Issues in Modeling Fish to 2020 within a Global Food Model

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Abstract. The International Food Policy Research Institute (IFPRI) and the International Center for Living Aquatic Resources Management (ICLARM), in collaboration with the Food and Agricultural Organization of the United Nations (FAO), are presently attempting to model supply and demand for highly aggregated fish categories within the context of IFPRI's IMPACT global food model (Rosegrant et al. 1995). The analytical purpose is to quantify insights on: (a) the increasingly important role of aquaculture in world food and trade, (b) its interaction with rapidly growing livestock production and consumption in developing countries, (c) trade-offs (if any) between low cost food from fish and fishmeal, and (d) trade-offs between the production of high-value fishery exports and food. Important practical issues that arise from this are discussed here. They concern how to aggregate existing country data from hundreds of species into the maximum of 4 to 6 product categories for which it is feasible to specify supply, demand, and trade parameters for each of 36 countries or country groups. On the supply side, major technological differences need to be highlighted (such as aquaculture or capture), whereas on the demand side issues involve aggregating products with similar demand parameters, regardless of how produced. Resolution of the aggregation issues is different for groups of developing and developed countries, because of fundamental differences in the underlying issues. Model structure, interactions with non-fishery food products, available data, practical choices made, and preliminary magnitudes obtained are discussed.

Keywords: Fish, 2020, Global Food Model, Data Aggregation, Methodology.

1. INTRODUCTION: SCOPE AND RATIONALE

From the beginning of the 1970s to the mid 1990s, consumption of meat products in developing countries increased by 70 million metric tons (MMT), almost three times the increase that occurred in developed countries. Fish consumption in developing countries increased by 34 MMT over the same period, seven times by weight (three times by value) as much as it did in developed countries over the same period. The market value of the *increase* (not the total) from 1971 to 1995 in meat consumption in developing countries was approximately $124 billion (1990 US$). This was more than twice the market value of the more widely publicized increased cereals consumption under the "Green Revolution", which was about the same as the $68 billion (1990 US$) value of increased fish consumption in developing countries over the same period (Delgado *et al.* 1999).

Clearly these trends represent a major change in the structure of world supply of and demand for animal protein, indeed in world food, over the past 20 to 30 years, with major implications for non-animal foods and feeds. The population growth, urbanization, and income growth that fueled the increase in animal protein consumption are expected to continue well into the new millennium, creating a veritable "Animal Protein Revolution". This has been argued and documented in detail for terrestrial livestock products in a number of world food models, but especially in a joint effort of three international organizations, the International Food Policy Research Institute (IFPRI), the Food and Agricultural Organization of the United Nations (FAO) and the International Livestock Research Institute (ILRI), reported in Delgado *et al.* (1999).

Although fish is known to be a close substitute in consumption for several livestock products (Delgado and Courbois, 1999b), to have become the most important food commodity in the exports of developing countries (Delgado and Courbois, 1999a), and to play a key role in the nutrition of the poor in many areas of the world (Ahmed *et al.*, 1998), fish products have generally not been well-integrated into these kinds of models.

The projection tool used in the work referenced above was IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), a global food model first reported in Rosegrant, Agcaolili-Sombilla, and Perez (1995). The absence of fish in this work means that it is hard to predict the true and changing importance of fish—and policies towards fisheries—in the major world events that will unfold in the food sector of developing countries over the next two decades. Inevitably, this will lead to less policy attention to fisheries and fishers than the sector merits. Therefore IFPRI, in close collaboration with the International Center for Living Aquatic Resources Management (ICLARM) and FAO, has decided to attempt to add fisheries to an updated version of the IMPACT model. While this is work in progress, the present paper seeks to lay out some of the conceptual and practical difficulties in doing this. Future work is planned in a fully collaborative mode to marry the fisheries expertise of ICLARM and FAO to the interpretation of insights from this modeling effort.

