Fish to 2030: The Role and Opportunity for Aquaculture

Mimako Kobayashi,[1] Siwa Msangi,[2] Miroslav Batka,[2] Stefania Vannuccini,[3] Madan M. Dey,[4] and James L. Anderson[1]

1 World Bank, Washington, USA

2 International Food Policy Research Institute, Washington, USA

3 Food and Agriculture Organisation, Rome, Italy

4 University of Arkansas at Pine Bluff, Pine Bluff, Arkansas, USA

Abstract

Seafood sector can contribute to the global food supply in an important way, and provide an important source of animal protein. Based on observed regional trends in seafood production and consumption and using a global, partial-equilibrium, multi-market model, this study investigates what the global seafood market may look like in 2030. The model projects that the total fish supply will increase from 154 million tons in 2011 to 186 million tons in 2030, with aquaculture entirely responsible for the increase. The fastest aquaculture growth is expected for tilapia and shrimp, while the largest expansion is expected in India, Latin America and Caribbean and Southeast Asia. Fast-growing seafood demand in China and elsewhere represents a critical opportunity for global fisheries and aquaculture to improve their management and achieve sustainable seafood economy.

Keywords

Market outlook, seafood trade, feed management, multi-market modeling

Introduction

The world is faced with a critical challenge of feeding the growing population that is expected to reach 9.6 billion by 2050. Global food and nutritional security must be achieved through increased food production, improved nutritional quality of food produced, and reduced food waste. An increase in food production must take place in a context where resources necessary for food production, such as land and water, are even scarcer in a more crowded world, while the world is required to change the ways it conducts economic activities in the face of global climate change. This article is concerned with roles that fisheries and aquaculture can play in this challenging context. Globally fish and seafood already represent 16.6 percent of all animal protein intake and this proportion has been increasing (FAO 2012). Yet, there are substantial geographical variations in global seafood supply and demand, and active international seafood trade importantly contributes to smoothing regional imbalances. In fact, seafood is among the most heavily traded food commodities, with 37-38 percent of all fish produced being exported in 2010-12 (FAO 2012). Therefore, it is essential to understand regional trends in the supply and demand and their implications on international market in discussing the role of seafood sector in achieving global food and nutritional security.

Based on observed regional trends in seafood production and consumption and using a global partial equilibrium model, this study investigates what the global seafood market may look like in 2030. Similar analyses on global fisheries, aquaculture, and seafood trade have been conducted, most notably by Delgado et al. (2003) and Anderson (2003). While three key observations – stagnant global capture fisheries, rapid expansion of aquaculture, and the rise of

China in the global seafood market – motivated these studies, a decade later, all of these trends and associated concerns and challenges remain valid. According to FAO (2012), while production from global capture fisheries has achieved a substantial increase from 18.7 million tons in 1950, with most of the key stocks fully harvested,[1] production has stabilized around 90 million tons since the mid-1990s. In contrast, rapid expansion of global aquaculture production has continued with no sign of reaching its peak: during the past three decades, global aquaculture production expanded at an average annual rate of over 8 percent, from 5.2 million tons in 1981 to 66.6 million tons in 2012 (FishStat). China represents the single largest seafood producing and consuming nation, and its influence on the global fish markets and trade has intensified (Zhang et al. 2014). China consumed 35 percent of global seafood in 2011 (FAO 2012). While Asia accounted for 88 percent of world aquaculture production by volume in 2012, China alone accounted for 62 percent. 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 re-exported after processing. China now represents 13 percent of world fish export in value, amounting to $17.0 billion in 2011 and $18.2 billion in 2012 (FAO 2013).

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. For example, the Chilean salmon industry experienced unprecedented losses due to infectious salmon anemia (ISA) disease (Tveteras et al. 2009; World Bank 2014). The recent outbreak of early mortality syndrome (EMS) in farmed shrimp has

[1] Stocks of 10 key fish species, which represent 30 percent of marine capture production, are fully harvested (FAO 2012).

caused substantial losses in Asia and the Americas (Leaño and Mohan 2012; World Bank 2014). Global climate change likely will cause changes in the oceans and aquatic ecosystems and impact the economies that depend on them (FAO 2009; World Bank 2013b). Climate change will further exacerbate the susceptibility of aquaculture to disease (see, for example, Leung and Bates 2013).

