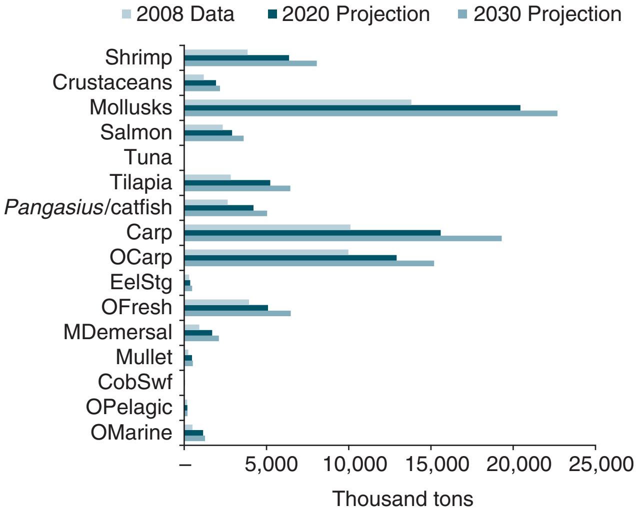
Sources: FishStat and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

FIGURE 3.4: Projected Global Fish Supply by Species



Sources: FishStat and IMPACT model projections.
Note: Pangasius/catfish = *Pangasius* and other catfish; OCarp = silver, bighead, and grass carp; EelStg = aggregate of eels and sturgeon; OFresh = freshwater and diadromous species (excluding tilapia, *Pangasius*/catfish, carp, OCarp, and EelStg); MDemersal = major demersal fish; CobSwf = aggregate of cobia and swordfish; OPelagic = other pelagic species; OMarine = other marine fish.

FIGURE 3.5: Projected Global Aquaculture Fish Supply by Species



Sources: FishStat and IMPACT model projections.
Note: Pangasius/catfish = *Pangasius* and other catfish; OCarp = silver, bighead, and grass carp; EelStg = aggregate of eels and sturgeon; OFresh = freshwater and diadromous species (excluding tilapia, *Pangasius*/catfish, carp, OCarp, and EelStg); MDemersal = major demersal fish; CobSwf = aggregate of cobia and swordfish; OPelagic = other pelagic species; OMarine = other marine fish.

and OCarp) also will likely grow fast. On the other hand, only marginal growth in supply is expected for species with limited aquaculture potential (for example, OPelagic, MDemersal, and tuna). Given the ongoing research and development efforts on various aquaculture species, these results are quite realistic. Since the introduction of genetically improved tilapia in Asia in the 1990s, many countries around the globe, including China, currently have ongoing tilapia genetic improvement programs (ADB 2005; Dey 2000; Eknath and others 2007; Gjedrem, Robinson, and Rye 2012). Genetic improvement programs have also been

TABLE 3.4: Projected Species Shares in Aquaculture Production

	2008	2010	2020	2030
	DATA	PROJECTION	PROJECTION	PROJECTION
Shrimp	7%	7%	8%	9%
Crustaceans	2%	2%	2%	2%
Mollusks	26%	28%	26%	24%
Salmon	4%	4%	4%	4%
Tuna	..	..	..	..
Tilapia	5%	5%	7%	7%
Pangasius/catfish	5%	5%	5%	5%
Carp	19%	20%	20%	21%
OCarp	19%	18%	16%	16%
EelStg	1%	..	..	1%
OFresh	7%	6%	6%	7%
MDemersal	2%	2%	2%	2%
Mullet	..	1%	1%	1%
CobSwf	0.1%	0.1%	..	..
OPelagic	0.3%	0.3%	0.2%	0.2%
OMarine	1%	1%	1%	1%

Note: Pangasius/catfish = *Pangasius* and other catfish; OCarp = silver, bighead, and grass carp; EelStg = aggregate of eels and sturgeon; OFresh = freshwater and diadromous species (excluding tilapia, *Pangasius*/catfish, carp, OCarp, and EelStg); MDemersal = major demersal fish; CobSwf = aggregate of cobia and swordfish; OPelagic = other pelagic species; OMarine = other marine fish; .. = negligible.

initiated for carp and shrimp (Dey and others 2010; Hung and others 2013; Ninh and others 2013). Though about 97 percent of the world salmon production is currently based on improved stock (Gjedrem and Baranski 2009), the salmon industry has been maintaining a strong research and development effort. There has been improvement in technical efficiency over time in the Norwegian salmon industry, mainly through restructuring the industry as well as making improvements in government regulations (Asche and Roll 2013).

Table 3.5 shows the top three regions in the production of each species in 2008 and 2030. Overall, the model does not predict a substantial shift in the major players in the global fish markets. SEA is expected to take some of China's share in the global shrimp supply, while LAC is likely to grow to account for a third of global salmon supply by 2030. The latter primarily represents recovery after the ISA outbreak and subsequent growth in Chile.

TABLE 3.5: Projected Top Three Fish Producing Regions by Species

	2008 – DATA			2030 – PROJECTION		
	1ST (SHARE)	2ND (SHARE)	3RD (SHARE)	1ST (SHARE)	2ND (SHARE)	3RD (SHARE)
Shrimp	CHN	SEA	LAC	CHN	SEA	LAC
	43%	27%	10%	39%	36%	10%
Crustaceans	CHN	NAM	ECA	CHN	NAM	SEA
	57%	11%	7%	63%	9%	7%
Mollusks	CHN	SEA	LAC	CHN	SEA	LAC
	63%	7%	7%	69%	7%	5%
Salmon	ECA	LAC	NAM	ECA	LAC	NAM
	52%	19%	15%	49%	29%	11%
Tuna	SEA	LAC	EAP	SEA	LAC	EAP
	23%	13%	12%	25%	14%	12%
Tilapia	CHN	SEA	AFR	SEA	CHN	MNA
	35%	27%	14%	37%	29%	15%
Pangasius/ *catfish*	SEA	CHN	AFR	SEA	CHN	AFR
	50%	22%	9%	55%	19%	8%
Carp	CHN	IND	SAR	CHN	IND	SEA
	49%	27%	10%	37%	36%	13%
OCarp	CHN	IND	SAR	CHN	SAR	IND
	93%	3%	2%	92%	3%	3%
EelStg	CHN	JAP	ECA	CHN	JAP	ECA
	82%	7%	5%	89%	5%	3%
OFresh	CHN	SAR	SEA	CHN	SEA	SAR
	32%	21%	17%	35%	20%	20%
MDemersal	ECA	CHN	NAM	ECA	CHN	NAM
	26%	20%	11%	26%	20%	11%
Mullet	MNA	CHN	SEA	MNA	CHN	SEA
	45%	13%	13%	57%	11%	11%
CobSwf	CHN	ECA	JAP	CHN	ECA	LAC
	32%	24%	9%	33%	26%	8%
OPelagic	LAC	ECA	SEA	LAC	ECA	SEA
	34%	15%	14%	39%	14%	13%
OMarine	SEA	CHN	SAR	CHN	SEA	SAR
	32%	26%	20%	29%	28%	21%

Sources: FishStat and IMPACT model projections.
Note: Pangasius/catfish = *Pangasius* and other catfish; OCarp = silver, bighead, and grass carp; EelStg = aggregate of eels and sturgeon; OFresh = freshwater and diadromous species (excluding tilapia, *Pangasius*/catfish, carp, OCarp, and EelStg); MDemersal = major demersal fish; CobSwf = aggregate of cobia and swordfish; OPelagic = other pelagic species; OMarine = other marine fish; ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

3.2. CONSUMPTION

In all of the simulations presented in this study, the drivers of change on the demand side are specified according to the income and population growth trends as found in table 3.6. According to the World Bank (2012), between 2010 and 2030, China's gross domestic product (GDP) per capita is expected to almost triple. Income levels in IND and SEA are expected to almost double. On the other hand, the UN (2011) projects the highest population growth in AFR. Between 2010 and 2030, the population in AFR is projected to increase by 57.6 percent, or at the annual rate of 2.3 percent.

Currently, about 80 percent of the fish produced globally is consumed by people as food. The model results suggest that this proportion is not expected to change into 2030. Given that the production is expected to grow by 23.6 percent during the 2010–30 period (table 3.1) and the world population is projected to grow at 20.2 percent over the same period (table 3.6), the world will likely manage to increase the fish consumption level, on average.

As seen in table 3.7, at the global level, annual per capita fish consumption is projected to increase from 17.2 kilograms in 2010 to 18.2 kilograms in 2030. The trend in per capita consumption, however, is diverse across regions. In general, per capita fish consumption is expected to grow fast in the regions with the highest projected income growth (CHN, IND, SEA). However, the highest growth in fish consumption is expected in SAR, where per capita fish consumption is expected to grow at 1.8 percent per year over the 2010–30 period. In all of these regions, however, the growth in per capita fish consumption is expected to slow relative to the 2000–06 period.

Japan, traditionally the world's largest consumer of seafood, is the only region where per capita fish consumption declined over the 2000–06 period (it declined from 67.7 kilograms to 59.2 kilograms). The model predicts a continued decline, but at a slower rate. A declining trend of fish consumption is also projected for EAP, LAC, and AFR.

Per capita fish consumption is projected to decline in AFR. Starting from a modest level of fish consumption in 2006—7.5 kilograms, which was the second lowest, after IND (5.0 kilograms)—per capita fish consumption in AFR is projected to decline to 5.6 kilograms by 2030.

TABLE 3.6: Income and Population Growth Assumptions

	GDP PER CAPITA		POPULATION			
	GDP/c (US$)	% CHANGE	POPULATION (MILLIONS)	% CHANGE	SHARE IN GLOBAL TOTAL	
	2010 (DATA)	2010–30	2010 (DATA)	2010–30	2010 (DATA)	2030 (PROJECTION)
Global total/average	**6,941**	**17.4%**	**6,941**	**20.2%**	**100%**	**100%**
ECA	12,906	40.5%	891	3.3%	12.8%	11.0%
NAM	36,764	25.2%	347	16.3%	5.0%	4.8%
LAC	4,986	32.2%	586	18.5%	8.4%	8.3%
EAP	13,724	48.6%	110	12.8%	1.6%	1.5%
CHN	2,797	177.0%	1,355	3.4%	19.5%	16.8%
JAP	40,092	22.4%	126	–5.4%	1.8%	1.4%
SEA	1,875	88.4%	550	18.7%	7.9%	7.8%
SAR	606	51.1%	460	28.8%	6.6%	7.1%
IND	828	92.6%	1,241	23.7%	17.9%	18.4%
MNA	3,380	29.0%	382	31.8%	5.5%	6.0%
AFR	646	77.3%	874	57.6%	12.6%	16.5%
ROW	7,103	79.0%	19	13.2%	0.3%	0.3%

Sources: UN 2011; World Bank 2012.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

Projections on per capita fish consumption in table 3.7 combined with the population growth projections in table 3.6 determine the aggregate projected trends seen in table 3.8. As with the world population, global fish consumption is also heavily centered in Asia. The Asian regions are also projected to have steady and rapid consumption growth over the period, with IND and SAR expecting

TABLE 3.7: Projected Per Capita Fish Consumption by Region

	DATA (KG/PERSON/YEAR)		PROJECTION (KG/PERSON/YEAR)			ANNUAL GROWTH RATE	
	2000	2006	2010	2020	2030	2000–06[a]	2010–30[b]
Global average	**15.7**	**16.8**	**17.2**	**18.0**	**18.2**	**1.1%**	**0.3%**
ECA	17.0	18.5	17.4	17.2	18.2	1.5%	0.2%
NAM	21.8	24.3	22.9	24.5	26.4	1.8%	0.7%
LAC	8.8	9.4	8.4	8.0	7.5	1.1%	–0.6%
EAP	32.1	36.5	27.1	26.1	23.8	2.2%	–0.7%
CHN	24.4	26.6	32.6	37.8	41.0	1.4%	1.2%
JAP	67.7	59.2	64.7	63.7	62.2	–2.2%	–0.2%
SEA	24.6	27.9	25.8	28.3	29.6	2.1%	0.7%
SAR	8.5	11.4	11.0	13.4	15.7	5.1%	1.8%
IND	4.5	5.0	5.6	6.2	6.6	1.7%	0.8%
MNA	8.3	10.2	9.3	9.4	9.4	3.5%	0.0%
AFR	7.1	7.5	6.8	6.1	5.6	0.8%	–1.0%
ROW	18.4	20.1	9.4	9.6	9.6	1.5%	0.1%

Sources: FAO FIPS FBS and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.
[a] Based on data.
[b] Based on projections.

TABLE 3.8: Projected Total Food Fish Consumption by Region

	DATA (000 TONS)	PROJECTION (000 TONS)			SHARE IN GLOBAL TOTAL		% CHANGE
	2006	2010	2020	2030	2010 (PROJECTION)	2030 (PROJECTION)	2010–30
Global total	**111,697**	**119,480**	**138,124**	**151,771**	**100.0%**	**100.0%**	**27.0%**
ECA	16,290	15,488	15,720	16,735	13.0%	11.0%	8.1%
NAM	8,151	7,966	9,223	10,674	6.7%	7.0%	34.0%
LAC	5,246	4,900	5,165	5,200	4.1%	3.4%	6.1%
EAP	3,866	2,975	3,068	2,943	2.5%	1.9%	–1.1%
CHN	35,291	44,094	52,867	57,361	36.9%	37.8%	30.1%
JAP	7,485	8,180	7,926	7,447	6.8%	4.9%	–9.0%
SEA	14,623	14,175	17,160	19,327	11.9%	12.7%	36.3%
SAR	4,940	5,063	7,140	9,331	4.2%	6.1%	84.3%
IND	5,887	6,909	8,688	10,054	5.8%	6.6%	45.5%
MNA	3,604	3,571	4,212	4,730	3.0%	3.1%	32.5%
AFR	5,947	5,980	6,758	7,759	5.0%	5.1%	29.7%
ROW	367	179	198	208	0.2%	0.1%	15.7%

Sources: FAO FIPS FBS and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

the largest growth to 2030, though from lower initial levels. Adding together all its regions (CHN, EAP, JAP, SEA, IND, and SAR), Asia is expected to represent 70 percent of global fish consumption by 2030. MNA, which represented 3.2 percent of global fish consumption in 2006, is projected to grow by more than 30 percent during the 2010–30 period.

Even though per capita consumption is expected to decline in Sub-Saharan Africa, the total consumption for the region is expected to grow by 30 percent over the projection horizon. This is much more than the 4.5 percent growth in production projected over that same period (table 3.1), and suggests that much of the increased fish consumption would be supported by imports as seen in the next section.