2. THE IMPACT GLOBAL FOOD MODEL

The current version of the IMPACT model is an agricultural sector model that is global in its coverage, dividing the world into 36 countries or country groups. The countries and groups can be conveniently aggregated into regions that are compatible with FAO definitions (such as "Latin America and the Caribbean"). The model covers 18 commodities, including on the livestock side: beef, pork, poultry, sheep meat, goat meat, bovine milk, and eggs. The base data used in the current version are an annual average of the 1996-98 annual data from FAO's main web-based database, FAO Stat. Supply and demand relationships are specified in detail from other studies in the literature. The model produces a series of market clearing prices for major commodities through an annual iterative process. In this limited sense, it is dynamic rather than comparative static, since it traces out a time path of solutions.

Key assumptions that must be specified in advance are: the income and population growth rates for each country group; price, cross-price, and income elasticities of demand for each commodity and region; trade distortions in effect in each country group; and a host of production response parameters. Examples of the latter for crops are area and yield growth trends, investment in research and irrigation, and price response parameters; for livestock they are herd size parameters, productivity trends, and initial levels and trends in feed conversion. All these items differ across the 36 country groups. Commodities cannot be produced in solutions without using up the requisite inputs, all of which have to be available according to rising price schedules. As feed demand goes up, for example, the overall demand for cereals and other feeds increases, which affects prices and supplies of both feeds and food cereal in a series of inter-linked global markets. Those prices and quantities in turn affect livestock and crop production in markets other than the initial one, with some effects fed back to the initial market.

The payoff to this annualized iterative process is an estimated annual series of projected market-clearing prices, consumption levels by commodity and country group, feed use levels, area, yield and production levels by commodity and region, and net trade across country groups by commodity. The analysis is currently pursued to the year 2025. The increasing globalization of agricultural markets is represented in the model through its endogenous world price formation that is arrived at through annual iterative solutions. Events affecting net exports from one country group will impact prices in others, which in turn changes their supply, demand and net trade, converging eventually to a solution.

3. CONCEPTUAL ISSUES IN ADDING FISH TO IMPACT

Any modeling effort requires a series of hard choices and assumptions. In such a large model as IMPACT, informed priors, conservative approaches, and consistent procedures are the best approach. The key is to let the assumptions and structure be guided by the issues being investigated, but not in a way that predisposes results (on the contrary, favorable results are most convincing when assumptions are governed by a set of principles unrelated to the issue or even random). A model such as impact involves many thousands of individual assumptions, and there is the hope, borne out by reasonable results, that errors are random and cancel each other out.

On the supply side the important issues to be investigated using the model are the expected rate of growth of production and its impact on incomes and the environment. To answer these questions requires disaggregation of the analysis between aquaculture and capture fisheries. Technological response parameters, input requirements, and substitutatibility in production with non-fishery items in response to relative price changes are all likely to be fundamentally different between culture and capture items, and between finfish and other fishery items. Furthermore, the quantities of capture fishery products are unlikely to grow in the future, and may even decline. Aquaculture commodities have the potential to grow rapidly. Aquaculture and capture fisheries also have different impacts on incomes and the environment.

On the demand side, the important difference is between low and high value commodities. The segments of society consuming high and low value items are quite different, and their demand parameters differ. The livestock items that are good substitutes for fish differ considerably across the high/low value divide, as well as the finfish/other dichotomy. Low value commodities are an important source of protein for many of the world's poor. They are also used for feed in production of many livestock and fisheries products. Events in feed markets can affect the price of low cost fish for the poor. High value commodities are also important to the poor as a source of income, and are critical to the trade balances of developing countries.

4. CHOICE OF RELEVANT FISHERY COMMODITY GROUPS AND DESCRIPTION OF SUPPLY DATA

In order to add fishery commodities to IMPACT, by far the most difficult and important issue in terms of final results is the choice of manageable commodity groups in the baseline. Most of this paper is devoted to this problem, although a final section will briefly discuss issues in parameter specification.

The groups used for analysis must be aggregated enough to avoid unnecessary complication of the model, but disaggregated enough to provide answers to the issues that interest policy makers. Principally they need to distinguish between high and low value and culture or capture. They also need to distinguish between finfish and other fisheries products.

