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A Model for Data Consolidation of the Fish Market in CAPRI

C.-Y. Chang; H.P. Witzke; C. Latka

Institute for Food and Resource Economics, , Germany

Corresponding author email: chiaoya.chang@ilr.uni-bonn.de

Abstract:

Economic fish and aquaculture modelling is still at the beginning. The lack of a comprehensive and consistent data set for the production and trade of fish and other fishery products has restrained the modelling attempts so far. Here we show a methodology for filling the present data gaps and for overcoming existent inconsistencies to create a database that may support modelling of the fish sector, illustrated at the case of the fish module in the CAPRI model. We avoid double counting with respect to fishmeal and fish oil production and trade by disentangling the available data from key statistical sources relying on a minimization of normalized least squares. The presented data correction procedure and the resulting database may furthermore be of value for other models of global fish markets. The impact of the data correction procedure is demonstrated for the most relevant fish and fishery products producing and trading countries, comparing the resulting consolidated to the initial data.

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Abstract

Economic fish and aquaculture modelling is still at the beginning. The lack of a comprehensive and consistent data set for the production and trade of fish and other fishery products has restrained the modelling attempts so far. Here we show a methodology for filling the present data gaps and for overcoming existent inconsistencies to create a database that may support modelling of the fish sector, illustrated at the case of the fish module in the CAPRI model. We avoid double counting with respect to fishmeal and fish oil production and trade by disentangling the available data from key statistical sources relying on a minimization of normalized least squares. The presented data correction procedure and the resulting database may furthermore be of value for other models of global fish markets. The impact of the data correction procedure is demonstrated for the most relevant fish and fishery products producing and trading countries, comparing the resulting consolidated to the initial data.

1. Introduction

Fish is an essential protein source, accounting for 16.6% of the global protein supply from animal protein sources (Tacon and Metian, 2013). Moreover, aquaculture is one of the most rapidly growing food producing sectors and its contribution to global food and nutrition security is uncontested. Despite the large potential of fish and fishery products in contributing to the food supply of an increasing global population, the sustainability of fish and seafood production is contentious. While fisheries are blamed for overfishing and the destruction of marine ecosystems, aquaculture is criticized for competing for land resources and for being dependent upon wild fish as fish feed for the cultured species (Boyd et al., 2007; Naylor et al., 2009).

Economic fish and aquaculture modelling is expected to bring new insights about the linkages of the fishing and aquaculture sector to the rest of the global economy, its

likely future development and its responsiveness to policies which may be implemented in the future.

However, economic fish and aquaculture modelling is still at the beginning (Chang et al., 2016). The IMPACT model (International Model of Policy Analysis of Agricultural Commodities and Trade) (Delgado et al., 2003; Kobayashi et al., 2015; Msangi et al., 2013) and the AgLink-CoSiMo Model (FAO-OECD) (FAO, 2012) are two of the most well-known large-scale agricultural economic models with a detailed fish sector. The CAPRI (Common Agricultural Policy Regionalize Impact Analysis) model (Britz, 2005; Britz and Witzke, 2012) is a global agricultural economic partial equilibrium model with a European focus that is applicable to analyzing seafood markets and their interaction with the remaining agricultural sector. We build upon the fish module in the CAPRI model in the study at hand.

Even though already some economic modelling is ongoing, so far no “ready to use”, up to date, comprehensive and consistent data set on aquaculture production and fish trade exists. Data about global fish markets are provided mainly by two sources, namely FAOSTAT and FAO FISHSTAT. The inspection of these data sources though reveals major inconsistencies and data gaps. In order to make the existing data accessible for the fish module in CAPRI, the present gaps in the time series data are filled and inconsistencies are corrected while double counting is avoided. Consolidation of the existing sources with gap filling is handled as a problem of minimizing normalized least squares under various constraints which is used prior to the actual use of the CAPRI fish module.

In the following, a conceptual framework of the fish module in CAPRI is presented. The available data sources are introduced and the occurring problems with these are outlined. Finally, the data correction method is presented and the consolidated data set is compared to the original data for exemplary cases.

2. Fish module in CAPRI

The CAPRI model is composed of two major modules, a set of regional programming models to represent the supply side of European regions and the global market module

representing demand and bilateral trade for all regions and the supply side for non-European regions as well (Britz and Witzke, 2012). The fish module is a part of the global market module and operates at the country level. So far it treats European and non-European countries alike.

The CAPRI fish module is based on three decision making stages. At each level a distinct optimization objective is fulfilled addressing a certain set of commodities (Table 1). Six fish categories are distinguished within the module, which are crustaceans (CRUS), mollusks (MOLS), freshwater and diadromous fish (FFIS), demersal fish (DFIS), pelagic fish (PFIS), and other marine fish (OFIS). Besides fishmeal (FIML) and fish oil (FIOL), twelve further categories, mainly crops, are differentiated as aquaculture feed ingredients. These are soya cake, maize, barley, wheat, paddy rice, rape seed, rape seed oil, rye and meslin, soya oil, sunflower seed, sunflower seed oil, and animal waste used in fish feed.