3.3. TRADE AND PRICES

Table 3.9 summarizes the model results on net exports for each region, where a positive number in the table indicates net exports and a negative number indicates net imports (shaded cells in the table). The row for AFR suggests that the net imports of fish by this region are expected to increase substantially from the 2010 level to 2020 and then 2030 levels. This implies an increasing import dependency in AFR, and it might expose the region to greater variability in the fish supply and vulnerability of their food security to shocks that occur in the global markets. Given the pattern of fish consumption and imports, the import to consumption ratio in AFR would rise from 14 percent in 2000 to nearly 34 percent in 2030.

Looking across other regions, we project that strong net export trends of regions like SEA, LAC, CHN, and IND will be balanced out by the strong net imports by other regions such as NAM, ECA, JAP, AFR, and MNA.

To look further into the patterns of global fish trade, tables 3.10a and 3.10b list the top three net exporter and net importer regions, respectively, of each traded species in 2006 (data) and 2030 (projection). While the net trade patterns remain the same for many cases, some new patterns are projected to emerge. LAC countries are projected to increase their share of shrimp net exports from

TABLE 3.9: Projected Net Exports of Fish by Region

	DATA (000 TONS)	PROJECTION (000 TONS)			% CHANGE
	2006	**2010**	**2020**	**2030**	**2010–30**
Global total trade volume	**12,258**	**12,677**	**14,652**	**17,756**	**40.1%**
ECA	–4,166	–4,145	–3,994	–4,602	11.0%
NAM	–2,405	–2,911	–4,121	–5,464	87.7%
LAC	2,520	2,018	2,879	3,678	82.3%
EAP	–983	155	151	394	154.0%
CHN	4,288	2,002	2,210	3,567	78.1%
JAP	–3,570	–4,239	–4,233	–3,953	–6.8%
SEA	2,741	5,372	6,482	7,735	44.0%
SAR	362	2,097	1,614	150	–92.9%
IND	596	623	1,220	2,232	258.1%
MNA	–560	–456	–675	–1,042	128.6%
AFR	–806	–927	–1,629	–2,633	184.2%
ROW	1,518	410	95	–63	–115.3%

Sources: FAO FIPS FBS and IMPACT model projections.

Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

TABLE 3.10a: Projected Top Three Net Fish Exporting Regions by Species

	2006 – DATA			2030 – PROJECTION		
	1ST (SHARE)	2ND (SHARE)	3RD (SHARE)	1ST (SHARE)	2ND (SHARE)	3RD (SHARE)
Shrimp	SEA	CHN	LAC	SEA	LAC	CHN
	45%	17%	14%	55%	25%	7%
Crustaceans	CHN	SEA	LAC	CHN	SAR	EAP
	72%	17%	5%	89%	9%	2%
Mollusks	CHN	LAC	SEA	CHN	LAC	EAP
	58%	23%	15%	59%	29%	5%
Salmon	LAC	ECA	ROW	LAC	ECA	ROW
	85%	11%	4%	82%	15%	2%
Tuna	CHN	SEA	ROW	ROW	CHN	EAP
	35%	23%	21%	29%	27%	24%
Freshwater and diadromous	SEA	CHN	AFR	SEA	CHN	IND
	49%	35%	14%	79%	17%	4%
Demersals	ROW	LAC	IND	IND	LAC	SEA
	49%	31%	7%	26%	25%	23%
Pelagics	LAC	NAM	MNA	SEA	ECA	EAP
	34%	17%	17%	56%	16%	11%
Other marine	CHN	SEA	SAR	CHN	IND	ROW
	69%	20%	8%	70%	27%	3%

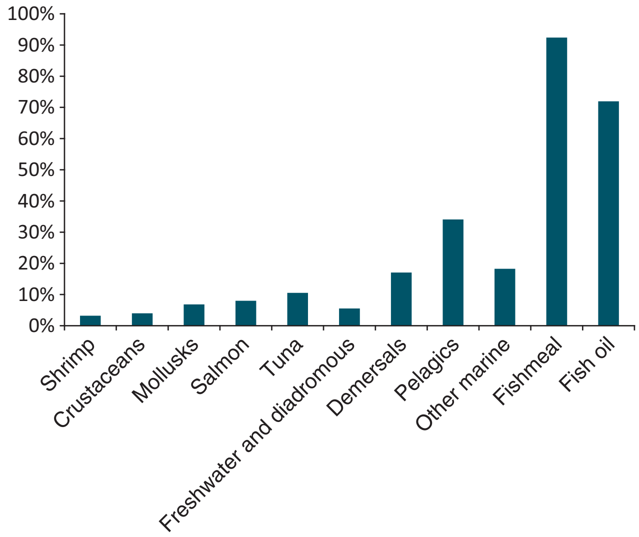
TABLE 3.10b: Projected Top Three Net Fish Importing Regions by Species

	2006 – DATA			2030 – PROJECTION		
	1ST (SHARE)	2ND (SHARE)	3RD (SHARE)	1ST (SHARE)	2ND (SHARE)	3RD (SHARE)
Shrimp	NAM	ECA	JAP	NAM	ECA	JAP
	46%	29%	16%	60%	21%	11%
Crustaceans	JAP	NAM	ECA	JAP	NAM	ECA
	61%	20%	19%	45%	28%	17%
Mollusks	ECA	JAP	NAM	NAM	ECA	SEA
	43%	33%	18%	39%	30%	11%
Salmon	CHN	JAP	NAM	CHN	NAM	JAP
	33%	30%	19%	55%	19%	18%
Tuna	ECA	NAM	JAP	ECA	NAM	JAP
	46%	24%	17%	42%	24%	17%
Freshwater and diadromous	ECA	NAM	JAP	AFR	ECA	NAM
	42%	41%	8%	50%	21%	13%
Demersals	CHN	ECA	EAP	ECA	CHN	JAP
	31%	31%	21%	43%	32%	15%
Pelagics	AFR	SEA	EAP	ROW	CHN	NAM
	45%	28%	14%	34%	24%	23%
Other marine	JAP	ECA	AFR	JAP	ECA	LAC
	46%	19%	13%	45%	17%	11%

Sources: FAO FIPS FBS and IMPACT model projections.
Note: The results shown in tables 3.10a and 3.10b represent net exports and net imports, respectively. Unlike many other agricultural commodities, in fish trade it is common that one country is both an exporter and importer of certain species. For example, the United States and Europe are both large exporters and importers of salmon, but the fact is buried underneath the net trade results that North America is a large net importer and that Europe (and Central Asia) is the second-largest net exporter, after Latin America. Latin America, on the other hand, is a larger exporter but not an importer of salmon; thus, the net trade results are easier to interpret for this region. ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

14 percent in 2006 to 25 percent in 2030. China's share in global salmon net imports is projected to increase from a third in 2006 to more than half by 2030. SEA is expected to increase their net export share in freshwater and diadromous fish from 49 percent in 2006 to 79 percent in 2030. On the other hand, much of freshwater and diadromous fish was destined to ECA in 2006, while exactly half of it will likely be imported by AFR by 2030.

FIGURE 3.6: Projected Change in Real Prices between 2010 and 2030 by Commodities



Source: IMPACT model projections.

Note that the importance of African imports for pelagics and other marine fish declines but the importance of fish in the freshwater and diadromous category increases substantially. The model predicts that the African need for fish imports increases as the population increases, but the price of traditional import fish will likely rise (due to rise in fishmeal price) such that imports will be substituted with freshwater fish, which are predicted to become relatively more abundantly available for direct human consumption.

Figure 3.6 shows the projected changes in the real prices during the 2010–30 period. The model projects that the prices of all fish and fish products will increase during the period. While modest increases are expected for most fish species, higher price increases are expected for fish in the pelagics, other marine, and demersals categories. These are used as ingredients of fishmeal and fish oil, whose prices are expected to rise substantially more than those of fish for direct consumption.

3.4. FISHMEAL AND FISH OIL

Production

Globally, a little less than 20 percent of total fish produced is currently used for fishmeal and fish oil production, and the proportion is expected to remain unchanged into 2030. As seen in table 3.11, global production of fishmeal in 2030 is projected to be around 7.6 million tons. Looking across regions, as expected, LAC is the largest fishmeal-producing region, accounting for about 40 percent of

TABLE 3.11: Projected Total Fishmeal Production by Region

	DATA (000 TONS)	PROJECTION (000 TONS)			SHARE IN GLOBAL TOTAL		% CHANGE
	2008	2010	2020	2030	2010 (PROJECTION)	2030 (PROJECTION)	2010–30
Global total	**5,820**	**7,044**	**7,401**	**7,582**	**100.0%**	**100.0%**	**7.6%**
ECA	703	1,000	1,005	1,008	14.2%	13.3%	0.7%
NAM	262	372	375	376	5.3%	5.0%	1.1%
LAC	2,305	3,033	3,064	3,080	43.1%	40.6%	1.5%
EAP	50	82	97	105	1.2%	1.4%	27.9%
CHN	1,319	815	903	941	11.6%	12.4%	15.4%
JAP	204	421	421	421	6.0%	5.6%	0.0%
SEA	556	615	719	779	8.7%	10.3%	26.7%
SAR	78	57	66	71	0.8%	0.9%	25.3%
IND	..	10	11	12	0.1%	0.2%	17.3%
MNA	88	92	119	133	1.3%	1.8%	44.4%
AFR	99	170	192	203	2.4%	2.7%	19.3%
ROW	157	376	428	452	5.3%	6.0%	20.3%

Sources: Compilation of data from FishStat, Oil World, and the IFFO and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world; .. = negligible.

world's fishmeal supply. In fact, in Latin America, reduction demand accounts for about three-quarters of their fish use. The projected fishmeal production of Latin America in 2030 is slightly more than that of all of Asia combined (including JAP and EAP). SEA—the fourth-largest producing region of fishmeal after LAC, ECA, and CHN—is expected to grow rapidly in the global fishmeal market, with their production volume reaching more than 10 percent of the global total by 2030.

Use of Fish Processing Waste

Throughout the projection period, the model indicates that about 15 percent of the global fishmeal supply originates from fish processing waste. Due to the issues surrounding data inconsistency discussed in chapter 2, the model overestimates the production of fishmeal relative to the available data. Thus, the baseline model does not reproduce the waste use figure indicated by the IFFO, where an estimated 25 percent of global fishmeal is currently produced from fish processing waste (Shepherd 2012). The restrictions on the set of countries that are allowed in the model to use fish processing waste will be relaxed in a scenario presented in the next chapter.

Utilization

Table 3.12 shows the projected distribution of fishmeal use across region. Note that this table pertains to total fishmeal use, including its use for livestock production. The use of fishmeal is concentrated in China, which is estimated to represent more than 40 percent of global fishmeal use throughout the projection period. Since available data suggest that the use of fishmeal in the livestock sector in China is negligible, the projected growth of fishmeal use in China is driven almost entirely by the growth of the aquaculture sector. The second-biggest user of fishmeal is the SEA region, and the ECA region is projected to be the third-largest user. Given the substantial rise in the projected prices of fishmeal and fish oil, these products are expected to be selectively allocated for the production of high-value commodities, both in aquaculture and livestock production. Efficiency of feed use that is embedded in the default specification also reduces the need for feed per unit of fish and livestock output. The last point is demonstrated in the next subsection.

Feed Efficiency Improvement

The projected growth of fishmeal production and utilization sharply differ from the fast growth projected for aquaculture production,

TABLE 3.12: Projected Fishmeal Use by Region

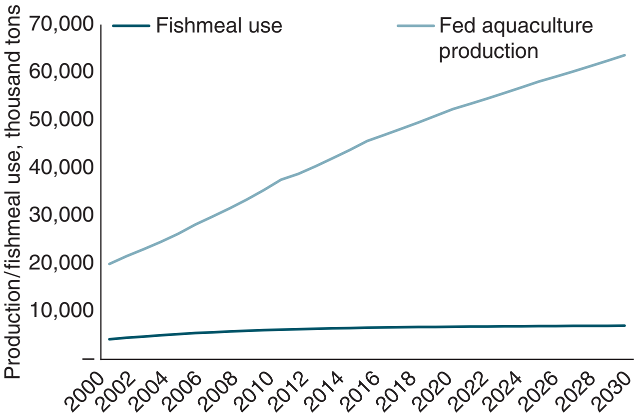
	PROJECTION (000 TONS)			SHARE IN GLOBAL TOTAL		% CHANGE
	2010	2020	2030	2010 (PROJECTION)	2030 (PROJECTION)	2010–30
Global total	**7,045**	**7,402**	**7,583**	**100.0%**	**100.0%**	**7.6%**
ECA	1,009	1,075	1,195	14.3%	15.8%	18.5%
NAM	79	68	72	1.1%	1.0%	–8.6%
LAC	214	163	136	3.0%	1.8%	–36.3%
EAP	39	20	15	0.6%	0.2%	–62.6%
CHN	3,262	3,379	3,390	46.3%	44.7%	3.9%
JAP	434	505	595	6.2%	7.8%	36.9%
SEA	1,148	1,244	1,264	16.3%	16.7%	10.1%
SAR	232	311	298	3.3%	3.9%	28.3%
IND	257	416	466	3.6%	6.1%	81.8%
MNA	155	110	80	2.2%	1.1%	–48.5%
AFR	208	105	67	2.9%	0.9%	–67.6%
ROW	10	6	5	0.1%	0.1%	–49.0%

Source: IMPACT Model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

especially of those species such as shrimp and salmon that have a higher dependence on fishmeal for their production. These results originate from the assumption used in the model that the importance of fishmeal and fish oil in aquaculture will decline as the industry continues to develop alternative feeds from plant-based sources and to improve efficiencies in feeding practices over time. As was mentioned before, this is one of the key drivers of aquaculture growth incorporated in the model.

Figures 3.7 and 3.8 illustrate the assumed efficiency improvement in fishmeal use in global aquaculture. Figure 3.7 contrasts the rate at which aquaculture production of fed species[23] is projected to grow and the growth rate of fishmeal use. The projected growth in fed aquaculture over the 2000–30 period, equivalent to an annual average growth rate of 3.9 percent per year, is much faster than the projected growth in fishmeal use in aquaculture (an average annual growth rate of 1.7 percent). Figure 3.8 plots the average feed conversion ratio (FCR) for global fed aquaculture—that is, how much fish is produced per unit of fishmeal used in fed aquaculture. The assumed improvement in the efficiency of aquaculture fishmeal use results in a constant decline in the average FCR.

FIGURE 3.7: Projected Production and Fishmeal Use in Global Fed Aquaculture



Source: IMPACT model projections.