The data challenges on the production side are relatively straightforward. Detailed production data exist in FAO's FishStat Plus database (FAO 2000b) that specifies individual species (marine and freshwater) and production method (culture or capture). The challenge is the need to have roughly two dozen response parameters for 36 country groupings *for each additional commodity group.* Obviously this is possible for only a strict minimum of groupings dictated by the minimum needs for the policy insights sought. We choose six commodity groups on the production side.

Commodity groups chosen on the supply side are: high value fish from aquaculture (HVFA), high value fish from capture (HVFC), low value fish from aquaculture (LVFA), low value fish from capture (LVFC), high value other from aquaculture (HVOA), and high value other from capture (HVOC).

High value fish from aquaculture (HVFA) and capture (HVFC) include fish such as salmon and flounder. These two commodity groups are the products that are consumed as high value fish for human consumption (HVFH). Some is also used for other uses (HVFO). Each region may also export and import high value fish (HVFX and HVFM respectively).

Low value fish include species such as carp from pond aquaculture (LVFA) and herring from capture (LVFC). These two commodity groups supply the products that are consumed as low value fish for human consumption (LVFH). Some is also used for other uses such as industrial production (LVFO). Low value fish from capture can also be processed into meals that are used as feed (LVFB). Each region may also export and import low value fish (LVFX and LVFM).

High value other from aquaculture (HVOA) and capture (HVOC) include fishery commodities such as squid and shrimp. They supply the commodity called high value other for human consumption (HVOH). Some is also used for other uses (HVOO). Each region may also export and import high value other (HVOX and HVOM).

In each region, sources (aquaculture and capture production plus imports) must equal uses (human consumption, other uses, feed, and exports) for each commodity (Equations 1-3). Unfortunately, they do not for a couple of reasons. The first is simply that FAO data come from a variety of sources with different levels of error in them. The second is that FAO fisheries utilization data is not as amenable to these chosen grouping as the production data. Utilization data are highly aggregated. A method for making equations 1-3 hold is described in the following sections.

(1) HVFA + HVFC + HVFM = HVFX + HVFH + HVFO

(2) HVOA + HVOC + HVOM = HVOX + HVOH + HVOO

(3) LVFA + LVFC + LVFM = LVFX + LVFH + LVFO + LVFB

5. PROBLEMS USING FAO DATA ON THE UTILIZATION SIDE

Available FAO data on the utilization side have been aggregated into commodity groups more appropriate to fisheries biology issues than the food policy and trade issues we would like to consider. It is necessary to estimate the disaggregated commodity groups that we require from the FAO data. This section describes the process for undertaking this operation.

Trade and consumption data are from FAO Stat (FAO 2000a). FAO Stat data are reported as aggregate commodity groups: cephalopods, crustaceans, demersal fish, freshwater fish, mollusks, pelagic fish, and unspecified fish. Mapping these aggregates into the two fish consumption and trade commodity groups (high and low value fish) is difficult. Without specific species information it is impossible to know whether a quantity of fish is high or low value. We use a series of assumptions and rules to disaggregate the FAO data.

On the consumption side, we wish to map these commodities into: high value fish for human consumption (HVFH), high value fish for other uses (HVFO), low value fish for human consumption (LVFH), low value fish for feed (LVFF), low value fish for other uses (LVFO), high value other for human consumption (HVOH), and high value other for other uses (HVOO).

Commodities are also traded. Each country has exports and imports of the three consumption commodities: high value fish exports and imports (HVFX, HVFM), low value fish exports and imports (LVFX, LVFM), and high value other exports and imports (HVOX, HVOM).

All cephalopods, crustaceans, and mollusks that are imported, exported, consumed (as human food or as other uses) are placed in the high value other groups (HVO). All demersal fish imports, exports, human consumption, and other uses are high value fish (HVF). All unspecified marine fish imports, exports, human consumption, and other uses are low value fish (LVF). All feed imports, exports, and other uses are low value fish. The remaining two commodities, pelagic and freshwater fish, are attributed to high or low value commodities following assumptions based on what we know about consumption and trade in certain regions.