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, driven in part by the growing body of knowledge on the key drivers of change within the global seafood industry and the understanding of management and good governance of capture fisheries and aquaculture. For example, Delgado et al. (2003) 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), and sustainability has now been recognized as the principal goal of aquaculture governance by many governments (FAO 2012). Furthermore, Delgado et al. (2003) 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 capture fisheries of those species used in feed production. While it could lead to an over-exploitative outcome as projected by Delgado et al. (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 (Tveteras et al. 2011). 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 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 in recent years (Shepherd 2012; FAO 2012; Chim and Pickering 2012).

In this dynamic context, this study extends the previous work by Delgado et al. (2003) and provides projections of the global supply, demand, and trade of fish and fish products to 2030. While the quantitative projection tool, International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), itself has evolved since Delgado et al. (2003), the fish component of IMPACT is substantially expanded for this study. In particular, the fish species and global regions are much more disaggregated in the new version so that more targeted seafood market analyses are possible. Fishmeal and fish oil supply and demand are now modeled explicitly and consistently. A detailed description of the model, including the specification of some equations, can be found in World Bank (2013a). The model generates a series of projections of commodity supply, demand, and trade into 2030 for 115 countries/regions and for 18 fish and fish products as well as other agricultural commodities. This article focuses on presenting projection results for aquaculture. The first set of results presented 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. The baseline scenarios are subsequently contrasted with results generated under selected hypothetical scenarios to illustrate how shocks and changes to the production or consumption side of the world seafood economy trigger market responses. By highlighting expected opportunity in aquaculture expansion by region and by species, we discuss anticipated importance of aquaculture in providing seafood to meet growing demand.

Methods and Data

IMPACT model (Rosegrant et al. 2001) developed at International Food Policy Research Institute (IFPRI) was used to generate projections presented in this article. IMPACT is a global, multimarket, partial equilibrium economic model that covers a wide range of agricultural commodities; the model’s main objective is to provide forward-looking projections. The version of IMPACT used for the study contained 45 agricultural commodities (e.g. cereals, oilseeds, roots and tubers, pulses, and livestock products), 16 fish species categories, and two fish products (fishmeal and fish oil). Table 1 summarizes the fish species and products incorporated in the model. Due to the lack of disaggregate data for fish consumption and trade, fish species are further aggregated into nine categories for these series.

Table 1 about here

The version of IMPACT used in the study contained 115 regions,[2] and supply and demand functions were specified for each of the commodities represented in the model in each of the regions. In the case of the 16 fish species categories, separate supply functions were specified for capture harvest and aquaculture production. For the definition of the IMPACT 115 regions, see the model description by Rosegrant et al. (2012). In this article, results are presented for 12 aggregate regions as defined in Table 2. Major fishing and aquaculture nations in Asia—namely China, Japan, and India—are separated from their corresponding regions to give special consideration in the analysis.

Table 2 about here

The IMPACT model finds a global market equilibrium in each year and continues solving sequentially over the projection time horizon. For each commodity market, the model reaches equilibrium by solving for a single world price that balances the net exports and imports for all regions so that the market effectively clears globally. At the country level, the supply and demand of each commodity adjust according to price movements, where the adjustment is regulated by commodity-specific price elasticities of supply and demand. At the country level, there can be either a net surplus or deficit, which is to be reconciled on the global market through international trade in the model.

The model begins its projections in 2000 and carries forward to 2030. To introduce dynamics, the IMPACT model incorporates exogenously-specified trends in the drivers of change for demand and supply. Key exogenous drivers of demand are income and population growth such

[2] These are mainly countries, with some smaller nations grouped together to form regions.

that per capita demand, endogenously regulated by price and income elasticities, is scaled each year according to projected income and population levels. Exogenous drivers on the supply side represent productivity and efficiency gains in agricultural production, essentially shifting the intercepts of the supply curves over time. In contrast, 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, while the growth of aquaculture supply is regulated by both price responses and exogenous trends in production and efficiency surrounding feed and feeding practices. For further detail of the model structure, see Rosegrant et al. (2012) and World Bank (2013a).

This study relied on three sets of data compiled by FAO: FAO FishStat for fish production, FAO FIPS FBS (Fisheries Information and Statistics Branch, food balance sheets) data for fish consumption and trade, and a combination of FishStat, Oil World, IFFO (The Marine Ingredients Organisation) data for production and trade of fishmeal and fish oil. In order to evaluate the quality of projections, model results under the baseline scenario were compared against the observed data for the 2000–08 period for production series and 2000–06 for consumption and trade series. In general, a close fit was obtained between projections and available data for quantities of fish supply and demand at the global and regional levels, while we could not obtain as close a fit to price data. Output evaluation exercise is detailed in World Bank (2013a).