Aquaculture vs. Livestock

The pressure for aquaculture to improve efficiency of fishmeal use also reflects the increasing competition for fishmeal on the global animal feed markets between aquaculture and livestock producers. Given the substantial and sustained growth of aquaculture that is projected, the overall amount of fishmeal that goes toward

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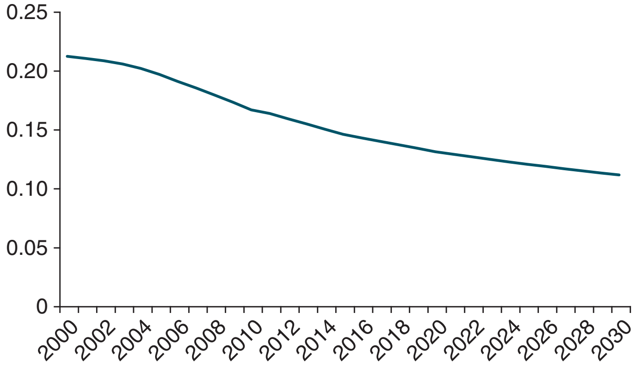
[23] Aquaculture production of shrimp, crustaceans, salmon, tilapia, ***Pangasius***/catfish, carp, OCarp, EelStg, MDemersal, CobSwf, OPelagic, and OMarine are considered in the calculation.

FIGURE 3.8: Projected Average Feed Conversion Ratio for Fishmeal in Global Fed Aquaculture



Source: IMPACT model projections.

aquaculture will likely continue to grow. Higher feed prices will imply that only feed-efficient and high-valued aquaculture products can be profitable with such inputs. As seen in figure 1.5, the use of global fishmeal by aquaculture grew from nil in 1960 to 10 percent in 1980 and to 73 percent in 2010, and accordingly the share of swine and poultry production has fallen sharply (Jackson and Shepherd 2010; Shepherd 2012).

Trade

Table 3.13 shows the projected trade patterns of fishmeal across regions that make possible the fishmeal use patterns seen in table 3.12 and the production patterns in table 3.2. Again, trade is represented in terms of net exports, with negative numbers representing net imports. From the table, we see that the largest exporter is Latin America, whereas the biggest importer is China. The volumes of Chinese imports and Latin American exports are similar. According to Globefish (2011), exports from Peru and Chile accounted for 70 to 80 percent of Chinese fishmeal imports during the 2008–09 period. The projection results suggest that the trade patterns are likely to continue into 2030.

The model predicts that net imports of Southeast Asia will decrease over that period, given that a faster growth is expected for fishmeal production than its use in the region. Since most of the fishmeal use in Southeast Asia is accounted for by aquaculture (already reaching 99 percent by 2015, as seen in table 3.13), the dynamics of efficiency in fishmeal use explain these trends almost entirely in this region. India is projected to increase imports over the projection period and become the third-largest net importer of fishmeal in 2030, after China and Southeast Asia.

TABLE 3.13: Projected Net Exports of Fishmeal by Region (000 tons)

	DATA	PROJECTION	PROJECTION	PROJECTION
	2008	**2010**	**2020**	**2030**
Global total	**2,111**	**3,518**	**3,768**	**3,882**
ECA	–660	–8	–70	–187
NAM	16	293	307	304
LAC	2,122	2,820	2,901	2,945
EAP	–29	43	77	90
CHN	–1,361	–2,446	–2,476	–2,449
JAP	–320	–13	–84	–173
SEA	–144	–533	–525	–485
SAR	2	–175	–244	–227
IND	–1	–246	–404	–454
MNA	37	–63	9	53
AFR	–35	–38	88	136
ROW	154	366	422	447

Sources: FAO FIPS FBS and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

TECHNICAL APPENDIX

A. Comparisons with OECD-FAO Analysis to 2020

In this analysis, we undertake a comparison of the projections by the IMPACT model to those in the fish section of the 2012 OECD-FAO analysis *World Agricultural Outlook 2012–2021*. The OECD-FAO fish analysis is conducted as part of the annual agricultural outlook series carried out by the joint effort of OECD and FAO agricultural market outlook teams using the combined AgLink-CoSiMo multimarket, partial equilibrium model (Dowey 2007).

The Fish and Seafood Model used for the OECD-FAO fish projections is not fully integrated into the larger AgLink-CoSiMo framework. Rather it consists of a stand-alone model covering the same 56 countries (and country-groupings) of AgLink-CoSiMo. There are essentially three commodities in this model: (an aggregate of all) fish, fishmeal, and fish oil. Each commodity has its corresponding world market and a market-clearing price. From the rather short model description given in the chapter on fish in the OECD-FAO outlook (OECD-FAO 2012), it is not fully clear how the Fish and Seafood Model is linked to the larger AgLink-CoSiMo model. Presumably the oilseed meal prices from the larger model are "fed" into the Fish and Seafood Model in an exogenous way so that aquaculture demand for feed can adjust accordingly. Furthermore, the livestock demand for fishmeal may also be imposed on the Fish and Seafood Model in an exogenous way, while the fishmeal prices that the Seafood Model generates endogenously may be used in the larger AgLink-CoSiMo model as well as the feed requirement of aquaculture.

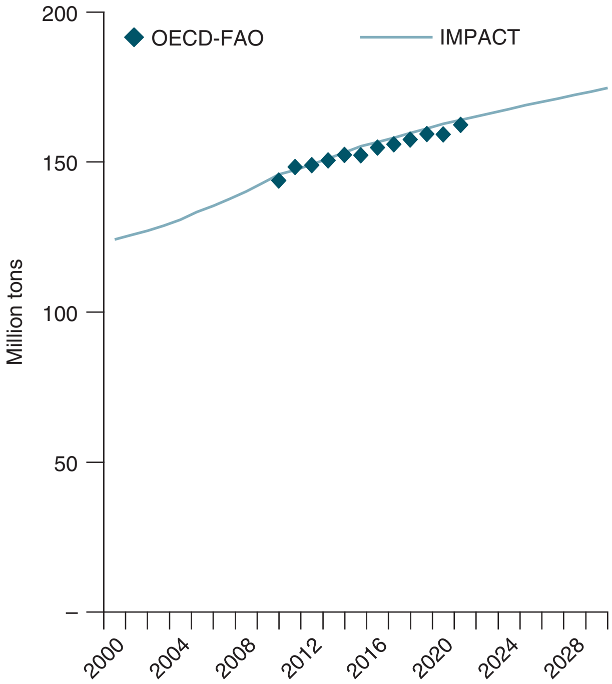
The OECD-FAO model combines fish of all species into one aggregate category, while they do maintain the distinction between capture and aquaculture production. Aquaculture supply in both the IMPACT and OECD-FAO models takes into account the availability of fishmeal and its price, and the two models seem to do so in a similar manner. Given that the OECD-FAO model also uses the UN projections of human population, its total food fish demand projections are likely derived as per capita demand times the population. The OECD-FAO baseline projections use a set of GDP growth drivers that are derived from an internal economic outlook process (based within OECD). These are not identical to, but clearly parallel to, the World Bank GDP projections used in this study. The existing documentation for the OECD-FAO Fish and Seafood Model does not go into specifics on supply-side drivers or their underlying assumptions. On the supply side, because of fishing quotas, only 12 percent of world capture is assumed to react to price in the model, while 99 percent of world aquaculture reacts to price. Farmed species requiring concentrated feeds also react to feed prices composed by fishmeal, fish oil, and cereals in different proportion, depending of the species.

After having "anchored" their starting assumptions based on the data for 2010 and the provisional data for 2011, the OECD-FAO model initiates their projections in year 2012 and continues up to year 2021. The available report (OECD-FAO 2012) does not show country-level details of the projections. Therefore, we have aggregated our results over countries as well as over species. Despite these aggregations, we are able to gain some insight from the model result comparisons to 2021.

Figure 3.9 compares the projections of the two models for the total fish supply at the global level. The figure shows that IMPACT projections from the year 2000 meet up perfectly with OECD-FAO projections at their starting point of 2012 and proceed in tandem to their ending point of 2021.

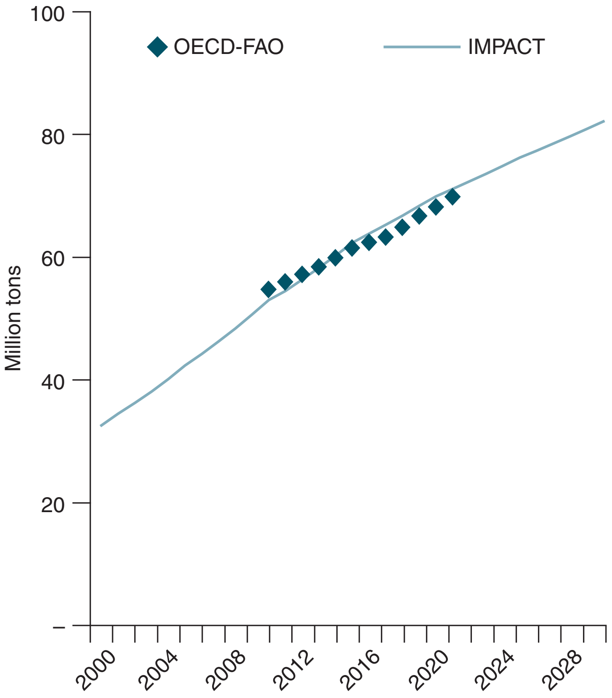
Figure 3.10 compares the two sets of projections for global aquaculture production. Again, there is a close match between the two

FIGURE 3.9: Comparison of IMPACT and OECD-FAO Projections for Global Fish Supply



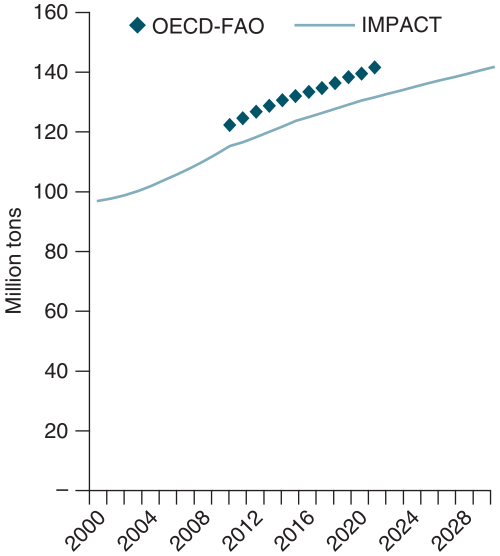
Sources: OECD-FAO 2012 and IMPACT model projections.

FIGURE 3.10: Comparison of IMPACT and OECD-FAO Projections for Global Aquaculture Production



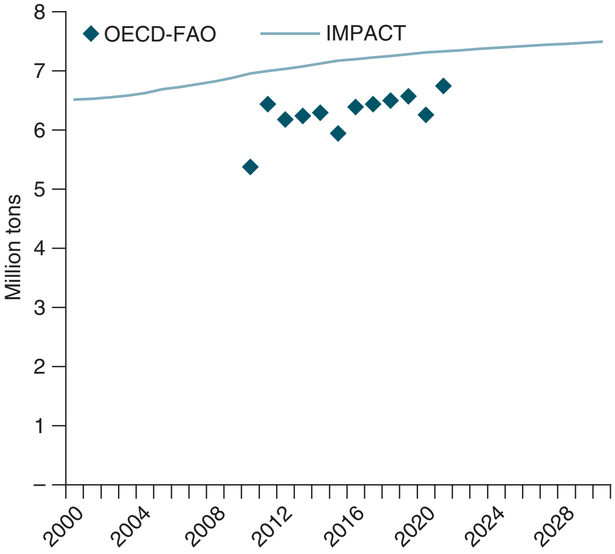
Sources: OECD-FAO 2012 and IMPACT model projections.

FIGURE 3.11: Comparison of IMPACT and OECD-FAO Projections for Global Food Fish Consumption



Sources: OECD-FAO 2012 and IMPACT model projections.

FIGURE 3.12: Comparison of IMPACT and OECD-FAO Projections for Global Fishmeal Supply



Sources: OECD-FAO 2012 and IMPACT model projections.

series in 2012, where the IMPACT projections meet with the OECD-FAO projections, through 2021.

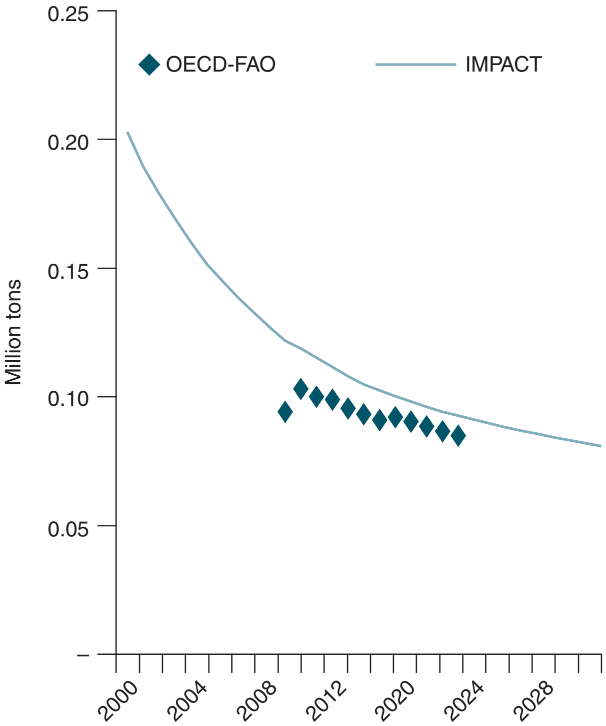
These comparisons suggest that, even though the two models differ substantially in the aggregation levels of fish species and countries, the overall tendency of the two models in predicting how the changes in demand drivers affect the expansion of supply is similar and consistent. The two models appear to be congruent in the how the FAO data are used on capture and aquaculture production.

However, when we compare projections of food fish consumption, we begin to see differences in the model projections. As seen in figure 3.11, the projections of food fish consumption by the IMPACT model are consistently lower than those of the OECD-FAO model. This appears to be related to the consistent underprediction of food fish consumption by IMPACT relative to the data for the calibration period discussed in section 2.5. The underprediction by IMPACT is because the projections are allowed to deviate from the data to reconcile the inconsistency originating from fishmeal-related data. In contrast, the OECD-FAO model results appear to adhere to the FAO data on fish utilization (that is, food fish consumption and meals input). This is also seen in the projection comparison for fishmeal production next.

Figure 3.12 compares the projected fishmeal supply by the two models. The figure shows a fairly consistent gap between the two sets of projections. Again, this is likely due to the consistent over-prediction of fishmeal production by IMPACT relative to the data to reconcile across data on fish reduction demand and fishmeal production and trade. Nonetheless, the projected trends are similar in both series: both models project a modest but steady increase during the 2012–21 period.