Table 1 Commodities in each decision making stage

	Optimization	Commodities
Level 1	Profit Maximization	Crustaceans, mollusks, freshwater and diadromous fish, demersal fish, pelagic fish, other marine fish
Level 2	Feed cost Minimization	Fishmeal, fish oil, aggregated crops
Level 3	Feed cost Minimization	Soya cake, maize, barley, wheat, paddy rice, rape seed, rape seed oil, rye and meslin, soya oil, sunflower seed, sunflower seed oil, animal waste used in fish feed

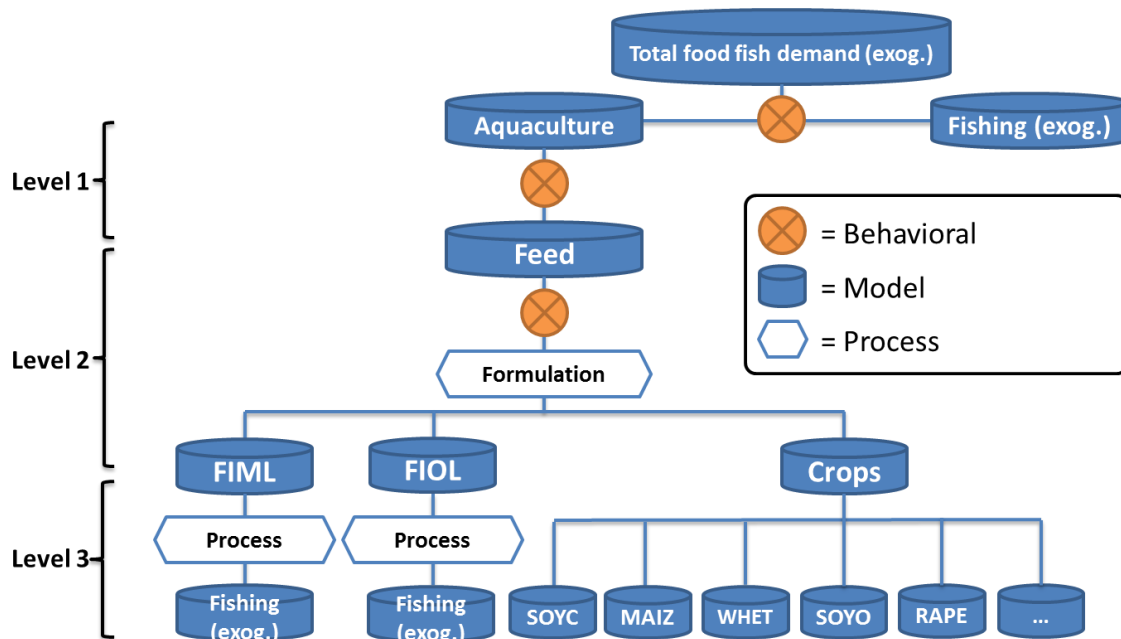
Source: Own compilation

The three-level structure is taken up in the conceptual framework of the CAPRI fish module shown in Figure 1. First of all, total fish supply is composed of fish from aquaculture production and from capture. While fish supply from captured fish is based on exogenous information, aquaculture production is further modelled. At this first level, the fish producers' profit maximization function is derived to investigate how fish farmers decide about the supply quantities of cultured fish from aquaculture.

At the next stage, a cost minimization function is set up to find the input quantities for the feed input needed in aquaculture production. First of all the overall feed quantity in standard quantity and composition is technically determined by the feed conversion ratio specific to each fish type. Regarding the three major input categories, fishmeal, fish oil and aggregated crops, relatively small substitution elasticity coefficients (between 0.5 and 1) are applied in the underlying CES production function. The composition of the main ingredients in the feed formulation is thus changeable only to a limited extent.

At the third level, mainly crop-based feed ingredients are disaggregated and assumed to be close substitutes for each other. Larger substitution elasticity coefficients are assigned to all feed crops referred to at this stage.

Figure 1 Conceptual framework of the CAPRI fish module



Source: Own illustration

Besides the data about fish production and trade described in detail in Chapter 3, further technical information about the linkages between live fish, the processing of fishmeal and fish oil, and fish feed has been collected and included in the fish module.

According to Tacon and Metian (2008), by weight, fishmeal and fish oil account for 9.5% and 2.2% of the total aquaculture feed in 2010, respectively. Aquaculture consumed 68% of fishmeal and 74% of fish oil of the total global consumption in 2012 (Tacon and Metian, 2015). Both products are extracted mainly from small pelagic forage fish, in particular, anchovies, mackerels and herrings (Péron et al., 2010).

The fishmeal and fish oil industry highly relies on reduction fisheries. These are fisheries whose catch is determined for the processing to fishmeal and fish oil and not for direct human consumption. They account for approximately 20% to 30% of the total captured landings (Péron et al., 2010). In addition, about 15% to 25% of fishmeal and fish oil production is based on fish processing waste (Msangi et al., 2013; Shepherd, 2012). The reduction ratio (RR) and the waste ratio (WR) are two important factors for computing fishmeal and fish oil production quantities and are therefore referred to in the data consolidation later on. The reduction ratio indicates how much fishmeal and fish oil can be obtained from a certain amount of fish. The waste ratio captures the share of fish initially designated for the food industry which is not suitable for human consumption so that it is further used in fishmeal and fish oil production.

On average, a ton of fish can be processed to roughly 225kg fishmeal and 50kg fish oil (Tacon and Metian, 2008). Accordingly, the global average reduction rates of fishmeal and fish oil are 0.225 and 0.05, respectively. Waste rates vary by seafood group between 0.25 and 0.5 (Msangi et al., 2013) as shown in Table 2.

Table 2 Fishmeal and fish oil processed from captured fish and fish waste

CAPRI fish groups	Reduction Ratio (Global Average)		Waste Ratio
	FIML	FIOL	
CRUS	0.23	0.05	0.45
MOLS	0	0	0
FFIS	0.23	0.05	0.25
PFIS	0.23	0.05	0.25
DFIS	0.23	0.05	0.29
OFIS	0.23	0.05	0.26

Remarks: Ratios for mollusks are not considered.