In this article, results from a total of five scenarios are presented. The 'baseline' scenario is characterized by a set of model parameters that were considered to reflect the trends of the global seafood economy currently observed in the aggregate statistics and consistent with findings in the literature. Baseline income and price elasticities were drawn from Rosegrant et al. (2001) and Delgado et al. (2003). Exogenous trend parameters for capture supply were specified according to the best fit to FishStat data over the 2000–08 period and plausible trajectories beyond 2008. Equivalent parameters for aquaculture were specified using FishStat data for 1984-2009. Feed demand functions incorporate required amount of feed per unit of livestock and aquaculture output supplied. For fed aquaculture species, feed coefficients were specified for fishmeal, fish oil and soybean meal, whose base values were drawn from Tacon and Metian (2008). For fishmeal and fish oil coefficients, their expected changes over time were also specified to capture the global tendency of feed efficiency improvement (Barnes et al. 2012; Hardy 1996, 2003; Naylor et al. 2009; Rana, Siriwardena, and Hasan 2009; Tacon, Hasan, and Metian 2011). Annual rates of change for these coefficients were calculated based on imputed amount of total use of these feeds for fed species production in each region in 2000 and 2009. See World Bank (2013a) for specification of other parameters in the baseline scenario.

Subsequently, model results under four hypothetical scenarios are presented. Scenario 1 addresses the case where aquaculture will grow faster than under the baseline scenario, implemented by increasing the exogenous growth rates of all aquaculture by 50 percent from 2011 through 2030. The specification is equivalent to shifting the supply curves outward relative to those under the baseline scenario. 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; in this scenario, in addition to the baseline 20 countries,[3] all countries that produce fishmeal or fish oil were assumed to have the option to use waste in their production starting in 2011. Scenario 3 introduces a hypothetical major disease outbreak in shrimp aquaculture in Asia,[4] where a sudden decline in affected shrimp aquaculture was simulated by lowering the exogenous growth rates to reduce the output by 35 percent relative to the baseline projection in 2015; the affected shrimp aquaculture was simulated to recover to the 2015 baseline level by 2020 and subsequently continue along the baseline growth trajectory. Scenario 4 simulates a more aggressive demand expansion for certain fish products among consumers in China: the scenario was specified such that Chinese per capita consumption of shrimp, crustaceans, and salmon in 2030 would be three times higher than in the baseline results for 2030 and that of mollusks would double the baseline value; the scenario was implemented by increasing the value of income and price elasticities for these commodities.

Results

Baseline Results

The model projects that the total fish supply will increase from 154 million tons in 2011 to 186 million tons in 2030 (Figure 1). With the production from global capture fisheries likely stable around 93 million tons during the 2010–30 period, the projected supply increase is entirely attributed to aquaculture expansion of 62 percent during the period. Aquaculture's share in

---

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

[4] The Asian countries affected in this scenario were Bangladesh, China, India, Indonesia, Malaysia, Myanmar, the Philippines, Singapore, Sri Lanka, Thailand, and Vietnam.

global supply will likely continue to expand to the point where capture fisheries and aquaculture will be contributing equal amounts by 2030. In 2006, 78% of fish was used for direct human consumption while 18% was used for fishmeal and fish oil production. With the increase of aquaculture, the model results suggest that this proportion will change slightly: direct human consumption is expected to account for 81% of all fish supply while 15% will be used in feed production in 2030. For fish destined for direct human consumption, aquaculture is projected to contribute 62 percent by 2030. Thus, the model indicates continued importance of aquaculture in global fish supply even though its projected growth will continue to slow down from a peak of 11 percent per year during the 1980s.

Figure 1 about here

Looking across aquaculture species, Figure 2 illustrates that carps and mollusks likely will remain the dominant aquaculture species in terms of volume (live weight). On the other hand, the fastest supply growth is expected for tilapia and shrimp. In particular, global tilapia farming is expected to more than double between 2010 and 2030. Other species where aquaculture is projected grow fast include salmon, carp, *Pangasius*/catfish, and other freshwater species, each expected to grow by over 65 percent between 2010 and 2030. Given the ongoing research and development efforts on various aquaculture species, these results appear 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 et al. 2007; Gjedrem, Robinson, and Rye 2012). Genetic improvement programs have also been initiated for carp and shrimp (Dey et al. 2010, 2013; Hung et al. 2013;

Ninh et al. 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).