Since the projections of aquaculture production by the two models are nearly the same, the gap found in the two projection series of fishmeal supply implies that fishmeal requirement per unit of aquaculture production in the OECD-FAO model must be lower. This is confirmed in the rough estimates of feed conversion ratio implied by the projections. In figure 3.13, the implied FCRs—derived as the ratio of total fishmeal supply to total aquaculture production—from the two models show a similar trajectory over the 2012–21 period. However, the ratio for the IMPACT model is consistently higher than that for the OECD-FAO model. Thus, the two models likely differ in the way to arrive at the amount of feed necessary to support a given amount of aquaculture production. It should be noted that the feed requirement parameters in IMPACT are derived from the literature and specified for each of the 15 categories of fish. It is unlikely that

FIGURE 3.13: Comparison of IMPACT and OECD-FAO Projections for Implied FCR for Fishmeal



Sources: OECD-FAO 2012 and IMPACT model projections.

a similar approach is taken for the single aggregate fish category in the OECD-FAO model.

While we are unable to undertake a more comprehensive comparison between the two studies, this brief analysis illustrates some important points of similarity and difference in how the future of fish supply and demand are projected. It confirms that the two studies make similar use of data and methodology and that basic supply and food demand projections are in line. However, there likely exist differences in the way the fishmeal and fish oil supply and demand are modeled. Some differences could also arise in the way the fish side of IMPACT is linked to the rest of the crop and livestock markets, compared with how this is done in the OECD-FAO framework. They describe a much "looser" link between the two parts of the model in their technical description study (OECD-FAO 2012), but it is not possible to fully judge the extent and implications of these differences without a much more detailed investigation. While a full comparison of the two models is beyond the scope of this study, the brief analysis presented here could be a useful starting point for discussion for comparison and further model improvement for both research teams.

Chapter 4: IMPACT PROJECTIONS TO 2030 UNDER SELECTED SCENARIOS

In this chapter, we explore a set of illustrative scenarios, so that we can (1) better understand the sensitivities of the model results to changes in some key parameters and (2) gain insights into potential impacts on the global fish markets of changes in the drivers of future fish supply, demand, and trade. In the spirit of the scenarios carried out in the *Fish to 2020* study, we explore some similar cases where aquaculture is able to grow faster than under the baseline scenario (scenario 1) and cases with different assumptions on the future productivity growth of capture fisheries. In particular, we explore both positive and negative scenarios of future capture fisheries, with the former potentially being achieved through effective tenure reforms (scenario 5) and the latter associated with global climate change (scenario 6). We also implement some scenarios that were not considered in the *Fish to 2020* study. In particular, we investigate how allowing expanded use of fish processing waste in fishmeal and fish oil production might affect the market of these fish-based products (scenario 2) and the implications of a large-scale disease outbreak in aquaculture for the markets of affected species and other commodities (scenario 3). In addition to these scenarios that are based on supply-side shocks, we consider an alternative demand-side scenario, where consumers in China expand their demand for high-value fish products more aggressively than in the baseline case (scenario 4).

Each scenario is constructed by changing some specific set of parameters. By examining the results from these illustrative cases, we are able to gain a deeper appreciation for how some key drivers of supply and demand growth can change the market outcomes in the medium-term outlook to 2030 and help identify where policy or technology interventions can be most useful.

4.1. SCENARIO 1: FASTER AQUACULTURE GROWTH

As the first exercise, we implement a scenario in which aquaculture production will grow at a faster pace for all species in all countries and regions. We have constructed this scenario in the same spirit as the aquaculture scenarios in the *Fish to 2020* study (see Delgado and others 2003, table 4.1), in which the exogenous growth rates of aquaculture production were increased and decreased by 50 percent of the baseline values. Here, we increase the aquaculture growth rates by 50 percent from 2011 through 2030. A scenario of reduced growth rates is discussed later in this chapter in the context of aquaculture disease outbreak.

Table 4.1 compares the results of the scenario with the baseline results on aquaculture production. At the global level, the total production at the end of the projection period would increase from 93.6 million tons under the baseline scenario to more than 101 million tons under the current scenario, representing an 8.1 percent increase. At the regional level, the projected aquaculture production levels in 2030 are higher in this scenario compared to the baseline scenario in most regions. Some regions, in particular LAC and MNA, would benefit proportionately more from this scenario. In contrast, North America and Japan would lose from this scenario. That is, even though we have increased the exogenous growth rates by 50 percent in all regions, it does not necessarily translate into the same growth rate increase across regions in the final results.

This is, in part, due to the interactions with the demand side, especially with the market for fishmeal, an important aquaculture production input. Faster growth of aquaculture production would entail more fishmeal use by some (mostly carnivorous) fish species groups, which is expected to drive fishmeal price upward. The latter,

TABLE 4.1: Projected Effects of Faster Aquaculture Growth on Aquaculture Supply by Region

	BASELINE (000 TONS)		FASTER GROWTH (SCENARIO 1) (000 TONS)	SCENARIO 1 RELATIVE TO BASELINE
	2008 (DATA)	2030 (PROJECTION)	2030 (PROJECTION)	2030 (PROJECTION)
Global total	**52,843**	**93,612**	**101,220**	**8.1%**
ECA	2,492	3,761	3,796	0.9%
NAM	655	883	840	–4.9%
LAC	1,805	3,608	4,455	23.5%
EAP	751	1,066	1,114	4.5%
CHN	33,289	53,264	56,153	5.4%
JAP	763	985	948	–3.8%
SEA	6,433	14,848	16,882	13.7%
SAR	1,860	4,163	4,850	16.5%
IND	3,585	8,588	9,179	6.9%
MNA	921	1,911	2,400	25.6%
AFR	231	464	525	13.1%
ROW	57	72	76	6.6%

Sources: FishStat and IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

in turn, would slow down aquaculture expansion for some species. On the other hand, as aquaculture growth accelerates, there would be larger dampening effects on fish prices, which also in turn would work to slow down the fish supply. The manner in which the price would rise or drop differs for each commodity. Further, each region has a different commodity mix, some with more fishmeal-intensive aquaculture and others with fish species whose market demands are more sensitive to price changes. Therefore, the final results, obtained as the equilibrium outcome in the global fish markets, represent intricate balancing of supply and demand, responding to signals transmitted by world prices.

In the *Fish to 2020* study, this scenario was aimed to explore what the cross-price response would be in capture production if aquaculture were to grow at an accelerated pace. However, the scenario does not affect the capture production in this study because capture supply is not price responsive—it is determined solely by specified exogenous rates of growth in the current model. Therefore, we do not measure the same effects as in *Fish to 2020*. In this study, what we really measure is the effects of faster aquaculture growth on commodity prices and the fishmeal market and their feedback to the aquaculture fish supply.

Table 4.2 shows the final outcome after such feedback for production and world prices of each species. While the model predicts that global aquaculture production in 2030 under this scenario would increase by 8.1 percent relative to the baseline specification, the increase in total fishmeal use would be limited to 2 percent, up from 7,582 thousand tons under the baseline scenario to 7,744 thousand tons. In contrast, its projected price in 2030 is higher by 13 percent than under the baseline. Since the supply of fishmeal ingredients from capture fisheries is more or less fixed, the supply response of fishmeal to price increases is limited. The supply of fishmeal thus would be reallocated, through the market price mechanism, away from livestock and lower-value fish toward higher-value aquaculture species. In the process, supply of some high-value fish products, such as mollusks and salmon, is increased so much that their prices are projected to fall noticeably relative to the baseline case. In fact, except for fishmeal and pelagics, prices in all categories would fall relative to the baseline scenario. Fish in the OPelagic category are

TABLE 4.2: Projected Effects of Faster Aquaculture Growth on Aquaculture Supply and Commodity Prices

PRODUCTION CATEGORY	AQUACULTURE PRODUCTION IN 2030 (000 TONS)		SCENARIO 1 RELATIVE TO BASELINE		CONSUMPTION CATEGORY
	BASELINE	FASTER GROWTH (SCENARIO 1)	PRODUCTION	PRICE	
Shrimp	8,061	8,868	10%	–0.5%	Shrimp
Crustaceans	2,174	2,369	9%	–0.9%	Crustaceans
Mollusks	22,689	25,359	12%	–1.7%	Mollusks
Salmon	3,613	4,015	11%	–1.9%	Salmon
Tuna	13	14	6%	–0.2%	Tuna
Tilapia	6,446	8,343	29%	–0.7%	Freshwater and diadromous
Pangasius/catfish	5,040	5,079	1%		
Carp	19,301	19,999	4%		
OCarp	15,190	15,369	1%		
EelStg	480	489	2%		
OFresh	6,473	6,523	1%		
MDemersal	2,105	2,229	6%	–0.2%	Demersals
Mullet	524	604	15%		
CobSwf	41	43	4%	1.3%	Pelagics
OPelagic	199	198	–0.2%		
OMarine	1,261	1,720	36%	–0.7%	Other marine
Fishmeal	7,582	7,744	2%	13.0%	Fishmeal

Source: IMPACT model projections.
Note: Pangasius/catfish = *Pangasius* and other catfish; OCarp = silver, bighead, and grass carp; EelStg = aggregate of eels and sturgeon; OFresh = freshwater and diadromous species (excluding tilapia, *Pangasius*/catfish, carp, OCarp, and EelStg); MDemersal = major demersal fish; CobSwf = aggregate of cobia and swordfish; OPelagic = other pelagic species; OMarine = other marine fish.

the main ingredient of fishmeal, and greater competition for this category between direct human consumption and use in fishmeal production would contribute to the price increase.

Together, these effects explain why the increase in projected aquaculture growth under this scenario is not as uniformly large across regions and across species as one would have expected purely from the scenario design. This exercise also illustrates why the links with fishmeal and fish oil markets are so important in understanding the place of aquaculture products in the world food economy.

4.2. SCENARIO 2: EXPANDED USE OF FISH PROCESSING WASTE IN FISHMEAL AND FISH OIL PRODUCTION

The *Fish to 2020* study examined a scenario of improved efficiency in fishmeal and fish oil use in aquaculture. However, the model generated limited insight since it did not completely endogenize the important links between food fish markets and fishmeal and fish oil markets. In the current model, the use of fish for human consumption and for conversion into feed is determined endogenously through supply-demand balance regulated through world prices. Further, the model now allows the use of fish processing waste in the production of fishmeal and fish oil, as explained in chapter 2. The IFFO estimates that currently about 25 percent of the world's fishmeal is generated from fish processing waste (Shepherd 2012). The proportion is expected to rise, given the growth of aquaculture of large fish species and associated development of fish processing industry, together with the trend of rising fishmeal and fish oil prices.

In the current scenario, we remove the restriction in the number of countries that are able to use fish processing waste from the

20 countries/groups of countries in the baseline scenario,[24] which was determined following the data and in the data reconciliation process (see technical appendix C to chapter 2). The scenario now allows any country that produces fishmeal to use fish processing waste starting in 2011. The assumptions on fish species whose waste can be used for fishmeal and fish oil production as well as the volume of waste per unit of live fish are shown in table 2.9. It is assumed that the amount of fish processing waste each country can use is restricted to the amount of waste produced, whether capture or aquaculture, in the country in a given year. This represents a limitation of the model because, in reality, fish are traded for processing purposes and final processed products are also widely traded. In particular, China and Thailand increasingly import raw material for reexport of processed products (FAO 2012). However, since the current model does not have separate supply functions for processed seafood, it does not keep track of the countries in which fish processing takes place. For this reason, the model is subject to overprediction of waste use in some countries and underprediction in others. Nonetheless, the extent of this cannot be confirmed, as no data exist on this issue to our knowledge. The levels of fish waste use are endogenously determined based on world prices of fishmeal, while we do not assign any market-clearing mechanism or price to the supply or use of fish processing waste. The specific procedure is described in chapter 2.

Allowing in the model all countries to freely use fish processing waste would effectively increase the supply of feedstock that is available for reduction into fishmeal and fish oil, much of which is likely to be used given the high fishmeal price simulated in the baseline scenario. Table 4.3 contrasts the results under the baseline and the current scenarios in terms of usage of fish processing waste. Globally, the projected use of processing waste in 2030 increases from 5.7 million tons under the baseline case to more than 10 million tons under the scenario. Looking across regions, while relatively few regions use processing waste in the baseline case, waste use is represented in all regions under the scenario. In fact, most of the gain in the use of fish processing waste under the scenario would come from those countries that are newly allowed to use waste, notably China.

TABLE 4.3: Projected Amount of Fish Processing Waste Used in Fishmeal Production by Region (000 tons)

	BASELINE		PROCESSING WASTE (SCENARIO 2)
	2010 (PROJECTION)	2030 (PROJECTION)	2030 (PROJECTION)
Global total	**5,304**	**5,656**	**10,206**
ECA	2,193	2,194	2,381
NAM	1,141	1,165	1,057
LAC	849	1,012	738
EAP	2	3	173
CHN	n.a.	n.a.	2,856
JAP	521	521	521
SEA	597	760	1,315
SAR	n.a.	n.a.	318
IND	n.a.	n.a.	419
MNA	n.a.	n.a.	91
AFR	1	1	98
ROW	n.a.	n.a.	240

Source: IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world; n.a. = not applicable.

As a result of the additional volume of fish processing waste made available for fishmeal production, the model projects a substantial increase in fishmeal supply in 2030: from 7,582 thousand tons in baseline to 8,473 thousand tons in this scenario, or a 12 percent increase. The expanded use of processing waste would slightly reduce the pressure on capture fisheries of supplying fishmeal ingredients. The whole fish used for fishmeal production would reduce from 28,367 thousand tons under the baseline scenario to 27,646 thousand tons under the scenario. The proportion of fishmeal produced based on processing waste also increases from 15 percent to 26 percent (figure 4.1).

The increase in fishmeal supply would result in a reduction in its price. For the 11.8 percent increase in supply, the corresponding price reduction is projected to be 14.1 percent (table 4.4). The reduced fishmeal price in turn would encourage aquaculture production. At the global level, aquaculture production in 2030 would

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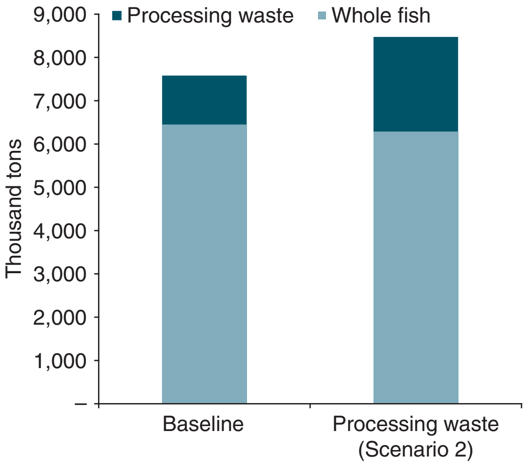
[24] The 20 countries/groups of countries are Argentina, Australia, Belgium-Luxembourg, Brazil, British Isles (including Ireland), Canada, Chile, Côte d'Ivoire, France, Germany, Italy, Japan, Mexico, Russian Federation, Scandinavia, Spain/Portugal, Thailand, United States, Uruguay, and Vietnam.