Sources: Msangi et al., (2013); Tacon and Metian, (2008)

The feed conversion ratio (FCR) determines the overall feed quantity required to produce one ton of farmed seafood type. In Table 3 it is indicated that on average 1.4 tons of feed is required to produce one ton of crustaceans. As aforementioned, fishmeal and fish oil are two substantial ingredients in the feed, in particular, for carnivorous groups such as crustaceans. However, these ingredients in fish feed are steadily replaced by crop meal and oil due to raising prices of fish-based products (Hardy, 2010).

Among the crop categories included in the CAPRI fish module, soybean processing byproducts are the predominate alternatives to fishmeal and fish oil. Consequently, the combination of fish-based and plant-based ingredients used in feed for various fish species determines how seafood markets interact with agricultural markets.

Table 3 Feed Conversion ratio (FCR) of the CAPRI fish group

#	CAPRI fish group	FAOSTAT description	FCR (1995-1999)	FCR (2000-2004)	FCR (2005-2009)	FCR (2010-2014)
1	CRUS	Crustaceans	1.4	1.4	1.4	1.4
2	MOLS	Cephalopods & Mollusks	-	-	-	-
3	FFIS	Freshwater fish & diadromous fish	0.9	0.9	1	1
4	DFIS	Demersal fish	1.3	1.3	1.3	1.3
5	PFIS	Pelagic fish	1.3	1.3	1.3	1.3
6	OFIS	Marine fish, other	1.3	1.3	1.3	1.3

Sources: Own calculations based on Boyd and Polioudakis, (2006); Tacon and Metian, (2008)

The feed formulation determines the crop use in feed production. While being aware of the heterogeneity in terms of single species within each CAPRI fish category this category is assumed to have a uniform diet structure. The feed formulation chosen for crustaceans is referring to shrimp feed. Mollusks are a filter non-fed seafood category and therefore have no feed demand. Pelagic, demersal and other marine fish are mostly cultured in the ocean and are assumed to be fed with similar feed.

Freshwater and diadromous fish is an important but heterogeneous CAPRI fish category which accounts for the largest part (47%) of total aquaculture production. This category includes herbivorous and omnivorous fish like carps, barbell and tilapias, and carnivorous fish such as sturgeons, eels, salmon, trout, smelt and shad. According to Tacon and Metian (2015, 2008), the feed conversion ratio of herbivorous fish like carps and tilapias ranges between 1.5 and 2, whereas the ratio of carnivorous fish like trout and salmon lies between 1.3 and 1.5. Furthermore, about 30% of the fish in the FFIS category belong to non-fed filter-feeding species. This is accounted for by reducing the feed conversion ratio accordingly for this fish group.

3. Fish data from FAO and its integration into the CAPRI fish module

The CAPRI fish module is reliant upon data representing fish, other seafood, fishmeal and fish oil production and trade. The data sources referred to are both databases from the Food and Agriculture Organization of the United Nations (FAO). The FAO provides two data sources for fish and fishery products (FIPS). These are the FAOSTAT FIPS Commodity Balance Sheets (CBS)¹ and FAO FISHSTAT². FAOSTAT FIPS CBS (hereinafter FAOSTAT) and FAO FISHSTAT (hereinafter FISHSTAT) contain time series data over the time period between 1990 and 2011 at country level.

FAOSTAT data are the key source for the global CAPRI database, which covers the fish related commodities including “Aquatic Animals, others”, “Aquatic Plants”, “Cephalopods”, “Crustaceans”, “Demersal Fish”, “Freshwater Fish”, “Marine Fish, Other”, “Pelagic Fish”, “Molluscs”, “Meat, Aquatic Mammals”, “Fish Meal”, “Fish Body Oil” and “Fish Liver Oil” and the market balance elements including “Production Quantity”, “Import Quantity”, “Export Quantity”, “Feed”, “Food” and “Other uses” etc.. Fish data in CAPRI used to be disaggregated into three fish groups and now are extended to six fish groups. Regarding fishmeal and fish oil, the data from FAOSTAT only includes the amount processed from fish offal and wastes. CAPRI used to take fishmeal based on FAOSTAT data as one of the protein sources used in the feed for

¹ <http://www.fao.org/faostat/en/#data/FBS>.

² <http://www.fao.org/fishery/statistics/software/fishstatj/en>.

terrestrial animals. However, fishmeal and fish oil obtained from captured fish is missing in these values, according to the FAOSTAT principle of recording products in primary product equivalents meaning in the fish sector that production, trade and demand for fishmeal from pelagic fish, for example, is not booked as fishmeal but as pelagic fish. As the fishmeal quantities reported by FAOSTAT only refer to the part produced from waste material, the globally reported production quantities are considerably falling short of the fishmeal demand of aquaculture. Therefore, we refer to the production and trade quantities of fishmeal and fish oil from FISHSTAT. FISHSTAT is a global database composed of four data sets: Global capture production (quantity), global aquaculture production (quantity and value), global commodities production and trade (quantity and value), and global production by production source (quantity). FISHSTAT provides the quantity data of fish and its processed products at country level and supplements FAOSTAT in four areas:

- Fishmeals and oils are two commodities in the set “global commodities production and trade” that are included to replace the conceptually less suitable FAOSTAT fishmeal data in the CAPRI database because of its more reasonable match with global aquaculture production data.
- The production data split into capture and aquaculture from FISHSTAT is conveniently given also by “FAOSTAT group”.
- The detailed information on species level from FISHSTAT helps to distinguish between fish for food and fish for fish meal in the demersal fish category.
- The breakdown of the freshwater and diadromous fish category by species helps to specify regional fishmeal and oil requirements according to the share of predominantly carnivore fish types.