Figure 2 about here

It is projected that China will continue to be by far the largest aquaculture producing country. Although its share in the global aquaculture production is expected to drop from 63 percent in the 2007-09 period, China's share is estimated to remain around 57 percent in 2030. While all regions are expected to expand their aquaculture production, the largest expansion (over 100 percent) is expected in India, Latin America and Caribbean (LAC) and Southeast Asia (SEA) during the 2010–30 period. Aquaculture in other South Asia (SAR) is also projected to grow over 90 percent during the two decades. Middle East and North Africa (MNA) and Sub-Saharan Africa (AFR) also show substantial expected growth over this period (76 and 54 percent, respectively), but they begin from much lower base production levels in 2010 compared to other regions. The projection results are in line with recent aquaculture research and development efforts in these countries and regions. 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).

The equilibrium supply projections are also influenced by trends in fish consumption demand. Total consumption demand in a country is obtained as a product of per-capita consumption demand and the (exogenously given) population, with the former endogenously determined in the model with reference to equilibrium prices, exogenously-given income levels, and price and income elasticities of demand. As seen in Figure 3, the model projects that the fastest increase in fish consumption will be observed in India and SAR over the 2010–30 period, followed by SEA, North America (NAM), MNA, and China. This increase, particularly in India and SAR, is driven in part by the fast rise in projected per capita income and population and partly because these regions start from relatively low baseline values of per capita fish consumption. In AFR, where the projected population growth is the highest at the average annual rate of 2.3 percent between 2010 and 2030, about 30 percent increase in fish consumption is projected, while per capita fish consumption in the region is projected to decline at an annual rate of 1 percent to 5.6 kilograms during the period. Fish consumption is estimated to decline in other East Asia and Pacific (EAP) region and in Japan.

Figure 3 about here

Given the projected fast expansion of the global aquaculture, the demand for fishmeal and fish oil likely will become substantially stronger. Figure 4 depicts the projected changes in the equilibrium prices of fish and fish products between 2010 and 2030. The model projects that real price of fishmeal will rise by 90 percent and that of fish oil by 70 percent. The price of 'other pelagic' fish is projected to rise relatively more than other fish species group because of the demand pressure for their use in feed production. Nonetheless, with significant improvements anticipated in the efficiency of feed and management practices, expansion of aquaculture likely 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 preferentially grown.[5]

Figure 4 about here

Hypothetical Scenarios

Tables 3 and 4 summarize and contrast results from the baseline and the four hypothetical scenarios as described in the previous section. 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 likely change the global market outcomes in the medium-term outlook to 2030.

Scenario 1 simulates faster technological progress that allows aquaculture to supply a given amount at a lower cost.[6] Relevant technical progress may include genetic improvement, innovations in distribution, improvements in disease and other management practices, control of

[5] 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.
[6] The scenario utilizes the same feed requirement coefficients for fed aquaculture as under the baseline scenario.

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 exogenous growth rate parameters in the baseline case, this scenario accelerates the changes by 50 percent. At the global level, the model projects that aquaculture production in 2030 would expand by 8 percent from 93.6 million tons under the baseline case to 101.2 million tons. The model also projects regional variations: in particular LAC and MNA would benefit proportionately more from this scenario, while production in NAM and Japan would be lower this scenario. The projected regional variations can be partly explained by the species mix in each region and associated strength in demand and feed requirements. The model projects 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. 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. 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 baseline results for 2030. 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).[7] 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 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 the loss to shrimp aquaculture production in the affected countries would be more than 1.36 million tons in 2015, with nearly half of the loss coming from the drop in Chinese production alone and the loss of more than half million tons in Southeast Asian production. All other regions unaffected by the hypothetical shrimp disease outbreak would increase their shrimp aquaculture production by about 10 percent or more in 2015 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 ability of the unaffected regions to

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

offset the Asian losses is 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, the global shrimp supply would contract by 1.28 million tons or 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. This exercise underscores the importance of disease management in any major aquaculture sector. As production intensifies and as fish population increases within a production system, both probabilities of disease outbreak and the consequences of outbreak intensify in aquaculture (Arthur et al. 2002). Given the projection of continuing rapid 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.

Scenario 4 is a case where consumers in China expand their demand for shrimp, crustaceans, salmon and mollusks faster than under the baseline case. These are higher-value commodities relative to other fish species and, except for mollusks, they require fishmeal in their production. Under this scenario, global aquaculture production would increase to 116 million tons by 2030. With relatively low aquaculture production under the baseline, Japan and NAM are expected to increase their aquaculture production by the largest percentage, 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. 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.