FIGURE 4.1: Projected Increase in Fishmeal Production due to Usage of Whole Fish and Fish Processing Waste in 2030



Source: IMPACT model projections.

increase 1.9 percent relative to the baseline case, from 93.6 million tons to 95.4 million tons. Looking across species, a reduced price of fishmeal would benefit the tuna, salmon, and crustacean aquaculture industry as well as species in the freshwater and diadromous category. All of these changes would lead to reduced fish prices.

It is worth noting that expansion and improvements of processing facilities for fishmeal and fish oil production could have unintended effects on wild fisheries. While the intended benefit is increased use of catch and processing waste that are currently unused, expanded processing capacity and markets could also result in greater reduction demand for fish, including those that otherwise would be used for direct human consumption and potentially encouraging harvest of all kinds of fish, including some protected and endangered species.

TABLE 4.4: Projected Effects of Expanded Use of Fish Processing Waste in Fishmeal Production on Aquaculture Supply and Commodity Prices

PRODUCTION CATEGORY	AQUACULTURE PRODUCTION IN 2030 (000 TONS)		SCENARIO 2 RELATIVE TO BASELINE		CONSUMPTION CATEGORY
	BASELINE	WASTE USE (SCENARIO 2)	PRODUCTION	PRICE	
Global total	**93,612**	**95,389**	**1.9%**	**n.a.**	**Global Total**
Shrimp	8,061	8,111	0.6%	–0.1%	Shrimp
Crustaceans	2,174	2,227	2.4%	–0.3%	Crustaceans
Mollusks	22,689	22,657	–0.1%	–0.1%	Mollusks
Salmon	3,613	3,731	3.2%	–0.7%	Salmon
Tuna	13	14	4.2%	–0.2%	Tuna
Tilapia	6,446	6,587	2.2%	–0.4%	Freshwater and diadromous
Pangasius/catfish	5,040	5,149	2.2%		
Carp	19,301	19,807	2.6%		
OCarp	15,190	15,800	4.0%		
EelStg	480	496	3.4%		
OFresh	6,473	6,676	3.1%		
MDemersal	2,105	2,102	–0.1%	–0.4%	Demersals
Mullet	524	522	–0.3%		
CobSwf	41	41	0.4%	–1.8%	Pelagics
OPelagic	199	201	1.1%		
OMarine	1,261	1,268	0.6%	–0.5%	Other marine
Fishmeal	7,582	8,473	11.8%	–14.1%	Fishmeal

Source: IMPACT model projections.
Note: n.a. = not applicable; *Pangasius*/catfish = *Pangasius* and other catfish; OCarp = silver, bighead, and grass carp; EelStg = aggregate of eels and sturgeon; OFresh = freshwater and diadromous species (excluding tilapia, *Pangasius*/catfish, carp, OCarp, and EelStg); MDemersal = major demersal fish; CobSwf = aggregate of cobia and swordfish; OPelagic = other pelagic species; OMarine = other marine fish.

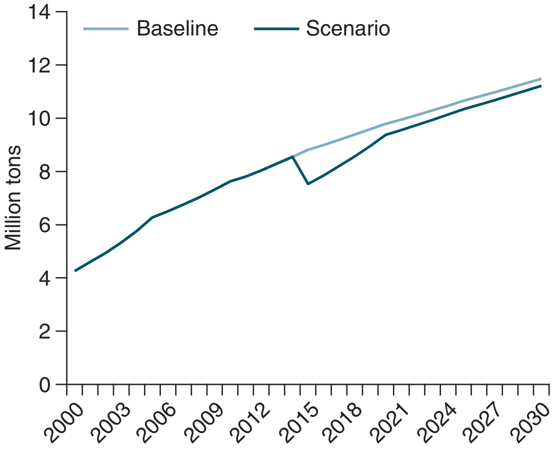
4.3. SCENARIO 3: A MAJOR DISEASE OUTBREAK IN SHRIMP AQUACULTURE IN ASIA

As aquaculture continues to rapidly expand, the risk of catastrophic disease outbreaks has become a major concern (Arthur and others 2002). In open and semiopen aquaculture production systems, especially, an incidence of contagious disease is difficult to contain within a production unit and is likely to spread throughout the system through waters and even beyond the system through other vectors and marketing activities. Furthermore, impacts of major, catastrophic disease outbreaks are felt globally, given much of seafood are internationally traded. According to FAO (2012), 38 percent of fish produced was exported in 2010.

In this scenario, we illustrate the impacts on the global market of a large-scale disease outbreak in a high-value aquaculture sector, in particular, shrimp aquaculture in Asia. We simulate a sudden decline in the aquaculture production of shrimp in the affected countries by 35 percent in 2015, relative to the baseline projection value in 2015. We then allow the affected shrimp aquaculture to recover to the 2015 level under the baseline by the year 2020. After that, the production is allowed to continue along the same growth trajectory as was the case under the baseline. Essentially, we set back the growth of Asian shrimp aquaculture by five years in this scenario and investigate how the shrimp production in other regions would respond and how the prices and regional trade might be affected. We have chosen this region for the disease scenario because of the high concentration of shrimp production in Asia, especially in China and Southeast Asia. The affected Asian countries are Bangladesh, China, India, Indonesia, Malaysia, Myanmar, the Philippines, Singapore, Sri Lanka, Thailand, and Vietnam.

In contrast to scenario 1, in which we increase the growth rates of aquaculture production, we examine in this scenario the implications of a reduction in the growth rates due to a disease shock to production. A scenario with reduced aquaculture growth rates was also implemented in the earlier *Fish to 2020* study. However, their model contained a highly aggregated set of commodities for both aquaculture and capture production, and it could not be used for specific scenarios in which a particular species was affected or the industry was affected by a shock of particular nature. Since the new model contains more disaggregated commodities, we can be much more flexible and targeted in designing scenarios.

FIGURE 4.2: Global Shrimp Supply under Baseline and Disease Scenarios



Source: IMPACT model projections.

Since capture production of all species, including shrimp, is maintained at the baseline levels through the specified exogenous rates of growth, the only possible direct response to the shock is in demand for shrimp[25] and other commodities through changes in relative prices as well as aquaculture supply. Since shrimp aquaculture is a heavy consumer of fishmeal, we also investigate the potential impacts of this sudden decline and temporary slowdown in Asian shrimp aquaculture on feed demand and price and its feedback to other markets.

The shock simulated in this scenario and its impacts on the global shrimp supply (from both capture and aquaculture origins) are illustrated in figure 4.2. The impact of 35 percent reduction in Asian shrimp aquaculture is somewhat attenuated in the global market of all shrimp: the global shrimp supply would be reduced by 15 percent in the first year of the shock (disease outbreak). A fast recovery is assumed during the subsequent five years so that, in the absence of market interactions, the supply would recover to the baseline level in 2020. However, the projected recovery falls short of this level, presumably due to the price-dampening effects of the fast recovery phase. After that the global production would continue to grow, but it would never reach the baseline trajectory by 2030.

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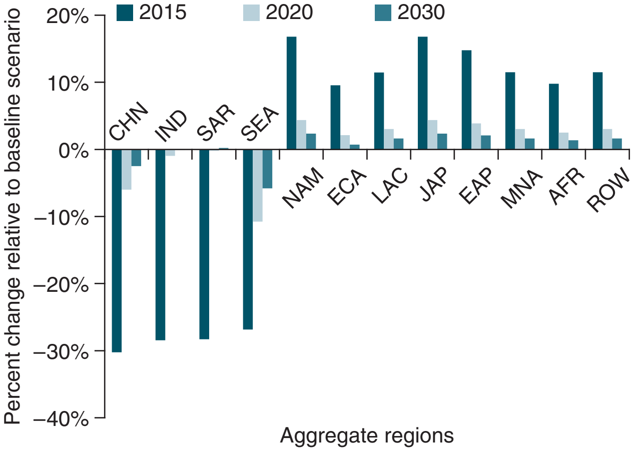
[25] While consumer perception and demand for affected commodities may be influenced by such large-scale disease outbreaks (Hansen and Onozaka 2011), such effects are not considered in this study.

TABLE 4.5: Projected Impact of Disease Outbreak on Shrimp Aquaculture Production (000 tons)

	2015		2020		2030	
	BASELINE	**DISEASE (SCENARIO 3)**	**BASELINE**	**DISEASE (SCENARIO 3)**	**BASELINE**	**DISEASE (SCENARIO 3)**
AFFECTED REGIONS						
CHN	2,287.2	−691.3	2,571.5	−154.3	2,970.3	−73.8
IND	209.0	−59.5	228.7	−2.2	263.7	−0.3
SAR	160.7	−45.5	177.2	−0.4	207.2	0.5
SEA	2,085.7	−560.2	2,611.4	−280.8	3,593.1	−208.8
Subtotal	**4,742.7**	**−1,356.4**	**5,588.8**	**−437.7**	**7,034.2**	**−282.3**
UNAFFECTED REGIONS						
NAM	1.9	0.3	2.1	0.1	2.6	0.1
ECA	0.3	0.0	0.5	0.0	0.9	0.0
LAC	604.9	69.4	719.5	21.9	955.9	15.7
JAP	1.6	0.3	1.8	0.1	2.2	0.1
EAP	6.2	0.9	6.8	0.3	8.2	0.2
MNA	31.5	3.6	35.3	1.1	40.5	0.7
AFR	9.7	0.9	10.6	0.3	11.9	0.2
ROW	3.8	0.4	4.2	0.1	4.8	0.1
Subtotal	**660.0**	**76.0**	**780.8**	**23.8**	**1,027.0**	**16.9**
Global total	**5,402.6**	**−1,280.5**	**6,369.6**	**−413.9**	**8,061.3**	**−265.5**

Source: IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.
* Subtotals and global totals may not match due to rounding error.

FIGURE 4.3: Impact of Disease Outbreak on Shrimp Aquaculture Production



Source: IMPACT model projections.

Table 4.5 and figure 4.3 illustrate how the impacts of the disease outbreak on shrimp aquaculture are distributed across regions and over time.[26] In the regions affected by the hypothetical disease outbreak, the loss to shrimp aquaculture production is more than 1.36 million tons in 2015, with nearly half of the loss coming from the drop in Chinese production alone. The loss in Southeast Asian production in 2015 is more than half a million tons. All other regions unaffected by the hypothetical shrimp disease outbreak are expected to respond to the decline in Asian shrimp aquaculture by expanding their production initially in 2015. As seen in figure 4.3, each unaffected region would increase its shrimp aquaculture production by about 10 percent or more in 2015. However, with the vast majority of shrimp aquaculture occurring in Asia (projected to be 88 percent under the baseline scenario in 2015), the ability of the unaffected regions to offset the Asian losses is

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[26] Note that, in figure 4.3, production reduction in affected regions is less than 35 percent. This is due to the fact that the 35 percent decline is imposed though the exogenous growth rates of aquaculture, rather than production itself. Following the sharp reduction in shrimp supply driven by the reduced exogenous growth rate values, the market would respond by raising the world shrimp price, which would lead to increased shrimp supply in all parts of the world, including Asia.

limited. Collectively the unaffected regions are expected to increase shrimp aquaculture production only by 76 thousand tons in 2015, to which Latin America alone contributes 69 thousand tons. As a result, in the year Asia is hypothetically hit by a major shrimp disease outbreak, the global reduction in shrimp supply would still amount to 1.28 million tons.

The rate of recovery, specified as the exogenously given growth rate of shrimp aquaculture, is specified uniformly across affected countries so that the production is expected to recover, more or less, to the projected levels under the baseline scenario by 2020. However, the impact of the simulated setback in the expansion of aquaculture would vary by region. The opportunity cost of lost growth during the disease period (2015–20) is relatively high for countries with high expected growth rates of aquaculture during the period, such as Thailand and China. From figure 4.3, by 2020 shrimp aquaculture production in Southeast Asia would be about 10 percent below what would be without the outbreak, as represented by the baseline scenario. China's production would be 6 percent below the baseline projection by 2020. The two major players in global shrimp aquaculture would continue to feel the shock of the 2015 disease outbreak into 2030, although the magnitude of the impacts would be gradually reduced. The aquaculture production of shrimp in China and Southeast Asia in 2030 would still be lower than under the baseline projection: by 2.5 percent and 5.8 percent, respectively. On the other hand, in other affected regions (IND and SAR), production would recover closer to the baseline projections by 2020.

As the affected Asian countries recover from the shock of the hypothetical disease outbreak, the contributions of unaffected regions in filling the supply gap would be reduced. However, in all unaffected regions, positive impacts would still be felt into 2030. Shrimp aquaculture production in these regions would be higher than under the baseline scenario by 0.7 percent to 2.4 percent in 2030 (figure 4.3).

Table 4.6 shows the resulting shifts in the shrimp trade patterns. Note the figures in the table include shrimp of both capture and aquaculture origins. The Asian regions affected by the hypothetical disease outbreak are all net exporters of shrimp at the onset of the disease outbreak. In 2015, all affected regions, except for India, would reduce their shrimp exports. India, with its substantial supply from capture shrimp fishery, is projected to increase exports,

TABLE 4.6: Comparison of Projected Net Exports of Shrimp by Region with and without Disease Outbreak (000 tons)

	2015		2020		2030	
	BASELINE	DISEASE (SCENARIO 3)	BASELINE	DISEASE (SCENARIO 3)	BASELINE	DISEASE (SCENARIO 3)
AFFECTED REGIONS						
CHN	574	391	457	471	244	279
IND	97	115	115	136	151	164
SAR	122	91	137	141	162	165
SEA	1,156	830	1,401	1,201	1,848	1,697
UNAFFECTED REGIONS						
NAM	−1,328	−1,172	−1,560	−1,510	−2,043	−2,009
ECA	−671	−553	−688	−652	−702	−682
LAC	533	648	636	672	853	877
JAP	−398	−343	−386	−370	−365	−357
EAP	−182	−147	−203	−192	−225	−219
MNA	−7	10	−6	−1	−4	−1
AFR	−28	−8	−36	−29	−51	−47
ROW	133	137	132	134	130	131

Source: IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

capitalizing on the higher shrimp price while reducing domestic consumption.