In spite of offering a great level of detail, FISHSTAT data suffer from the lack of differentiation into several demand components such that it can only supplement, but not replace the FAOSTAT database.

In Figure 2 the integration of the two data sources in the CAPRI fish module and the interactions between fish and other agricultural markets are demonstrated. FAOSTAT provides data of the six fish groups with respect to the activity elements as shown. This

graphic illustrates the interaction between aquaculture and reduction fisheries through the fishmeal and fish oil processing from fish for feed (FEDM) and industrial and other uses (INDM) as presented. By feed conversion ratios and ingredient shares, the use of fishmeal and fish oil in feed for aquaculture is computable. Along with the increasing substitution of fishmeal and oil by crop meal and oil, the linkage between the fish sector and the agricultural sector is therefore intensifying.

In order to investigate aquaculture activities and to eliminate data inconsistencies, we calculate the share of cultured and captured fish in the total production from FISHSTAT (B1) and compute new quantities according to the production given by FAOSTAT (A1) as shown in Table 4.

Table 4 Fish activities, commodities and corresponding data sources

i = activities	j = commodities	
	(A) FAOSTAT (FAO FIPS FBS)	(B) FAO FISHSTAT
Six fish groups based on FAO categories (1)	MAPR, IMPT, EXPT, HCOM, FEDM, INDM, STCM, PCRM = FEDM + INDM $Aquaculture = AQUAshare * MAPR$, $Captured = CAPshare * MAPR$	MAPR, AQTOTL, EXOG, $AQUAshare = \frac{aquaculture}{total\ production}$, $CAPshare = \frac{captured}{total\ production}$
Fishmeal & Fish Oil (2)	MAPR, IMPT, EXPT, HCOM, FEDM, INDM, STCM, DOMM = MAPR + IMPT – EXPT, $HCOMshare = \frac{HCOM}{DOMM}$ $FEDMshare = \frac{FEDM}{DOMM}$, $INDMshare = \frac{INDM}{DOMM}$	MAPR, IMPT, EXPT, DOMM1 = MAPR + IMPT – EXPT, $HCOM = HCOMshare * DOMM1$, $FEDM = FEDMshare * DOMM1$, $INDM = INDMshare * DOMM1$

Remarks: AQTOTL: total aquaculture production, IMPT: import, EXPT: export, FEDM: feed use, INDM: other use, PRCM: processing use, HCOM: human consumption, STCM: stock change, MAPR: marketable domestic production, EXOG: captured fish

Source: Own compilation

To estimate the composition of total domestic use for feed (FEDM), human consumption (HCOM), and other uses (INDM), we compute the share of each demand

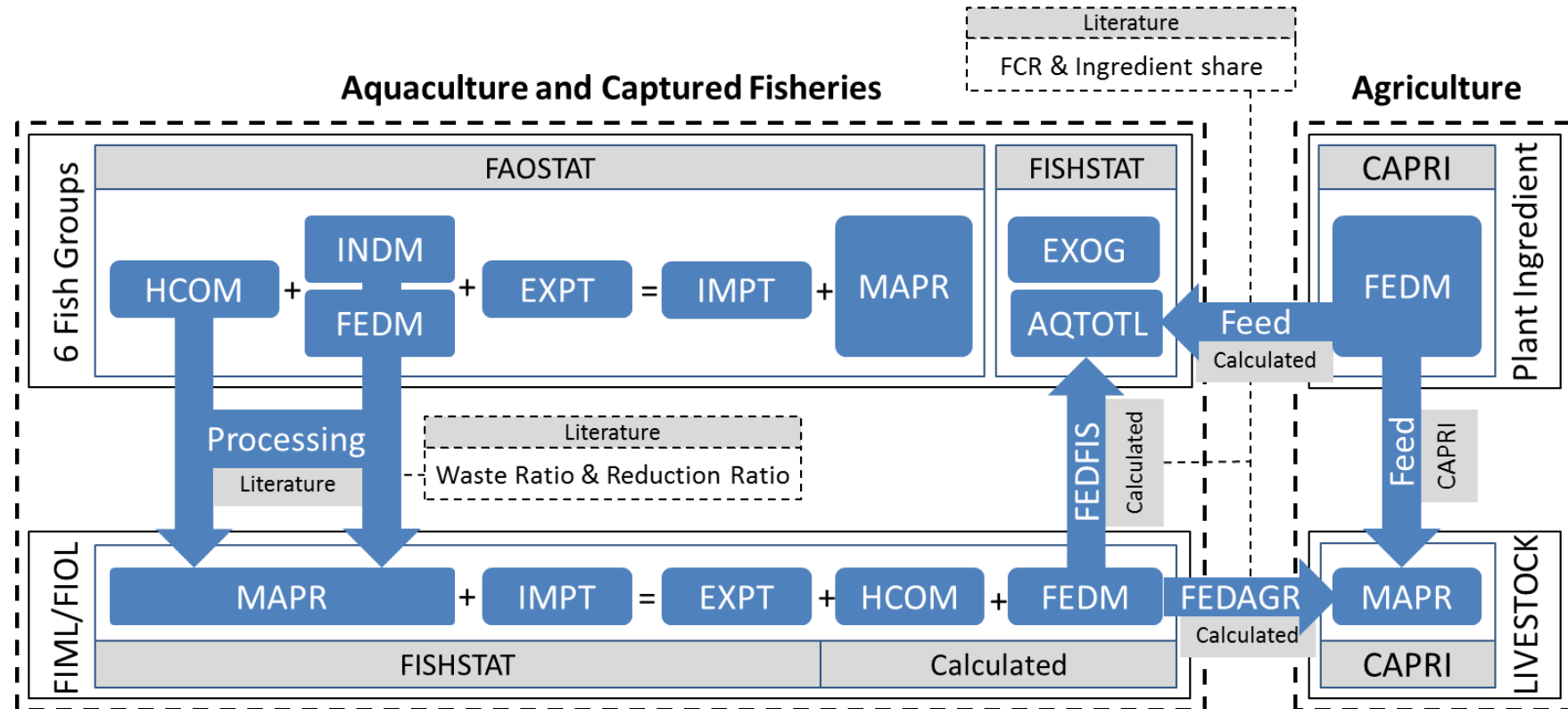
component in total domestic use (DOMM) from FAOSTAT (Table 4, A2) and multiply this with domestic use ($DOMM1 = MAPR + IMPT - EXPT$) calculated in accordance with FISHSTAT (Table 4, B2), as the latter does not offer a decomposition by demand components.