Pelagic and freshwater fish have to be treated differently because they include both high and low value fish. Pelagic fish include both low value herring and high value tuna. Freshwater fish include low value carps and high value trout. Without country-level consumption and trade information about the proportion of high and low value fish in these two groups, we need a procedure to distribute the aggregate quantities into the high value fish and low value fish groups.

6. ATTRIBUTION OF PELAGIC AND FRESHWATER FISH AMONG HIGH AND LOW VALUE COMMODITY GROUPS

Table 1 details how pelagic and freshwater fish are divided between high and low value uses in the first stage of fitting FAO data to our commodity groups. In developed countries, pelagic and freshwater fish that are imported, consumed by people, or use for other uses are classified as high value fish. Pelagic and freshwater fish that are exported from developed countries are classified as low value fish. In developing countries, pelagic and freshwater fish that are imported, consumed by people, or use for other uses are classified as low value fish. Pelagic and freshwater fish that are exported from developing countries are classified as high value fish.

The result of the first stage is that we have values for sources and uses of fisheries products in each country. For developed countries, this procedure will result in an overestimate of high value imports, human consumption, and other uses. This is because it assumes all pelagic and freshwater imports and consumption were tuna, bonitos, and the like, rather than fishmeal feedstock. It will also underestimate low value imports and human consumption because no pelagic and freshwater fish were added to those groups. It will also result in an overestimate of low value exports and an underestimate of high value exports (because all exports of pelagic and freshwater fish are considered low value).

Table 1: Attribution of pelagic and freshwater fish into value group

Region	Value Group	Imports	Exports	Human Consumption	Other Uses
Devel-oped	High value	XXX		XXX	XXX
	Low value		XXX		
Devel-oping	High value		XXX		
	Low value	XXX		XXX	XXX

For developing countries, this first iteration will result in an overestimate of high value exports (since it assumes that all exports of pelagic and freshwater fish were high value items such as Nile Perch fillets, for example) and an underestimate of low value exports. It will also result in an overestimate of low value imports and human consumption, and an underestimate of high value imports and human consumption. These errors will be corrected to a large extent at a later stage, as set out below.

7. REFINING ESTIMATES OF UTILIZATION-SIDE COMMODITY GROUPS

This first stage will result in error primarily because of the attribution of pelagic and demersal fishery products to high or low value based solely on whether a region is developed or not. That error will be corrected in the second stage with further assumptions about why the quantities do not balance. A third stage can also be added where information about specific countries can be used to increase accuracy.

The error that remains after the first stage is identified by adding imports to local production then subtracting exports, human consumption, other uses, and feed use (Equations 4 and 5). The remainder is error. Some of the error cannot be avoided. These data come from different sources and do not balance exactly. For low and high value fishery commodities some of the error can be corrected because it results from the assumptions about how to classify pelagic and freshwater fish. Improving these assumptions will reduce the error. Examples of this error for several developed and developing regions are shown in Tables 2 and 3.

(4) High Value Error =
HVFA + HVFC + HVFM
– HVFX – HVFH – HVFO

(5) Low Value Error =
LVFA + LVFC + LVFM
– LVFX –LVFH – LVFO – LVFB

Table 2: Sample of sources and uses data for fishery products, high value fish

Region	**HVFA**	**HVFC**	**HVFM**	**HVFX**	**HVFH**	**HVFO**	**Error**
				(MT)			
USA	41,088	2,990,726	1,776,999	1,127,752	3,892,338	91,667	-302,944
EC	358,418	3,098,206	12,494,918	7,507,038	6,063,156	244,171	2,137,176
China	44,762	1,920,269	20,969	83,072	1,577,421	0	325,508
Mexico	1,494	284,593	7,227	121,851	103,467	0	67,995
Thailand	842	444,809	22,000	881,970	177,867	0	-592,186
Brazil	882	158,770	269,178	26,043	428,808	0	-26,021

Notes: HVFA High value fish aquaculture.
HVFC High value fish capture.
HVFM High value fish import.
HVFX High value fish export.
HVFH High value fish for human consumption.
HVFO High value fish for other uses.
Error Remainder.