Table 3 about here

Table 4 about here

Discussion and Conclusions

We have developed a rigorous analytical tool that is capable of making projections on the implications of the shifts in market drivers on global fish production and international trade. The model, though having known limitations, is successfully calibrated to observed historical data and is then employed to evaluate different scenario-based policies and shocks and to illustrate the likely evolution of the global seafood economy under these scenarios.

From the modeling exercise, it is clear that aquaculture, notably in Asia, 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 origins by 2030, the model projects that 62 percent of fish for direct human consumption will be produced by aquaculture by 2030. Species such as shrimp, salmon, tilapia, *Pangasius*, and carp are likely 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. Beyond 2030, aquaculture will likely continue to dominate future global fish supply, and remain the engine of its growth.

Scenario analysis also demonstrated that, since global seafood economy is tightly connected through international trade, repercussion of various shocks to the system could reach across countries and regions and across fish species. For example, the model results suggest that a strong expansion of seafood demand in a large consumer market such as China could squeeze the global market such that seafood availability in other markets would decline, including those in poor regions such as Sub-Saharan Africa. Changes and trends that influence the global fishmeal market would also trigger global responses in seafood supply induced by higher or lower price of fishmeal, or the outbreak of disease. Both of these scenarios point to the importance of adopting best management practices to control disease incidence, as well as to boost feeding efficiency of aquaculture. The lessons learned in Chilean salmon industry, or in other sectors that have dealt with serious disease problems, are critical for the emerging aquaculture sectors that are expected to rise in under-developed parts of Asia and Africa.

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), and this gives us a degree of confidence in the model's ability to reproduce the observed dynamics of the global seafood market. However, we acknowledge limitations and rigidity of the model results, which in large part stems from applying a model originally developed for agricultural commodities to the highly-dynamic global fisheries and aquaculture sector. In the current specification, the trend of fish supply from global capture fisheries is determined outside the model based solely on observed catch levels during the 2000s, and their dynamic interactions through environmental factors (e.g. El Nino) or fisheries management policies are not incorporated. On the aquaculture side, the model does not endogenize the dynamics of its expansion, which is driven in large part by technological innovations in the industry as well as biophysical interactions (e.g. disease outbreak). Further, the model does not fully capture the dynamics on the demand side, where consumer preferences can make a discrete jump from one seafood commodity to another. A model that can capture these peculiarities of the fisheries and aquaculture sector will be useful in analyzing the trend, challenge and prospects for the global seafood market.

All in all, fast-growing seafood demand in China and elsewhere represents a critical opportunity for global fisheries and aquaculture to improve their management and achieve sustainable seafood economy. 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 as well as the ecosystem and society in which it operates. 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.

Acknowledgements

This is the result of a collaborative effort between IFPRI, FAO, the University of Arkansas at Pine Bluff, and the World Bank. Preparation and publication of the report was supported by the Global Program on Fisheries (PROFISH) Multi-Donor Trust Fund, the Trust Fund for Environmentally & Socially Sustainable Development (TFESSD), and the Japan Policy and Human Resources Development (PHRD) Fund Staff Grant.

References

ADB (Asian Development Bank) (2005) *An Impact Evaluation Study of the Development of Genetically Improved Farmed Tilapia and Their Dissemination in Selected Countries.* Manila, Philippines: ADB.

Anderson, J. L. (2003) *The International Seafood Trade*. Cambridge, U.K.: Woodhead Publishing Ltd.

Arthur, J. R., M. J. Phillips, R. P. Subasinghe, M. B. Reantaso, and I. H. MacRae, eds. (2002) *Primary Aquatic Animal Health Care in Rural, Small-Scale, Aquaculture Development.* Fisheries Technical Paper 406. Rome: Food and Agriculture Organization of the UN.

Asche, F., and K. H. Roll (2013) Determinants of Inefficiency in Norwegian Salmon Aquaculture. *Aquaculture Economics and Management*, **17** (3): 300–321.

Ayyappan, S. (2012) Indian Fisheries on a Fast Tract. *The Economic Times* (New Delhi, India), September 28.

Barnes, M. E., M. L. Brown, K. A. Rosentrater, and J. R. Sewell (2012) An Initial Investigation Replacing Fish Meal with a Commercial Fermented Soybean Meal Product in the Diets of Juvenile Rainbow Trout. *Open Journal of Animal Sciences*, **2** (4): 234–43. doi:10.4236/ojas.2012.24033.

Brummett, R. E. (2013) Growing Aquaculture in Sustainable Ecosystems. Agricultural and Environmental Services Department Notes (June), World Bank, Washington, DC. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2013/06/26/000442464_20130626121301/Rendered/PDF/788230BRI0AES00without0the0abstract.pdf.