Nearly 100% of fishmeal and 90% of fish oil is used in animal feed production, of which 70% of fishmeal and 80% of fish oil are produced for aquaculture feed (Tacon and Metian, 2008). As shown in Table 4 FAOSTAT data for 2006 to 2010 is used to calculate the different demand shares. The results for fishmeal support the literature findings, revealing a share of 97% going into animal feed production. With respect to fish oil the FAOSTAT data indicates a demand share for human consumption of about 10%, for animal feed of 47% and 43% being determined for other uses. The latter two are aggregated because the assignment within the demand category ‘other use’ is unclear and commodities are indicated to be used as pet food or in tourism. This aggregation is also applied to the six fish categories. In the following, furthermore the quantity booked as “fish for feed use (FEDM)” is considered “fish for processing use (PRCM)” (for fishmeal and oil) and rebooked accordingly with breakdown to the six fish groups.

The interactions between agricultural markets, aquaculture production and capture fisheries are taken up in the CAPRI model as explained in the following. The linkage between fishmeal and fish oil production and their sources are shown in Equation 1.

The parameter $MAPR(f)$ represents the total fishmeal and fish oil domestic production in all regions over the full time period, originating from two sources. These are fish specifically used for reduction to fishmeal and fish oil ($PRCM(fg)$) and fish waste from human consumption that is partly again processed to fishmeal and oil. This quantity is derived from multiplying total human fish consumption ($HCOM(fg)$) with a waste ratio ($WR(fg)$) specific for each fish category.

Figure 2 Scheme of the CAPRI Fish Module, its linkage to the agricultural sector and data sources used



Remarks: AQTOTL: total aquaculture production, IMPT: import, EXPT: export, FEDM: feed use, INDM: other use, PRCM: processing use, HCOM: human consumption, STCM: stock change, MAPR: marketable domestic production, EXOG: captured fish, FEDFIS: feed for aquaculture, FEDAGR: feed for land animals

Source: Own illustration based on Heckelee et al., (2018)

Subsequently, the total domestic production of fishmeal and fish oil can be calculated as the sum of these two quantities over all six fish categories (fg) multiplying the corresponding reduction ratios ($RR(f)$) (Equation 1).

Equation 1

$$MAPR(f) = \sum_{fg} (PRCM(fg) + HCOM(fg) * WR(fg)) * RR(f)$$

With f = fishmeal, fish oil; fg = CRUS, MOLS, FFIS, PFIS, DFIS, OFIS

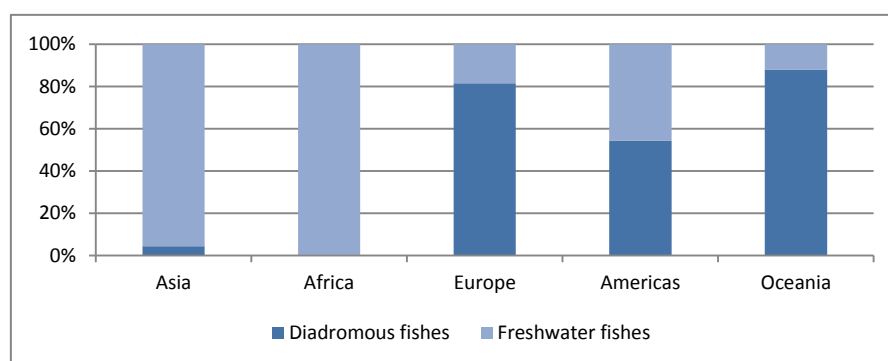
Due to diverse diet habits of the fish species in the freshwater and diadromous fish category, the structure of feed for the different fish in this group requires particular attention. Generally, the major freshwater fish species, such as carps and tilapia, on average consume rather vegetarian feed that contains plant-based ingredients up to 85% (Boyd and Polioudakis, 2006). In contrast, diadromous fish like trout and salmon demand rather carnivorous feed with a share of fishmeal and fish oil of 35% and 15% to 20%, respectively (Tacon and Metian, 2008). In Figure 3 the proportion of freshwater fish production to diadromous fish production is shown by continent in 2005. The high demand for plant-based feed ingredients of some fish species stresses once more the interdependencies of the fish and the agricultural sector.

In order to project accurate demand quantities of feed ingredients for freshwater and diadromous fish, countries are classified into three groups. These are carnivorous fish farming countries (group C) with a mainly diadromous fish production, vegetarian fish farming countries (group V) producing mostly freshwater fish species, or mixed farming regions (group M) as shown in Table 5. The classification is based on the fraction of carnivorous fish in the freshwater fish category for each country based on data from FISHSTAT (Table 5). A country that produces more than 70% of carnivorous fish is assigned to group C, with less than 30% to group V, and to group M if the carnivorous fish share lies between 30% and 70%. The introduction of the three categories allows for more accurate projections of the future demand for fishmeal, fish oil and crop ingredients by aquaculture.