Table 3: Sample of sources and uses data for fishery products, low value fish

Region	**LVFA**	**LVFC**	**LVFM**	**LVFX**	**LVFH**	**LVFB**	**LVFO**	**Error**
					(MT)			
USA	221,755	1,155,858	67,542	154,879	34,106	1,104,731	22,596	128,842
EC	41,277	3,032,897	1,162,481	428,063	474,285	5,412,611	360,122	-2,438,430
China	9,653,998	7,648,825	310,485	169,831	16,230,776	26,651	2,865	1,183,185
Mexico	11,369	812,493	215,630	17,392	675,535	346,282	77,266	-76,982
Thailand	201,920	2,105,161	1,164,505	4,770	1,154,826	1,783,382	14,693	513,915
Brazil	38,874	496,516	173,978	5,934	638,315	95,397	18	-30,296

Notes: LVFA Low value fish aquaculture.
LVFC Low value fish capture.
LVFM Low value fish import.
LVFX Low value fish export.
LVFH Low value fish for human consumption.
LVFB Low value fish for animal consumption.
LVFO Low value fish for other uses.
Error Remainder.

Consider the developed regions first. The USA has a deficit of high value fish and a surplus of low value fish. Some of this error results from the assumptions about how pelagic and demersal fish are distributed between high and low value imports, exports, and human, animal and other uses. This can be corrected by re-allocating some of the pelagic and freshwater fish from low value uses to high value uses.

For high value fish, a deficit indicates that either imports were higher than estimated, exports were lower than estimated, human consumption was lower than estimated, other uses were lower than estimated, or a combination of these. A combination of these is probably the correct answer, but if we make that assumption then we cannot reduce the error. Instead we will identify a likely cause and change the estimates in a systematic way.

As described above, because of how pelagic and freshwater fish were distributed, exports were underestimated and imports, human consumption, and other uses were overestimated. Because we have a deficit, increasing exports (underestimated) or decreasing imports (overestimated) would make the problem worse. What remains is to decrease human consumption and/or other uses.

For low value fish, a surplus indicates that either imports were lower than estimated, exports were higher than estimated, human consumption was higher than estimated, other uses were higher than estimated, or a combination of these. Because of how pelagic and freshwater fish were distributed, exports were overestimated and imports, human consumption and other uses were underestimated. With a surplus decreasing exports or increasing imports will not solve the problem. What remains is to increase human consumption and/or other uses.

By decreasing human consumption and other uses of high value fish and increasing human consumption and other uses of low value fish we have essentially re-defined some pelagic and freshwater fish from high value human consumption and other uses to low value human consumption and other uses. We are saying that some of this consumption that was thought to be tuna filets is actually anchovies.

In some cases the deficit and surplus are nearly equal in absolute value. This is a good indication that the reason for the error is a misinterpretation of the value of pelagic and freshwater fish. In other cases, such as the US, the deficit and surplus differ in absolute value (deficit of high value fish is 302,944; surplus of low value fish is 128,842). Only the smaller value can reasonably be attributed to the pelagic/freshwater fish problem. The 128,842 metric tons of low value fish uses are reclassified as high value fish uses. Error in low value fish will then be zero. The remaining error in high value fish is left to be dealt with later.

Estimates for other developed regions that, like the USA, have a deficit of high value fish and a surplus of low value fish will be recalculated in a similar way. This will not remove all of the error but it is an improvement.

For the other developed region listed here, the European Community, there is a substantial surplus of high value fish and a deficit of low value fish. Using similar logic as what was applied to the USA, a surplus of high value fish can be reduced by decreasing imports or increasing exports, human consumption, or other uses. Because of how pelagic and freshwater fish were allocated, exports were underestimated and imports, human consumption, and other uses were overestimated. Reducing human consumption and other uses will increase the error. Reducing imports and increasing exports will improve the situation.

The similarly sized deficit of low value fish in the EC can be corrected by increasing the underestimated imports and decreasing the overestimated exports. Human consumption and other uses are already underestimates. By changing these allocations of low and high value fish, we have essentially assumed that some of the pelagic and freshwater fish exports from Europe were high value rather than low value and that some of the pelagic and freshwater fish imports to Europe were low value rather than high value. Other developed countries with a similar distribution of error will be treated similarly.