Most of the unaffected regions are net importers of shrimp, except for LAC and ROW. All of the net importers would be forced to reduce their imports in 2015 given the shortage in the global shrimp supply. The reduction in imports varies across the regions, from 12 to 19 percent in NAM, JAP, ECA, and EAP to 73 percent in AFR. Higher-income regions, with their stronger income elasticities, would likely manage to secure shrimp consumption better than lower-income countries. The winners in this scenario would be LAC and MNA. Traditionally a net exporter of shrimp, LAC would manage to increase their export thanks to the gain in aquaculture production in 2015. MNA would turn from a net importer to a net exporter during the shock in the global shrimp market, even though they would again become a net importer by 2020.

The contrast between baseline and scenario trade values would become much less sharp in 2020 and then in 2030, as the production trajectory in affected countries would more or less have already recovered by then, as seen in figure 4.3. However, prolonged impacts would remain especially for Southeast Asia, where the reduced exports relative to the baseline case would be 200 thousand tons in 2020 and 150 thousand tons in 2030, or a 14 percent and 8 percent reduction, respectively.

This scenario helps illustrate the global implications of a localized shock to fish supply. We have deliberately chosen a supply shock of a moderate size, but in a region that controls the vast majority of the global supply of the affected species. As expected, the model predicts adjustments in the aquaculture supply in unaffected regions. However, if a supply shock hits a major production region, such "swing" capacity to fill in the gap would be limited and the world market would be hit hard.

In an event of a sudden downturn in seafood supply, consumers around the globe would have to adjust to the resulting higher shrimp price by cutting back on consumption. We have seen in this simulation exercise that Sub-Saharan Africa would have to cut back 70 percent of their shrimp net imports in the initial year of the shock. While shrimp is a high-value commodity that is unlikely to form a staple of food-insecure, vulnerable populations, food security consequences of a large-scale seafood supply shock would be relevant for some other aquaculture commodities.

Finally, this particular example of a supply shock—a major outbreak of shrimp disease in Asian aquaculture—also underscores the importance of disease management in any major aquaculture sector. As production intensifies and as fish population increases within a production system, both risks of disease outbreak and the consequences of outbreak intensify in aquaculture (Arthur and others 2002). Given the projection of continued expansion of aquaculture, disease shocks of the magnitude simulated in this scenario can and are likely to occur. With seafood being one of the most internationally traded food commodities, efforts to prevent major catastrophic disease outbreaks in aquaculture and, in such an event, to minimize negative impacts on the seafood market represent a global public good.

4.4. SCENARIO 4: ACCELERATED SHIFT OF CONSUMER PREFERENCES IN CHINA

In this scenario, we explore the implications of demand-side changes on global fish markets. In particular, we investigate potential impacts of shifts in consumer preferences for food fish in China, the single most important country in the global seafood market. The earlier *Fish to 2020* study also included a China-focused scenario, but it was motivated by the uncertainty over the veracity of the available data for China. They implemented the scenario to examine the implications of having slower-than-reported production and consumption growth in the country. On the contrary, the focus in this analysis is on the implications of socioeconomic change—in particular, accelerated preference shifts toward high-value fish—in the mega fish consumption market.

Consumer preference shifts toward high-value fish are already being observed in China, driven mainly by demographic change, urbanization, higher rates of education, and greater overall levels of income in Chinese society (Fish Site 2012, Godfrey 2011, Redfern Associates 2010, World Bank 2013c). These trends are incorporated in the default specification in terms of elasticities, particularly income elasticities, for different food fish commodities. This scenario simulates faster food fish demand growth for high-value fish commodities in China by changing these parameters. More specifically, we allow the per capita consumption of the higher-value products—namely shrimp, crustaceans, salmon, and tuna—to increase three times higher compared to the baseline case in 2030. For medium-value commodities, namely mollusks, we allow the per capita demand to double the baseline 2030 level. Demand growth for all other commodities is left unchanged at their baseline levels.

In order to reflect these increases in food fish demand, the income elasticities of demand for these commodities in China are set at a level that realizes the target increases in per capita food fish demand in 2030. Effectively, a higher income elasticity implies that people desire to consume proportionately more of a good for a given increase in their incomes. In this exercise we maintain the levels of exogenous drivers of demand—that is, population and income growth—at the baseline levels, so that we capture the pure effects of preference change. In other words, in this scenario, we simulate what would happen if consumer tastes reacted more strongly to income growth, rather than trying to simulate faster rates of socioeconomic growth itself. Adjustments are also made to price elasticities of demand in order to maintain internal consistency in the scaling of the food demand system and to achieve the target increases in per capita food fish demand in 2030 even in the face of higher commodity prices. To avoid complications associated with modifying the demand system midway through the projections, the changes to these elasticities are implemented from the start of the model simulations in 2000. Thus, the entire trajectory of consumption growth to 2030 is affected under this scenario.

Table 4.7 compares the model output for China's total food fish consumption under the baseline and current scenarios. By design, consumption of the targeted species (shrimp, crustaceans, salmon, tuna, and mollusks) is substantially larger under the scenario in 2030. We also note that there are changes (albeit much smaller) in the consumption patterns of other nontargeted commodities, owing to the fact that there is cross-price demand response between fish categories. In particular, while consumption of freshwater and diadromous category would increase by 3 percent, consumption of other categories (pelagics, demersals, and other marine) would decline. Overall, fish consumption in China would increase by 58 percent, or by 33 million tons, under this scenario.

TABLE 4.7: Projected Changes in the Food Fish Consumption in China due to Accelerated Preference Shift

	2030 (000 TONS)		SCENARIO 4 RELATIVE TO BASELINE
	BASELINE	CHINA (SCENARIO 4)	
TARGETED SPECIES			
Shrimp	4,183	13,021	211%
Crustaceans	1,504	4,583	205%
Salmon	971	2,876	196%
Tuna	165	493	199%
Mollusks	17,695	36,201	105%
NONTARGETED SPECIES			
Freshwater and diadromous	25,833	26,616	3%
Demersals	5,456	5,231	–4%
Pelagics	145	126	–13%
Other marine	1,409	1,346	–4%
Total fish consumption	57,361	90,494	58%

Source: IMPACT model projections.

The relevant question in this scenario is: how would this massive increase in Chinese consumption be made possible? Would the accelerated growth in demand stimulate world aquaculture production? Would trade patterns shift in such a way that it would impact food insecure regions, such as Sub-Saharan Africa?

To shed light on these questions, we first examine the projected aquaculture production in 2030 (table 4.8). Under this scenario, global aquaculture supply would increase by 22.6 million tons, 10.5 million tons less than the incremental demand by Chinese consumers. Aquaculture production would increase in all regions relative to the baseline scenario. However, the magnitude of increase would differ across regions. With relatively low aquaculture production under the baseline, JAP and NAM are expected to increase their aquaculture production by the largest percentage (88 percent for JAP, due to expansion of mollusk production, and 77 percent in NAM, due to expansion in production of shrimp, crustaceans, and mollusks). EAP has the next highest growth (64 percent), followed by ECA (43 percent), LAC (43 percent), and SEA (32 percent). China itself would increase production by 21 percent. Having no significant production base for high-value commodities, the other regions (SAR, MNA, and AFR) are expected to grow only up to 10 percent relative to the baseline case. Note that the model may exaggerate

TABLE 4.8: Projected Aquaculture Production in 2030 under Accelerated Consumer Preference Shift in China

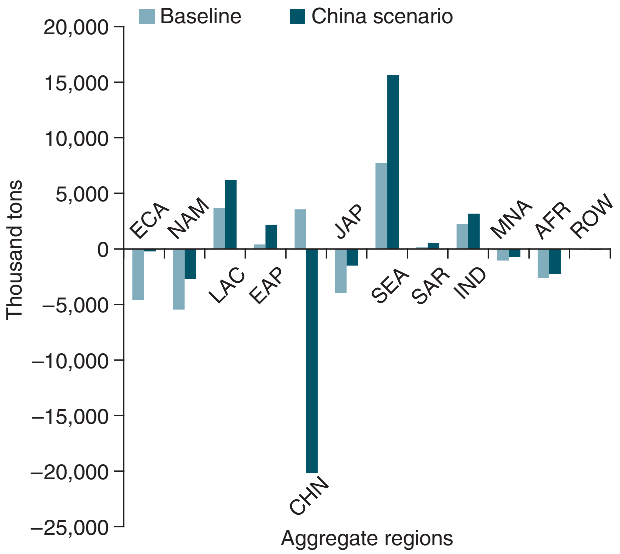
	2030 (000 TONS)		SCENARIO 4 RELATIVE TO BASELINE
	BASELINE	CHINA (SCENARIO 4)	
Global total	**93,612**	**116,205**	**24%**
ECA	3,761	5,253	40%
NAM	883	1,561	77%
LAC	3,608	5,168	43%
EAP	1,066	1,747	64%
CHN	53,264	64,502	21%
JAP	985	1,851	88%
SEA	14,848	19,626	32%
SAR	4,163	4,500	8%
IND	8,588	9,446	10%
MNA	1,911	1,978	4%
AFR	464	496	7%
ROW	72	76	7%

Source: IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

the favorable results generated for regions with an existing production base of high-value commodities and the unfavorable results for other regions. Since supply responses in the model are based on growth rates, a sector with positive initial value can grow or decline during the projection period, while production in a sector with no initial value remains zero throughout the simulation. In reality, new sectors can pop up in any country when business opportunities arise—a scenario that is ruled out by the model. Nonetheless, the results suggest the favorable position of countries that have an existing production base in capturing the opportunities to expand and diversify their production when a boom in a high-value, export-oriented sector, such as hypothesized in this scenario, would present itself.

The drastic changes in global aquaculture production induced by shifts in China's consumer preferences would certainly impact global trade patterns across all regions and across all categories of fish. Much of the changes are concentrated in the five specific species that were targeted in this scenario. Figure 4.4 illustrates the comparison of projected total net regional exports of fish in 2030 under the default and the current scenarios. The figure shows that China's net trade position would shift dramatically in 2030 relative to the baseline case: turning from a position of net exporter to that of sizable net importer of fish. In response to this, the exports by regions such as SEA and LAC would increase to supply this massive import demand by China. Other regions, such as ECA, JAP, NAM, MNA, and AFR, would decrease their net imports. Of these, reduced net imports by JAP and NAM are attributed to increased exports of high-value products made possible by substantial production expansion (table 4.8). In contrast, in MNA and AFR, aquaculture would fail to ride the wave of the demand boom and achieve only limited expansion (table 4.8), and reduction in the net imports could have food security implications. The net imports in 2030 would be lower by 30 percent in MNA and by 14 percent in AFR relative to the baseline case.

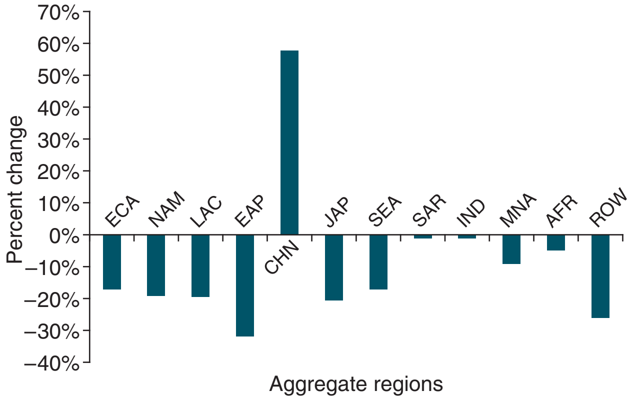
FIGURE 4.4: Projected Net Exports of Fish by Region under Accelerated Consumer Preference Shift in China



Source: IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

In fact, in all regions but China total food fish consumption in 2030 would be lower under this scenario relative to the default case (figure 4.5). Food security concerns are already severe in AFR, where per capita food fish consumption is expected to decline during the projection period. A further reduction in consumption by 5 percent, triggered by expansion of consumption elsewhere, could aggravate the food fish supply gap in this region.

FIGURE 4.5: Projected Change in Total Food Fish Consumption in 2030 by Region under Accelerated Consumer Preference Shift in China



Source: IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

Finally, similarly to the case in scenario 1, where aquaculture production is assumed to expand faster than in the default scenario, fast demand-driven aquaculture expansion in the current scenario would also place severe pressure on the global fishmeal market. Overall, the model predicts that fishmeal supply would be higher by 4 percent and the fishmeal price higher by 29 percent in 2030 relative to the baseline case (results not shown in table). As a result, global aquaculture (and livestock) production would experience a secondary effect of a tighter fishmeal market as seen in section 4.1 and fishmeal use would be further reallocated across aquaculture species.

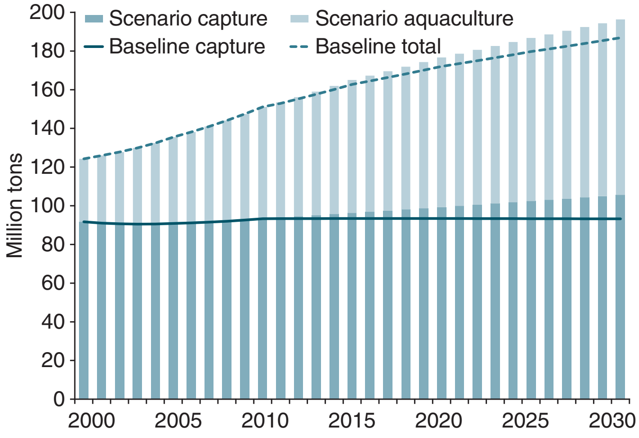
4.5. SCENARIO 5: IMPROVEMENT OF CAPTURE FISHERIES PRODUCTIVITY

The next two scenarios pertain to the productivity of capture fisheries. In a recent World Bank study, *The Sunken Billions* (Arnason, Kelleher, and Willmann 2009), it was estimated that successfully restored and managed world fisheries would sustainably provide 10 percent more yield annually relative to the 2004 harvest level. Restoring and improving the productivity of stressed capture fisheries will be possible in many cases if correct actions are taken by country governments, marine resource managers, and the fishing fleets and communities. These actions would include management improvements and proper tenure reforms to reduce fishing effort, letting the aquatic ecosystems and stocks recover, reducing the open-access nature of fisheries, and sustainably managing their productivity. Global fisheries restoration efforts will likely be accelerated under several new key global initiatives, such as the Global Partnership for Oceans.