As shown in Table 5, in America, the ratios of freshwater fish and diadromous fish cultures are split. Among the American countries, Brazil is specialized in freshwater

fish farming (98%) like carps which consume feed low in fishmeal and fish oil. In contrast, Chile farms only carnivorous salmonids. Most of the Asian countries focus on freshwater fish farming. However, Japan has a high diadromous fish production, and Taiwan and South Korea have an equivalent production of both (Table 5). In all African regions, freshwater fish dominate aquaculture production so that this also holds for the overall African continent. In principle, Oceania is differentiated into two regions. These are Australia and New Zealand, both dominated by a diadromous aquaculture fish production. For the analysis in CAPRI, Oceania is treated as one diadromous fish farming region.

Figure 3 Distribution of vegetarian freshwater fish and carnivorous diadromous fish at continental level (2005)



Source: FAO FISHSTAT

Table 5 Classification of countries by the share of carnivorous fish in FFIS

Group V (carnivorous fish production < 30%)	Group C (carnivorous fish production > 70%)	Group M (carnivorous fish production > 30% and < 70%)
Africa		
Asia		
Other Asian countries	Japan	Taiwan, South Korea
America		
Brazil, other American countries	Uruguay, Chile, Peru, Canada	Bolivia, Argentina
Europe		
Croatia, Hungary, Romania, Ukraine, Russian Federation, Czech Republic	Other European countries	Bulgaria, Poland, Netherlands, Germany

	Oceania	
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Source: Own compilation based on data from FAO FISHSTAT

4. Problem with available fish data

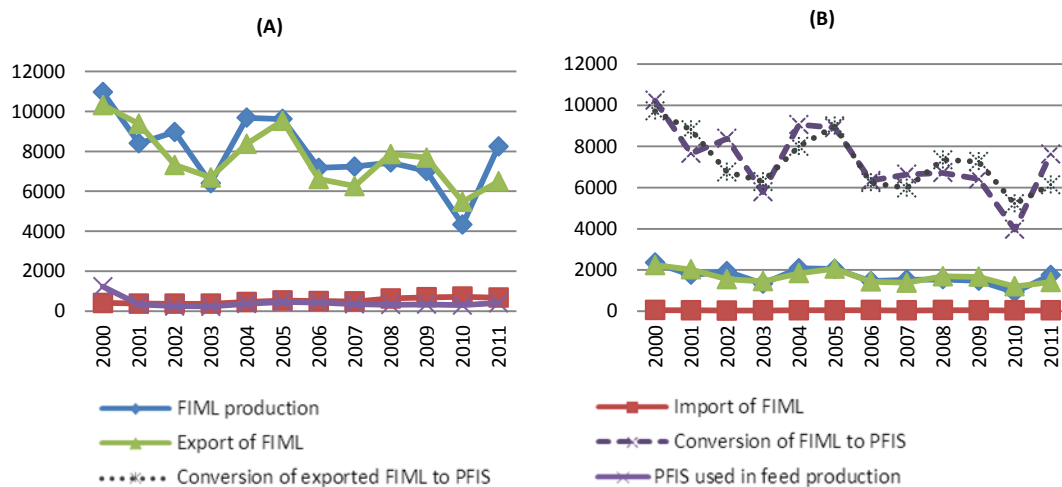
During the integration of the two data sources, we observe data gaps and inconsistencies in the given export and import quantities of each seafood category. These likely also include the information of the export and import quantities of fishmeal and fish oil.

As mentioned before FAOSTAT market balances follow accounting rules unsuitable for modelling, as large parts of fish that in fact go into the processing industry to be converted into fishmeal and fish oil are classified as exports or imports of live fish.

The data problem is exemplified for one CAPRI region covering several countries in Middle and South America (RSA) namely Peru, Ecuador, Columbia, Costa Rica, Nicaragua, Panama, El Salvador, Guatemala, Honduras, and Bermuda (Figure 4). According to the left graph (A), in the year 2010 the production and export of pelagic fish in this region amount to 10,966 thousand and 10,311 thousand tons, respectively, according to FAOSTAT. Peruvian anchovy is a crucial natural pelagic fish resource used as raw material in the fishmeal and fish oil industry in South America. Relying on the abundant Peruvian anchovy stock, this region is the biggest fishmeal and fish oil producing and exporting CAPRI region with fishmeal production and export quantities of 913 thousand and 1,199 thousand tons respectively (FISHSTAT). Converted back into live fish as shown in the right graph (B), the production of these amounts of processed fishmeal and fish oil requires 9,248 thousand tons of pelagic fish. We may conclude therefore that the export values reported by FAOSTAT for pelagic fish are unreasonably high (when taken literally as exports of fish) in some cases and incompatible with the reported fishmeal and fish oil production from FISHSTAT. We therefore adopt the export values for fishmeal and fish oil from FISHSTAT and combine those with FAOSTAT fish market balance data in CAPRI. However, to avoid a double counting of trade in fishmeal (and oil), we revise the FAOSTAT fish export quantities as explained in the following chapter.