Chim, L., and T. Pickering (2012) Feed for Aquaculture. Presentation at the SPC/IFREMER seminar “Fish Waste Utilization,” Noumea, New Caledonia, June 11.

Delgado, C. L., N. Wada, M. W. Rosegrant, S. Meijer, and M. Ahmed (2003) *Fish to 2020: Supply and Demand in Changing Global Markets*. WorldFish Center Technical Report 62. Washington, DC: International Food Policy Research Institute.

Dey, M. M. (2000) The Impact of Genetically Improved Farmed Nile Tilapia in Asia. *Aquaculture Economics and Management,* **4** (1–2): 109–26.

Dey, M. M., P. Kumar, F. J. Paraguas, O. L. Chen, M. A. Khan, and N. Srichantuk (2010) “Performance and Nature of Genetically Improved Carp Strains in Asian Countries. *Aquaculture Economics and Management* **14** (1): 3–19.

Dey, M. M., P. Kumar, Oai Li Chen, M. A. Khan , N. K. Barik , L. Li , A. Nissapa , and N. S. Pham (2013) Potential impact of genetically improved carp strains in Asia. *Food Policy*, **43**: 306-320

Eknath, A. E., H. B. Bentsen, R. W. Ponzoni, M. Rye, N. H. Nguyen, J. Thodesen, and B. Gjerde (2007). Genetic Improvement of Farmed Tilapias: Composition and Genetic Parameters of a Synthetic Base Population of *Oreochromis niloticus* for Selective Breeding. *Aquaculture*, **273**: 1–14.

FAO (Food and Agriculture Organization of the UN) (2009) Climate Change Implications for Fisheries and Aquaculture. FAO Fisheries and Aquaculture Technical Paper 530, FAO, Rome.

FAO (2012) *The State of the World Fisheries and Aquaculture 2012*. Rome: FAO.

FAO (2013) *Food Outlook: Biannual Report on Global Food Markets (June)*. Rome: FAO. http://www.fao.org/docrep/018/al999e/al999e.pdf.

Gjedrem, T., and M. Baranski (2009) *Selective Breeding in Aquaculture: An Introduction*. Dordrecht, Netherlands: Springer.

Gjedrem, T., N. Robinson, and M. Rye (2012) The Importance of Selective Breeding in Aquaculture to Meet Future Demands for Animal Protein: A Review. *Aquaculture*, **350–353** (June): 117–29.

Globefish (2011) Commodity Update: Fishmeal and Fish Oil. FAO, Rome.

Hardy, R. W. (1996) Alternate Protein Sources for Salmon and Trout Diets. *Animal Feed Science and Technology*, **59** (1–3): 71–80.

Hardy, R. W. (2003) Use of Soybean Meals in the Diets of Salmon and Trout. Technical factsheet written in conjunction with United Soybean Board and American Soybean Association. http://www.soymeal.org/FactSheets/SalmonidTechReview.pdf (accessed February 28, 2013).

Hung, D., N. H. Nguyen, R. W. Ponzoni, D. A. Hurwood, and P. B. Mather (2013) Quantitative Genetic Parameter Estimates for Body and Carcass Traits in a Cultured Stock of Giant

Freshwater Prawn *(Macrobrachium rosenbergii)* Selected for Harvest Weight in Vietnam. *Aquaculture,* 404: 122–29.

IFFO (The Marine Ingredients Organisation) (2011) *IFFO Statistical Yearbook 2011*. London: IFFO.

Leaño, E. M., and C. V. Mohan (2012) Early Mortality Syndrome Threatens Asia's Shrimp Farms. *Global Aquaculture Advocate,* (July–August): 38–39.

Leung, T. L. F., and A. E. Bates (2013) More Rapid and Severe Disease Outbreaks for Aquaculture at the Tropics: Implications for Food Security. *Journal of Applied Ecology,* **50** (1): 215–22.

Naylor, R. L., R. W. Hardy, D. P. Bureau, A. Chiu, M. Elliott, A. P. Farrell, I. Forster and others. (2009) Feeding Aquaculture in an Era of Finite Resources. *Proceedings of the National Academy of Sciences,* 106 (36): 15103–10.

Ninh, N. H., R. W. Ponzoni, N. H. Nguyen, J. A. Woolliams, J. B. Taggart, B. J. McAndrew, and D. J. Penman (2013) A Comparison of Communal and Separate Rearing of Families in Selective Breeding of Common Carp *(Cyprinus carpio):* Responses to Selection. *Aquaculture,* 408–409: 152–59.