In scenario 5, we explore the implications of productivity recovery in global capture fisheries on global fish markets. This scenario contrasts to the “ecological collapse” scenario simulated in the *Fish to 2020* study, which aimed at reflecting the environmental consequence of *not* taking on these actions and continuing to overharvest and compromise aquatic ecosystems to the point where they undergo biological collapse. To simulate this scenario of improved capture productivity, we make changes to the capture fisheries growth parameters. More specifically, we augment the exogenous annual growth rates of capture production by 0.6 percentage points so that the total harvest would gradually increase starting from 2011 and reach the global MSY estimated in *The Sunken Billions* in 2030. The increase in the capture production growth rates is applied to all capture fisheries in the model, including inland fisheries. Note that the 0.6 percentage points are added to the existing exogenous growth rates. As a result, those capture fisheries modeled as declining in the baseline specification would decline more slowly, recovering or growing fisheries would grow faster, and stagnant fisheries would grow exactly at the annual rate of 0.6 percent under this scenario. The MSY value in *The Sunken Billions* is scaled for consistency with FAO harvest data employed in this study.

Figure 4.6 depicts the evolution of projected total fish supply on a global level under this scenario (represented by bars) together with the baseline values (lines). The improvement in capture fisheries productivity allows the global capture production level to reach more than 105 million tons by 2030, which represents a 13 percent increase over the level under the baseline case. Under this scenario, aquaculture still grows at an impressive rate over the projection period, but it does not quite reach the baseline 2030 level due to lower market prices resulting from the additional supply from capture fisheries. Furthermore, under this scenario global capture fisheries would supply 15 million tons more than aquaculture would in 2030,

FIGURE 4.6: Global Fish Supply under Improved Productivity, 2000–30



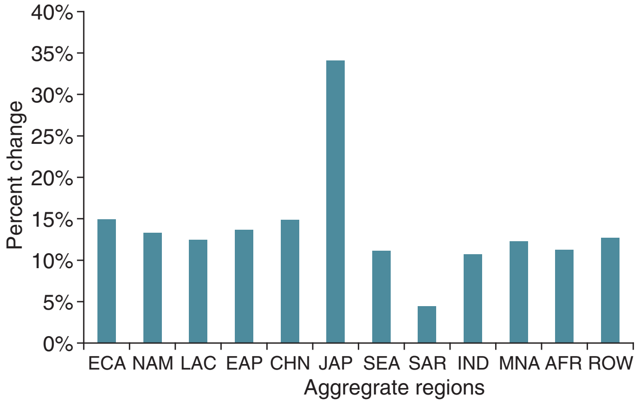
Sources: FishStat and IMPACT model projections.

whereas capture and aquaculture production would contribute essentially an equal amount to the global supply in 2030 under the baseline case.

Although this scenario uniformly adds 0.6 percent to the exogenous growth rates of all capture fisheries in the model, the default growth rates vary, with some fisheries growing and others declining or stagnant. As a result, there would be differences in the rate at which each region gains in terms of capture production. Figure 4.7 attempts to illustrate the point. The figure confirms projected increases in the production levels of capture production in all regions. Japan would benefit the most under this scenario, achieving 34 percent increase in capture production in 2030 relative to the baseline scenario. Other regions would enjoy 11–15 percent increase in capture production. SAR would benefit the least, achieving 4 percent increase in their capture production in 2030 relative to the baseline case. The last result is attributable to the relatively rapid growth that the capture fisheries of this region would be enjoying already under the baseline scenario (0.4 percent per year between 2010 and 2030). Thus an additional 0.6 percent in the growth rate under this scenario would not bring about as dramatic an increase in the capture production level. This contrasts sharply with the results for Japan, where the production under the baseline scenario is expected to decline at the annual rate of 9 percent.

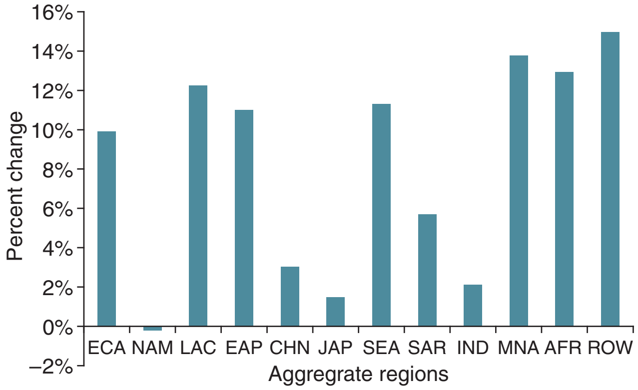
Increase in capture harvest would also imply increased food fish consumption than under the baseline scenario across all regions except North America[27] (figure 4.8). Again, there would be regional variations in the consumption gains from this scenario. The degree to which fish consumption increases would depend on how much of the increased harvest would be consumed domestically rather than exported. Some countries gain more than 10 percent in domestic

FIGURE 4.7: Projected Changes in Capture Production in 2030 under Capture Productivity Improvement Scenario



Source: IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

FIGURE 4.8: Projected Changes in Fish Consumption in 2030 under Capture Productivity Improvement Scenario



Source: IMPACT model projections.
Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

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[27] From the results, it is likely that the increased domestic capture production in North America would substitute imports rather than increasing overall domestic consumption.

fish consumption. In particular, Sub-Saharan Africa would achieve consumption increase of about 13 percent, as much of the additional harvest would be retained for consumption within the region, possibly after some intraregional trade. In terms of per capita fish consumption, the region would achieve 6.4 kilograms, as opposed to 5.6 kilograms under the baseline case in 2030.

These results demonstrate that a recovery of global capture fisheries can have varied but potentially substantial impacts on regional seafood sectors and on food security. There are known difficulties that are inherent in the attempt to implement comprehensive and coherent reform of capture fisheries. These reforms often require regional cooperation as well as determination and political will in each nation. By illustrating the considerable gains that can be enjoyed at the regional level, these results are consistent and in support of the benefit of regional cooperation in fisheries reform.

4.6. SCENARIO 6: IMPACTS OF CLIMATE CHANGE ON THE PRODUCTIVITY OF CAPTURE FISHERIES

The recent World Bank report *Turn Down the Heat: Why a 4°C Warmer World Must Be Avoided* (World Bank 2013b) describes the possible future state of the world in which the global temperature climbs 4 degrees Celsius above preindustrial levels. The report states: "Even with the current mitigation commitments and pledges fully implemented, there is roughly a 20 percent likelihood of exceeding 4°C by 2100. If they are not met, a warming of 4°C could occur as early as the 2060s." Coastal communities will be among the first to be impacted by changes in the oceans due to climate change. Changes in the oceans will include a rise in the sea level, which directly affects habitability of the coastline, and rising water temperature and ocean acidification, which affect productivity of local fisheries and the health of marine life and ecosystems. The impact of climate change on capture fisheries is a topic that has been closely studied by a number of groups in public and private sectors, academia, and civil society organizations. Here we wish to contribute to the growing, but still limited, body of knowledge by carrying out some illustrative simulations of impacts of climate change on capture fisheries and global fish markets.

Rather than using an ecosystem model that can directly provide estimates of productivity changes for capture fisheries in various parts of the world, we simulate the global market effects based on impacts of climate change on capture fisheries estimated elsewhere. As an illustrative example of climate change impacts, we use the predictions of catch potential provided by Cheung and others (2010). Incorporating the effects of various climate change symptoms in the oceans, Cheung and others (2010) provide maximum catch potential (maximum sustainable yield, MSY) in exclusive economic zone (EEZ) in 2055 under two scenarios:

a. Global atmospheric carbon dioxide content is kept constant at the level of year 2000.
b. Global atmospheric carbon dioxide content rises according to an IPCC-based scenario out to the year 2100.

Scenario (a) may be interpreted as a case where mitigation measures would be in place so that effectively "no" additional climate change would occur beyond the level in the year 2000. On the other hand, scenario (b) may be a case where, in the absence of radical mitigation measures, the "normal" progression of environmental effects would accumulate over time, including rising ocean temperature and ocean acidification.

According to Cheung and others (2010), some countries would gain and others would lose in terms of catch potential due to climate change–induced changes in the oceans. In particular, they provide, for selected countries, how much the catch potential is projected to change between 2005 and 2055 under the two climate change scenarios. According to their results, in general, potential catch would increase in high-latitude regions while catch would tend to drop in the tropics. These results would hold generally under both scenarios but would be more prominent under scenario (b).

Based on these two sets of climate change scenarios, we simulate climate change impacts on global fish markets. There are three specific assumptions of the scenario. First, the percent-change values for catch potential provided for the selected countries in Cheung and others (2010) are extrapolated to other countries represented in the IMPACT model based on geographical proximity. Second, while their projection period is from 2005 to 2055, our projection period is to 2030. Thus, we truncate their projections by cutting their percent changes in half. Third, we modify the exogenous growth rates of capture fisheries for the 2006–30 period based on the extrapolated and truncated percent-change values. We apply the modified

TABLE 4.9: Projected Capture Production in 2030 under Baseline and Climate Change Scenarios

	2030 (000 TONS)			CC-a RELATIVE TO BASELINE	CC-b RELATIVE TO CC-a
	BASELINE	CC-a	CC-b		
Global total	**93,229**	**90,217**	**90,200**	**–3%**	**–0.02%**
ECA	12,035	12,876	13,771	7%	7%
NAM	5,589	5,467	5,433	–2%	–1%
LAC	18,221	17,285	17,240	–5%	–0.3%
EAP	2,890	3,044	2,938	5%	–3%
CHN	15,686	15,824	15,582	1%	–2%
JAP	3,717	4,426	4,338	19%	–2%
SEA	14,244	12,710	12,228	–11%	–4%
SAR	5,811	3,994	4,038	–31%	1%
IND	4,143	3,821	3,826	–8%	0.1%
MNA	2,769	2,555	2,524	–8%	–1%
AFR	5,472	5,330	5,394	–3%	1%
ROW	2,652	2,884	2,888	9%	0.1%

Source: IMPACT model projections.
Note: CC-a = climate change with mitigation; CC-b = climate change without drastic mitigation; ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

exogenous capture growth rates to all species and to all countries that have *marine* capture fisheries in the model. No change is made to the capture growth rates for the 2000–05 period.

Though various studies have shown the likely negative effect of climate change on fish production and consumption in small island countries like Pacific island countries and territories (see, for example, Bell, Johnson, and Hobday 2011), our model structure does not allow us to implement this climate change scenario for small island countries. As mentioned earlier, small island countries have been aggregated in the ROW category. We also did not explicitly differentiated between various types of capture fisheries, such as oceanic fisheries, costal fisheries, and inland fisheries.

Table 4.9 lists the projected regional capture production in 2030 under the baseline and the two climate change scenarios. First, the simulation based on Cheung and others' (2010) scenario (a) with mitigation (CC-a, hereafter) generates a gloomier picture of global capture fisheries than our baseline simulation. In regions other than ECA, EAP, CHN, JAP, and ROW, CC-a yields 2–31 percent lower projection for 2030 capture production than in our baseline scenario. At the global level, however, CC-a scenario's prediction for capture production in 2030 is only 3 percent lower than our baseline scenario. With this in mind, we shall compare the results of two sets of climate change scenarios. Comparing between results under scenarios CC-a and CC-b (the simulation based on Cheung and others' (2010) scenario (b)), the model predicts that the overall effect of climate change on global capture production is negligible (a 0.02 percent decrease). Across regions, however, the projected impact of climate change on production varies. Cheung and others (2010) suggest that the catch potential of high-latitude European nations would increase under scenario b), which is reflected in the results under scenario CC-b. Capture production in ECA region would be 7 percent greater under CC-b than under CC-a. SAR and AFR would also gain capture harvest by 1 percent. The largest negative impacts would be observed in SEA (–4 percent) and EAP (–3 percent).

TABLE 4.10: Projected Fish Supply in 2030 under Baseline and Climate Change Scenarios

	2030 (MILLION TONS)			CC-a RELATIVE TO BASELINE	CC-b RELATIVE TO CC-a
	BASELINE	CC-a	CC-b		
Capture	93.23	90.22	90.20	–3%	–0.02%
Aquaculture	93.61	94.70	94.79	1%	0.1%
Global total	**186.84**	**184.92**	**184.99**	**–1%**	**0.04%**

Source: IMPACT model projections.
Note: CC-a = climate change with mitigation; CC-b = climate change without drastic mitigation.

While the shock is introduced to capture fisheries in this scenario, the ultimate interest to society is the impact of climate change on the total fish supply. Table 4.10 shows the projected fish supply from capture and aquaculture origins and their total. Comparing the baseline to CC-a scenarios, global aquaculture production would increase by only 1 percent in 2030, picking up only 39 percent of the loss in capture fisheries. As a result, the total fish supply would be lower under CC-a than under the baseline scenario. Again, the change between CC-a and CC-b is small for both aquaculture and global total fish supply.

Finally, table 4.11 shows the projections of regional food fish consumption. In CC-a, the impacts on regional capture fisheries are attenuated in regional consumption patterns due to aquaculture expansion and

TABLE 4.11: Projected Food Fish Consumption in 2030 under Baseline and Climate Change Scenarios

	2030 (000 TONS)			CC-a RELATIVE TO BASELINE	CC-b RELATIVE TO CC-a
	BASELINE	CC-a	CC-b		
Global total	**151,771**	**149,851**	**149,915**	**–1%**	**0.04%**
ECA	16,735	16,445	16,490	–2%	0.3%
NAM	10,674	10,670	10,680	–0.04%	0.1%
LAC	5,200	5,089	5,087	–2%	–0.04%
EAP	2,943	2,894	2,896	–2%	0.1%
CHN	57,361	56,977	57,029	–1%	0.1%
JAP	7,447	7,422	7,410	–0.3%	–0.2%
SEA	19,327	18,935	18,917	–2%	–0.1%
SAR	9,331	9,070	9,040	–3%	–0.3%
IND	10,054	9,966	9,972	–1%	0.1%
MNA	4,730	4,620	4,630	–2%	0.2%
AFR	7,759	7,562	7,566	–3%	0.1%
ROW	208	200	198	–4%	–1%

Source: IMPACT model projections.
Note: CC-a = climate change with mitigation; CC-b = climate change without drastic mitigation; ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacific; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

international trade. The changes in the oceans due to the climate change scenarios based on Cheung and others (2010) would have no major impacts on projected food fish consumption into 2030.

The apparently insignificant impacts of climate change on global fish markets projected in this section are due in part to the shorter time horizon considered in this report. While the projected changes in global marine capture fisheries by Cheung and others (2010) continue beyond 2030 and into 2055, we have truncated such changes by half. Climate change is an ongoing process whose impacts would materialize decades, even centuries, later. Readers should be reminded that the results presented in this report represent medium-term projections into 2030 and do not represent long-term impacts of climate change. Nonetheless, already by 2030, climate change will likely affect global fish markets in the form of distributional changes in the global marine fish harvest and resulting trade patterns.