Moreover, two inconsistencies are concerned to be consolidated. First, a reassignment of fishmeal and fish oil for animal feed is conducted. The feed quantity given by FAOSTAT is based on the six fish categories which are directly assigned to feed use. Fish protein though is generally included in the feed in the form of fishmeal and fish oil. Hence, we remove the “feed use” quantities and rebook them to “processing use” to represent the fish used as raw material to process fishmeal and fish oil. In the case of the considered region RSA, 9,248 thousand tons are assigned to the processing use of pelagic fish. A second inconsistency stems from the integration of two data sources. For example, regarding the fishmeal and fish oil markets in the Netherlands in the year 2008, the data from FAOSTAT indicates that 92 thousand tons of pelagic fish are used for feed. This indicates that in the Netherlands some production of fishmeal from pelagic fish is likely taking place. However, FISHSTAT shows zero production of fishmeal and fish oil in the Netherlands, which is supported by Aidos et al. (2000). This is contradicting to the stated amounts of fish used in feed production in FAOSTAT. A similar data situation is found for Germany, as data from FAOSTAT shows a great amount of fishmeal produced locally, which contradicts the zero production of fishmeal given in FISHSTAT. In such cases where FISHSTAT reports zero fishmeal production but FAOSTAT gives nonzero use of fish for reduction, we give priority to FISHSTAT and rebook the quantities reported as feed use by FAOSTAT to human consumption.

Figure 4 Consolidation of fish data of CAPRI region RSA (thousand tons)



Source: Own illustration based on CAPRI database

5. Data correction

In order to correct the identified problems in the data obtained from FAO, several steps are undertaken to derive a consolidated data set that is suitable for fish sector modelling. In the following it is explained, how fish are correctly assigned to the processing industry while avoiding double counting of fishmeal and fish oil trade quantities. In the second step, a minimization of normalized least squares model is applied. Like this, the two FAO data sources are integrated, data gaps are filled and market balances can be closed. The whole procedure is applied to all regions over the full time period from 1990 to 2011 in CAPRI.

As aforementioned, fishmeal and fish oil are two substantial inputs for the aquaculture industry. The raw materials for their production are mainly small pelagic fish. Péron et al. (2010) list also two demersal species (Norway pout and blue whiting) dominating in fishmeal and fish oil production. These two species are referred to in the numerator *DFIS used for FIML FIOL* in Equation 2. Within the demersal fish group only these two fish species require some data corrections. Furthermore the same correction is applied to the whole pelagic fish category.

We first convert the traded fishmeal and fish oil quantities given from FISHSTAT into equivalent live weight to obtain the total trade quantity that needs to be removed from the reported FAOSTAT trade of live fish. This reported trade that shall be corrected, is denominated as *Total raw materials of FIML FIOL(t0)* in Equation 2 and represents the sum of the traded pelagic fish and the fraction of demersal fish usable as raw material in the fishmeal and fish oil production. Taking the ratio of the fishmeal trade expressed in live fish equivalent to the total trade “inflated” by this fishmeal trade gives a correction factor that may be applied to remove the fish meal component, at least approximately, from the reported trade in pelagic and “fish meal suitable” demersal fish (Equation 3 and Equation 4).

Note that we also need to add the amount of fish deducted from exports back to the processing industry (*PRCM*) of the corresponding seafood group. The respective captured forage fish are first processed and then exported or imported in the form of

fishmeal and fish oil. With respect to the imports, the imported amounts are deducted from the processing as these might be overstated otherwise (Equation 5).

Equation 2

$$\text{Total raw materials of FIML FIOL}(t_0) = PFIS(t_0) + DFIS(t_0) * \frac{DFIS \text{ used for FIML FIOL}}{\text{total DFIS production}}$$

With t_0 = original export quantity (EXPT), original import quantity (IMPT)

Equation 3

$$PFIS(t_1) = PFIS(t_0) * (1 - \frac{PFIS(t_0)/RR(FIML)}{\text{Total raw materials of FIML FIOL}(t_0)})$$

With t_1 = consolidated export (EXPE), consolidated import (IMPE)

Equation 4

$$DFIS(t_1) = DFIS(t_0) - DFIS(t_0) * \frac{DFIS \text{ used for FIML FIOL}}{\text{total DFIS production}}$$

Equation 5

$$PRCM1(g) = PRCM0(g) + ((EXPT(g) - IMPT(g)) - (EXPE(g) - IMPE(g)))$$

With g = pelagic fish, demersal fish

The previous rebooking of fishmeal trade but also various other inconsistencies with technical constraints (detailed below) relationships are the reason why the establishment of a consistent data set requires a flexible procedure that is applicable to global time series at the country level. In the study at hand a minimization of normalized least squares model is applied (Equation 6).

Equation 6

$$\text{Min } v_Obj = \sum_{i,j} (v_Data_{i,j} - p_Data_{i,j})^2 \cdot wgt_{i,j}$$

s.t

$$v_Data_{i,j}^{LO} \leq v_Data_{i,j} \leq v_Data_{i,j}^{UP}$$

With i = aquaculture and fishing activities (Table8 in the Annexes),

and $j = \text{fish and agricultural commodities (Table9 in the Annexes)}$

In the technical implementation there is also a need for constant region specific scaling factors to avoid numerical problems but these are just side remarks in a presentation of the basic data consolidation methodology.

In the objective (Equation 6) we see that the squared deviations of the final solution values $v_Data_{i,j}$, with i and j representing aquaculture or fishing related items and fish and agricultural commodities, respectively from their initial values $p_Data_{i,j}$ which have gaps or inconsistencies.

Gaps and inconsistencies are removed by additional restrictions (Equation 7 to Equation 14) for the estimation process. A list of the long texts of the following abbreviated subscripts is given in Table8 and Table9 in the Annexes.