Rana, K. J., S. Siriwardena, and M. R. Hasan (2009) Impact of Rising Feed Ingredient Prices on Aquafeeds and Aquaculture Production. FAO Fisheries and Aquaculture Technical Paper 541, FAO, Rome.

Rosegrant M. W., M. S. Paisner, S. Meijer, and J. Witcover (2001) *Global Food Projections to 2020: Emerging Trends and Alternative Futures*. Washington, DC: International Food Policy Research Institute.

Rosegrant, M. W., and the IMPACT Development Team (2012). International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description." Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/sites/default/files/publications/impactwater2012.pdf (accessed February 25, 2012).

Shepherd, J. (2012) Aquaculture: Are the Criticisms Justified? Feeding Fish to Fish. *World Agriculture*, 3 (2): 11–18.

Tacon, A. G. J., and M. Metian (2008) Global Overview on the Use of Fish Meal and Fish Oil in Industrially Compounded Aquafeeds: Trends and Future Prospects. *Aquaculture*, **285** (1–4): 146–58.

Tacon, A. G. J., M. R. Hasan, and M. Metian (2011) Demand and Supply of Feed Ingredients for Farmed Fish and Crustaceans: Trends and Prospects. FAO Fisheries and Aquaculture Technical Paper 564, FAO, Rome.

Asche, F., H. Hansen, R. Tveteras, and S. Tveteras (2009) The Salmon Disease Crisis in Chile. Marine Resource Economics, **24** (4): 405–411.

Tveteras, S., C.E. Paredes, and J. Peña-Torres (2011) Individual Vessel Quotas in Peru: Stopping the Race for Anchovies. *Marine Resource Economics*, **26**:225-232

Ward, T., and B. Phillips, eds. (2008) *Seafood Ecolabelling: Principles and Practices*. Chichester, U.K.: Wiley-Balckwell.

World Bank (2013a) Fish to 2030: Prospects for Fisheries and Aquaculture. Washington, DC: World Bank.

World Bank (2013b) *Turn Down the Heat: Why a 4°C Warmer World Must Be Avoided*. Washington, DC: World Bank.

World Bank (2014) *Reducing Disease Risk in Aquaculture*. Washington, DC: World Bank.

Zhang, D., R. Tveteras, and K. Lien (2014) China's Impact on Global Seafood Markets. *Aquaculture Economics and Management*, **18** (2), 101–119.

Tables

Table 1. 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

Table 2. 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

Table 3. Summary Results for Year 2030 under Baseline and Alternative Scenarios

	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		Faster growth	Waste	Disease	China
Total fish supply (million tons)	186.8	194.4	188.6	186.6	209.4
Capture supply (million tons)	93.2	93.2	93.2	93.2	93.2
Aquaculture supply (million tons)	93.6	101.2	95.4	93.4	116.2
Shrimp supply (million tons)	11.5	12.3	11.5	11.2	17.6
Salmon supply (million tons)	5.0	5.4	5.1	5.0	6.1
Tilapia supply (million tons)	7.3	9.2	7.4	7.3	7.4
Regional aquaculture supply (million tons; % to baseline)					
ECA	3.8	0.9%	1.9%	0.1%	39.7%
NAM	0.9	-4.9%	1.7%	0.1%	76.8%
LAC	3.6	23.5%	1.5%	0.5%	43.2%
EAP	1.1	4.5%	0.3%	0.0%	63.9%
CHN	53.3	5.4%	2.4%	-0.1%	21.1%
JAP	1.0	-3.8%	0.0%	0.0%	87.9%
SEA	14.8	13.7%	1.2%	-1.4%	32.2%
SAR	4.2	16.5%	0.8%	0.0%	8.1%

IND	8.6	6.9%	1.8%	0.1%	10.0%
MNA	1.9	25.6%	-0.1%	0.0%	3.5%
AFR	0.5	13.1%	-1.1%	0.0%	6.8%

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

Table 4: Comparison of Projected World Price of Fish and Fish Products between Baseline and Senarios

(% to baseline)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Faster growth	Waste	Disease	China
Shrimp	-0.5%	-0.1%	1.0%	4.5%
Crustaceans	-0.9%	-0.3%	0.0%	11.0%
Mollusks	-1.7%	-0.1%	0.0%	35.1%
Salmon	-1.9%	-0.7%	-0.1%	7.2%
Tuna	-0.2%	-0.2%	0.0%	3.0%
Freshwater and diadromous	-0.7%	-0.4%	-0.1%	1.5%
Demersals	-0.2%	-0.4%	-0.1%	1.8%
Pelagics	1.3%	-1.8%	-0.4%	4.8%
Other marine	-0.7%	-0.5%	-0.1%	2.0%
Fishmeal	13.0%	-14.1%	-4.6%	29.3%
Fish oil	6.9%	-8.2%	-0.3%	18.3%

Note: For all scenarios except the disease scenario, the difference from baseline world price is shown for the year 2030. For the disease scenario, the difference shown is for 2015, since the scenario design includes a recovery by 2020 after the initial disease outbreak in 2015 and thus projected world prices largely converge by 2030.