Again, like the US case, only the smaller value of the errors in absolute value is shifted from high value to low value. Some error will remain in the EC's low value fish. That error cannot be blamed on the pelagic/freshwater problem.

Turning to the developing countries, there are more combinations of error. Thailand, like the USA, has a deficit of high value fish and a surplus of low value fish. Because the original allocation of pelagic and freshwater fish in developing countries was the reverse of that in developed countries (Table 1), the solution is the reverse as well. High value fish exports are decreased and imports are increased. Low value fish exports are increased and imports are decreased. This in effect assumes that some of the pelagic and freshwater fish imported were high value and exported were low value.

Mexico, like the EC, has a surplus of high value fish and a deficit of low value fish. Because Mexico's original allocation was the reverse of the EC, the correction is also the reverse. Human consumption of high value fish is increased and human consumption of low value fish is decreased. This assumes that some of the pelagic and freshwater fish consumed were high value rather than low value.

China and Brazil have different patterns of error. China has a surplus of both low and high value fish. Brazil has a deficit of both low and high value fish. These errors cannot be attributed to the pelagic/freshwater fish problem. They are caused by error in the FAO data sets and will be dealt with in the same way as error that remains after correcting the pelagic/freshwater problem.

High value other (HVO) sources and uses data also have error in them. Sources and uses in each region do not sum to zero. This is also dealt with in the section dealing with the error that remains.

8. REMAINING AGGREGATION ERROR

By construction, any "error" that remains as we have defined the term can only come from inconsistencies between the supply and utilization sides of the FAO data. In some regions a surplus remains that indicates that either production or imports are "too high" or that figures for exports, human consumption, animal consumption, or other uses are "too low". In other regions a deficit remains, indicating the opposite. Better incorporation of priors at a later date may give a better indication of how to resolve remaining error. For the time being, a simple rule is proposed to eliminate remaining inconsistency error in a reasonable way.

The proposed solution is to adjust each source or use by a fraction of the error equal to the relative size of the source use. This solution assumes that each source or use has equal percentage error in it and all are adjusted until the error equals zero.

For example, there are surpluses of both low and high value fish in China (Tables 3 and 4). Reclassifying some fish as high or low value will not solve this problem. Instead, either a source must be reduced or a use must be increased. Without information about which option to choose, all are adjusted proportionately. Sources (aquaculture and capture production and imports) are decreased by a proportion, and uses (exports, human consumption, other uses, and feed) are increased by a proportion. Each adjustment is equal to the absolute value of the source or use quantity divided by the sum of the absolute value of all sources and uses.

9. OTHER MODELING PROBLEMS SUCH AS PARAMETER SPECIFICATION

The specification of complete sets of supply and demand parameters for supply, demand and trade relationships in 36 country groups and up to 6 commodities is not an easy task, but less critical to results and actually less difficult to do than the previous aggregation issues. Individual country studies such as those surveyed in a variety of articles or macro level country regressions such as Delgado and Courbois (1999a, 1999b) can be used to get basic insights into substitution relationships and price responsiveness. These can be generalized across countries of similar income levels, sizes and locations for a given commodity group.

One key is to recognize that a consistent philosophy must be adopted of similar orders of magnitude for "responsive" (not 2 in one country and 0.2 in another, in the same model that allows trade flows). Secondly, IMPACT is a uniformly conservative model, and "price responsive" for crops and livestock may mean a price elasticity of 0.3, rather than 1.0. Similar discipline needs to be exhibited in the fisheries sector, or the results will be serious biased in terms of explosive growth in fisheries. Third, priors should always be used, as informed by empirical case studies. Fish and chicken are passable substitutes in demand in most countries, but fish and sweet potatoes are not.

Finally, our objective as in all modeling is to try things out, investigate why striking results are obtained in some countries and sectors if this is the case, and iterate to a generally defensible research tool. All suggestions are welcome.

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