Besides these six, a number of other relevant and practical scenarios can also be implemented. For example, a scenario where small pelagic fisheries collapse to affect reduction industry (fishmeal and fish oil production) can be implemented to analyze the impact on aquaculture production that is dependent on fishmeal and fish oil as input. Climate change also affects aquaculture production (see, for example, FAO 2009), and impacts of climate change on both capture fisheries and aquaculture and their interactions on global fish markets can be analyzed using the model. These and other scenarios may be studied in another volume.

Chapter 5: DISCUSSION

5.1. MAIN FINDINGS FROM THE ANALYSIS

Given the discussion of the baseline and scenario results to 2030, we now synthesize some of the key messages that emerge from our analysis of the global and regional supply, demand, and trade of fish. First, the remarkably dynamic character of the aquaculture sector stands out in the results and underscores the tremendous contribution that will likely be made by the Asia region, in particular, in meeting the growing world seafood demand in the next 20 years. The growth of global aquaculture production is projected to continue at a strong pace, until it matches the production of capture fisheries by the year 2030. China will likely still be at the top of the producer list of major fish species, but other Asian countries/regions (particularly SEA, IND, and SAR) will likely become stronger contributors of future aquaculture growth. Species such as shrimp, salmon, tilapia, *Pangasius,* and carp are seen to grow fairly rapidly over the projection horizon, with projected annual average growth rates well in excess of 2 percent a year over the 2010–30 period. This represents a strong contrast with the stagnant nature of capture, whose growth in the model is kept at exogenous rates that reflect its historical patterns of production.

Even though our classification of fish categories is more aggregated on the consumption side, we are able to obtain a much clearer picture of trends in demand across species compared to the earlier *Fish to 2020* analysis. The model projects strong growth in the global consumption of shrimp, although the largest overall share of consumption is in the freshwater and diadromous category, which encompasses such fast-growing categories as tilapia, *Pangasius,* and carp.

Other pelagic will likely continue to be the most important category for use in producing fishmeal and fish oil. The supply of these fish-based feeds is projected to grow at a steady pace, although nowhere near as quickly as the overall trajectory of aquaculture production that unfolds to 2030. Much faster growth in aquaculture production than in fishmeal supply toward 2030 reflects our assumption that there will continue to be steady improvements in the feed and feeding efficiency within the aquaculture sector. While such technological improvements are exogenously imposed in the model, rather than endogenously determined, this trend is reflected in the historical data. Dissemination of best management practices will likely continue from more advanced regions—for example, Scandinavia for salmon aquaculture—throughout the industry. This will likely come about as a result of competition for quality, the pressures of sustainability certifications, and the purely economic drive to lower costs per unit production of output as much as possible. The fishmeal price that is projected to steadily rise over the projection horizon to 2030 represents a continuing imperative and driver for technological change and efficiency gains. This is also reflected, in our results, in terms of the increasing use of fish processing waste for reduction into fishmeal and fish oil. Use of such “free” feedstock will likely increase, especially as fishery operations become more consolidated and vertically integrated within the industry. All in all, it is likely that technological change surrounding feed production and feeding practices will enable aquaculture to become more efficient and sustainable in nature as we move into the medium- to long-term horizon.

In our 2030 projections, the prices of all fish products continue on a slightly increasing trajectory into the future, which is consistent with what we observe in other global food commodity markets and projections. This reflects the “tightness” of market conditions that we expect to prevail across a number of food categories, given the steady demand growth for food and feed products that is expected to continue on a global level toward 2030 and beyond. This in turn is driven by steady growth in emerging economies like China, India, and the faster-growing countries within the Latin America and Sub-Saharan Africa regions.

As was the case in the earlier *Fish to 2020* study, a good deal of production and consumption growth and volume is expected to continue to be centered in China. The projections also highlight a number of Southeast Asian countries increasing their aquaculture supply in order to meet the growing food fish demand of regions such as China as well as their own internal consumption needs. The model predicts that the fishmeal to fuel the future growth of Asian aquaculture will largely be imported from Latin America, which will likely continue to produce a surplus of feed for both fish and livestock production.

One of the illustrative scenarios that we explore in this study points toward important sources of feed for aquaculture: fish processing waste that can be reduced, along with whole fish, into fishmeal and fish oil. The projected sizable increase in fishmeal production and reduction in world prices suggests this as a promising source of change within the industry. Increased use of processing waste will likely help relieve the pressure on marine stocks in the future as well. This kind of development could be one of the factors that leads toward the "faster growth" scenario simulated for aquaculture worldwide, in which a greater pressure on fishmeal markets (in the absence of any other technological change) and higher prices for fishmeal, fish oil, and their ingredient fish species are projected.

The disease scenario for shrimp aquaculture in Asia shows, by design, a very dramatic initial decline in shrimp production, but the shocks even out toward 2030 as the industry recovers. The shift in trade patterns would be the main mechanism through which the Asian production loss is made up, by additional production from other regions, especially Latin America. However, given the size of the aggregate shock to the market, Latin America would not be able to fill the initial global supply gap. Given the projected tightness of shrimp markets due to the continuing growth in global demand, such large-scale disease outbreaks will likely cause substantial impacts on the global market.

The scenarios focusing on capture fisheries show potentially dramatic changes in production and distribution of production across regions. The effects of restoring global capture fisheries will be positive in all aspects—both in production and consumption across all regions. This contrasts with the climate change scenario, where some regions gain in productivity due to more favorable biophysical conditions than other regions. This result underscores the importance of understanding and properly measuring the region-specific environmental changes, including ocean temperature and acidity levels that would occur under various climate change projections, and their implications on regional fisheries. The fact that there remains a large degree of uncertainty and inconsistency across various climate model projections in terms of the degree and direction of these effects underscores the importance of resolving these issues before meaningful interpretations can be given to their simulated effects on capture fisheries and, more broadly, on global fish markets. This also shows the growing need to manage fisheries in a precautionary fashion, given all the unknowns surrounding climate change.

A scenario on the demand side illustrates the effects of accelerated food preference changes among consumers in China. Substantially increased demand for high- and medium-value fish species within China would shift the global fish trade. The trade position of China for these products would shift from either small net exporter or large net importer to a solid net exporter by 2030. As a result fish consumption would be reduced in every other region by 1 to 32 percent.

Each of these scenarios helps to illustrate important dimensions of the world fish economy that might be substantially affected by technical, environmental, or socioeconomic change, and how sensitive the model results are to those shifts. They also help point to areas that should receive closer attention in future work—such as sourcing of alternative feedstock for fishmeal—and which countries and regions could be significant game changers in the industry as it evolves over the next 20 years.

5.2. DISCUSSION AND POSSIBLE FUTURE DIRECTIONS

The series of comparative analyses presented in section 2.5 and in the technical appendix to chapter 3 confirm that the IMPACT model generates projections that are consistent with the available data during the 2000s and with the model projections provided by OECD-FAO (2012). This gives us a degree of confidence in the model's ability to reproduce the observed dynamics of the global fish markets. However, the model shows some difficulty in generating consistent price projections, despite its success in reproducing their supply, demand, and trade volumes. In particular, for shrimp, crustaceans, and other freshwater and diadromous categories, the model does not reproduce the sharply falling price trend over the 2000–08 period. However, we are confident that the model has captured reasonably well the features of each of these markets at the regional and global level. As is often the case with a large and detailed model, this model contains a necessary degree of simplification so that the model is consistently clear in the construction and framework, tractable in its computational properties, and easily modifiable to introduce exploratory scenarios. Although there may be some features specific to certain segments of the fish markets that have not been fully incorporated in our representation of fish supply and demand relationships, we feel that this has not compromised the overall fidelity of the model to its original goal of representing the basic drivers of change and capturing the dynamics in the global fish markets to 2030.

Nonetheless, there are areas where improvements can be made on the model representation, especially when additional and better data become available.

Aquaculture Growth Rates

One set of parameters that can be improved is exogenous growth rates of aquaculture production. Except for those related to feed and price-driven supply responses, the dynamics of aquaculture are approximated by their historical trends observed in aggregate statistics. Given the sheer number of country-fish species combinations represented in the IMPACT model, case-by-case investigation of aquaculture expansion potential is not conducted. For example, each country faces species-specific and overall capacity constraints for aquaculture that are driven by geographical characteristics, such as soils, topography, climate, and water availability (Pillay and Kutty 2005; Boyd, Li, and Brummett 2012). Without sufficiently controlling the culture environment (for example, putting fish in greenhouses), aquaculture of certain species is simply infeasible in certain countries. If country-level information is compiled, that information can be incorporated into the model by fine-tuning the growth rate parameters. Alternatively, capacity constraints may be explicitly specified within the model.

Capture Growth Rates

Similarly, the representation of the dynamics of capture fisheries can be improved. In this study, the harvest of capture fisheries is treated as entirely exogenous, and their trends are determined using the aggregate statistics. Use of fishery-specific information about capacity and trends will likely improve the model predictions and expand the scope of analysis. While the state of world fisheries are periodically assessed and reported by the FAO (see, for example, FAO 2012), many fisheries, especially those in developing countries, are not currently assessed. However, tools are available to infer the state of unassessed fisheries. For example, Costello and others (2012) provide a regression-based predictive model of the state of unassessed fisheries. While efforts at the University of Washington aim at quantifying the variability in management systems around the world to evaluate which particular attributes lead to more successful outcomes for fish populations and fisheries (see, for example, Melnychuk, Banobi, and Hilborn 2013), recently developed Fishery Performance Indicators (FPI) can be used for rapid assessment of fisheries that are not formally assessed (Chu, Anderson, and Anderson 2012). Interacting the IMPACT model with an ecological simulation model may be an alternative way to characterize the dynamics of capture fisheries.

Trends in Consumption Demand

Consumption trend is another area where country- or region-specific parameters could be improved. In this study, the dynamics of demand for food by individual consumers is driven solely by growth in per capita income, and resulting per capita consumption demand is scaled up for each country or region by the total population, whose trend is exogenously given. All other changes in consumption in the model are purely price driven, which is regulated by price and income elasticities of demand that are fixed throughout the projection horizon. However, factors such as affluence and urbanization as well as concerns for health, environment, and other ethical and social values are considered to affect consumer preferences (FAO 2012) and, hence, own- and cross-price elasticities and income elasticities of demand. Where available, country- or region-specific updates in elasticity estimates could be incorporated to reflect observed trends and shifts in consumer preferences.

Linking with Ecosystem Model

As we have pointed out in earlier discussions, there could have been greater detail brought to the analysis of capture fisheries if an ecosystems-based framework had been used to replace our simple treatment of the sector in the IMPACT model. In earlier conceptions of the *Fish to 2030* study, it was envisioned that the IMPACT model could be linked to a marine ecosystems model such as those within the Ecopath with Ecosim (EwE) family of models (Christiansen and Walters 2004a, 2004b). The EcoOcean model (Alder and others 2007), for example, is built on the EwE modeling platform and provides global-level projections of capture production potential across all of the FAO fishing regions. This model could potentially be linked to IMPACT. Since the EcoOcean model takes into account the quantity and value of marine fishery landings, the effort required, and the ability of the ecosystem to regenerate itself, it would have provided a much more dynamic feedback to the market-driven demand for capture species in IMPACT—especially as it relates to the demand for whole fish that are reduced for fishmeal for the aquaculture sector. Since it was designed to project ecosystem impacts of longer-term environmental change, such as climate change, it could have been used to extend the projections to a longer horizon (for example, to 2050).

Linking with an ecosystem model could allow us to address a much wider range of policy-relevant questions by combining questions of trade and agricultural policy with questions of environmental management and technology adoption in fisheries. There would be considerable value-added created by developing a robust link between a market-based, global food supply and demand model, such as IMPACT, and ecological process models for fisheries, such as EcoOcean. Such a link enables the study to

a) examine more closely the effects of climate change–induced changes in aquatic ecosystems and ocean conditions, the resulting impact on the productivity of marine ecosystems, and how that affects global fish market dynamics; and
b) gain a better sense of how global supply and demand for fish products would be impacted by the ecological collapse of certain fisheries due to various causes, including overfishing, climate change, or a combination of ecological factors. While *Fish to 2020* included such a scenario, it was not underpinned by this kind of detailed biophysical modeling.

Consumption and Trade Data

At the time of model preparation, production data from the FishStat database were available through 2009, whereas consumption and trade data from FAO FIPS FBS were available only up to 2007. Lack of more recent data for the consumption/trade side has posed a limitation in the calibration exercises for these series.

More importantly, the use of FAO FIPS FBS data determines the level of disaggregation of fish species, which limits the scope of analysis in this study. For example, the level of species aggregation dictated by the FAO FIPS FBS data precludes the analyses of most dynamic fish markets, such as for tilapia and *Pangasius,* mainly due to limitation of trade raw data availability for these species. Furthermore, the FAO FIPS FBS data are geared toward understanding the supply-consumption balances of food commodities; for that reason, trade is expressed in terms of "net export." However, fish is traded heavily and extensively both in the form of fish and processed seafood. Allowing the model to represent fish trade for processing purposes would require substantial changes in the code, and obtaining consistent series of trade and consumption for fish and seafood would require a more complicated data preparation. But it may be a possible direction to go in to improve the model representation.

Overall Data Quality

We have tried as much as possible to maintain a close match between the model projections and the existing data for the calibration period. However, we have to recognize that complete congruence was not possible as the development of the fish part of IMPACT relies on three different datasets that are not mutually consistent. As a result, much time has been spent identifying the sources of discrepancy and reconciling them to reconstruct a plausible and consistent picture of the global fish markets. For example, there are many cases in which positive fishmeal production is observed (based on IFFO data) in countries where there is no recorded "reduction" of whole fish (in FAO data), and the converse. To a lesser degree, discrepancies are also identified between the more detailed production data from the FAO's FishStat database and the more aggregated consumption and trade data from the FAO FIPS

FBS database. It is desirable that these two important datasets are updated in tandem so that they can be more readily used together. Unfortunately, at present, it is not technically possible because datasets are updated sequentially starting with production series, then trade series, and then consumption series. Furthermore, as many countries do not report trade data that are as highly disaggregated by species as production data, trade and consumption series are necessarily more aggregated. The FAO has initiated an effort to encourage member countries to report disaggregated fish trade data. Undoubtedly, this would be a desirable goal for anyone working on fish supply and demand studies within the FAO and within the wider research community. Investment in consistent fisheries data seems especially sensible given the parallel modeling work that the FAO undertakes in collaboration with the OECD (OECD-FAO 2012; see technical appendix to chapter 3). In many ways, our effort in this study to reconcile across the datasets is, by itself, a valuable contribution toward that goal and will hopefully form a basis for further work within the FAO and its partner organizations.

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