Figures

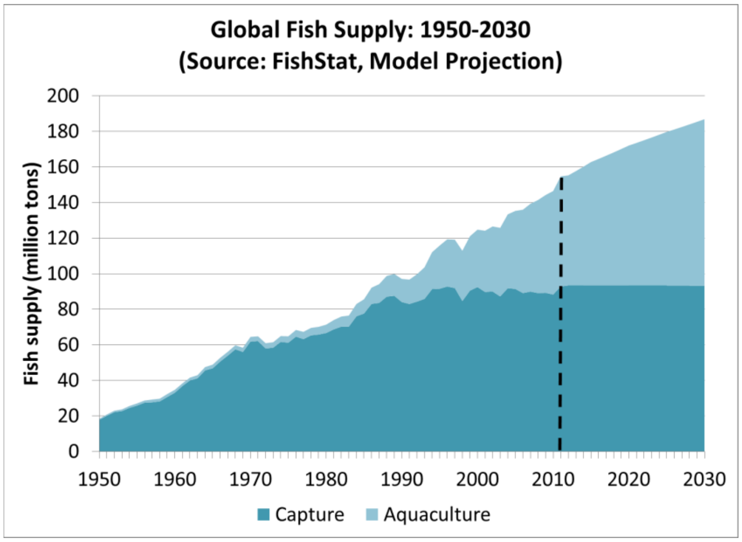

Figure 1. (projection after 2011)

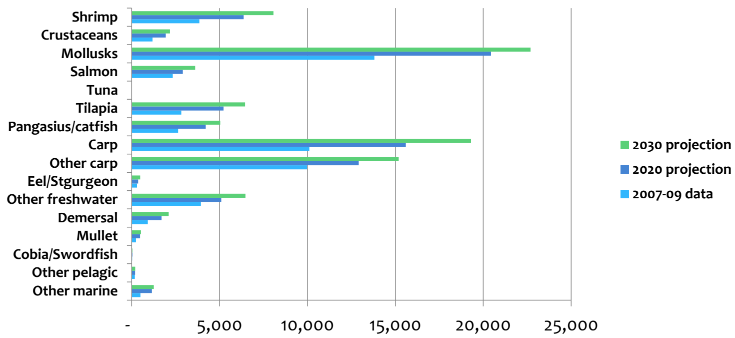

Figure 2. Aquaculture Supply Growth: Species (in thousand tons, live weight)

Source: FishStat and IMPACT model projections.

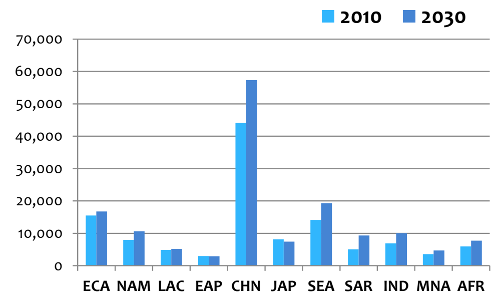

Figure 3. Projected Food Fish Consumption by Region (in thousand tons, live weight equivalent)

Sources: 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

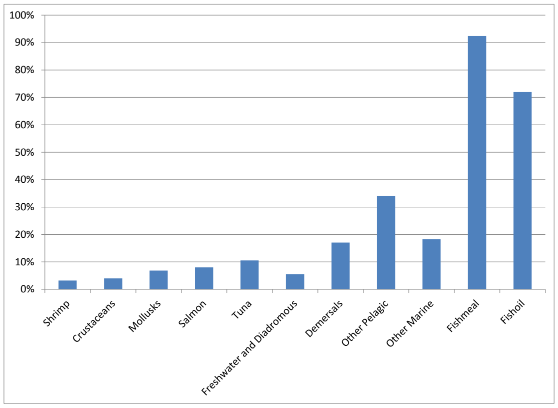

Figure 4. Projected Change in Real Prices between 2010 and 2030 by Commodities

Source: IMPACT model projections.