In the equation system feed use has to be consistent with the crop ingredients, fishmeal and fish oil demanded for fish feed. Therefore Equation 7 requires that the feed conversion ratio level for each fish (fg), $FEED(fg)$, so the total feed quantity used to produce one ton of fish equals the sum of feed inputs of all feed ingredients used by this fish type:

Equation 7

$$FEED(fg) = \sum_d Ingredient\ Use(d, fg)$$

With $d = \text{fishmeal, fish oil, soya cake, soya oil, corn, wheat, rapeseed oil, sunflower oil, sunflower oil, barley, paddy rice, rape seed, rye and meslin and other animal waste use in fish feed}$

In Equation 8 $Ingredient\ Use(d, fg)$ represents the use of each feed ingredient per ton of produced fish which is multiplied with the (production) level of each respective fish type. This gives the total quantity of feed ingredients demanded by each fish type. The quantity of total feed demanded by aquaculture in one region, $FEDFIS(d)$, is the sum of these over all the fish types.

Equation 8

$$FEDFIS(d) = \sum_{fg} Ingredient\ Use(d, fg) \cdot AQTOTL(fg)$$

Total use of fishmeal, fish oil and crops for overall feed production is determined by the sum of the demanded ingredients for aquaculture feed (*FEDFIS*) as well as for land animal feed (*FEDAGR*) in one region as shown in Equation 9.

Equation 9

$$FEDM(d) = FEDAGR(d) + FEDFIS(d)$$

The total production of seafood in each category is the sum of animals caught by fisheries (*EXOG(fg)*) and those farmed in aquaculture production systems (*AQTOTL(fg)*) (Equation 10). The former data is exogenously given.

Equation 10

$$MAPR(fg) = AQTOTL(fg) + EXOG(fg)$$

The market balance is shown in Equation 11. The sum of production (*MAPR*) and imports (*IMPT*) of each fish commodity must equal the sum of all demand components i.e. the respective stock changes (*STCM*), exports (*EXPT*), human consumption (*HCOM*), feed use (*FEDM*), processing (*PRCM*) and other uses (*INDM*). Frequently, some components are zero like human consumption for fishmeal and feed use for fresh fish.

Equation 11

$$MAPR(j) + IMPT(j) = STCM(j) + EXPT(j) + HCOM(j) + FEDM(j) + PRCM(j) + INDM(j)$$

Fishmeal and fish oil are processed products obtained from fresh fish (typically from capture) as well as based on fish waste from human food consumption. The variable *PRDHCO(f)* represents the production of fishmeal or fish oil from human consumption waste (Equation 12). First we multiply the human consumption quantity of each fish category with the waste ratio to calculate the possible amount of food fish waste that might be used in fishmeal and fish oil production. And then we multiply the computed

quantity with $RR(f)$ which is the reduction ratio to obtain the final quantity of fishmeal or fish oil.

Equation 12

$$PRDHCO(f) = \sum_{fg} HCOM(fg) \cdot WR(fg) \cdot RR(f)$$

With $f = \text{fishmeal, fish oil}$

The major source of raw materials for fishmeal and fish oil production is the caught small pelagic forage fish in the reduction fisheries as aforementioned. Therefore $PRDRED(f)$ refers to the production quantity of fishmeal or fish oil from the reduction fisheries as shown in Equation 13.

Equation 13

$$PRDRED(f) = \sum_{fg} PRCM(fg) \cdot RR(f)$$

The total production of fishmeal and fish oil is derived from the aggregation of sources, fish from human food waste and fish from reduction fisheries (Equation 14).

Equation 14

$$MAPR(f) = PRDHCO(f) + PRDRED(f)$$

To develop a consistent time series data set on the yield of fish, fishmeal and fish oil, feed production and market balances, we assign weights and bounds to reduce the need for manual data corrections. We choose higher weights and tighter bounds for statistical data considered reliable; say the production of fishmeal from FISHSTAT. By contrast we apply lower weights for items with higher uncertainties like the demand composition for fishmeal and oil which had been estimated based on FAOSTAT shares applied to a FISHSTAT residual. The same idea is applied to technical coefficients taken from the literature which may be subject to fluctuations depending on the underlying methodology and the fish species investigated. The data consolidation procedure is applicable also to other periods of time (hence usable for next year's database update) or

to another disaggregation of the global fish sector to regions and seafood items (hence usable also for other modelling systems).

6. Consolidated data (in comparison to original data)

We only apply the rebooking procedure explained in Section 5 to import and export of pelagic and demersal fish because these two groups include the most important fish species used as raw material in the fish processing industry. However, we consider the other fish (except for mollusks) also as raw material for fishmeal and fish oil production. These fish categories contribute comparably little to the fish used for animal feed and detailed information about their usage in feed is scarce. Therefore we simply rebook the share of fish that is reported as feed use by FAOSTAT to processing use for these fish categories, without further revision of trade data. The rebooking reflects that any fish used as feed is converted to fishmeal and fish oil first.

As shown in Table 6 Peru is the biggest producer as well as the biggest exporter of both fishmeal and fish oil in the world, and Chile is the second biggest producer and exporter of fishmeal based on FISHSTAT. China is the largest importer of fishmeal.

Table 6 Fishmeal and fish oil quantities (2006-2010 average) of the most relevant producing and trading countries (thousand tons)

	Producer		Exporter		Importer	
	FIML	FIOL	FIML	FIOL	FIML	FIOL
1	Peru	Peru	Peru	Peru	China	Norway
	1,258	269	1,371	287	1,131	222
2	Chile	Chile	Chile	Denmark	Japan	Denmark
	624	166	485	140	336	128
3	Thailand	Denmark	Germany	Chile	Norway	Chile
	453	110	214	69	242	72
4	China	United States of America	Denmark	United States of America	Germany	China
	447	72	205	61	230	45

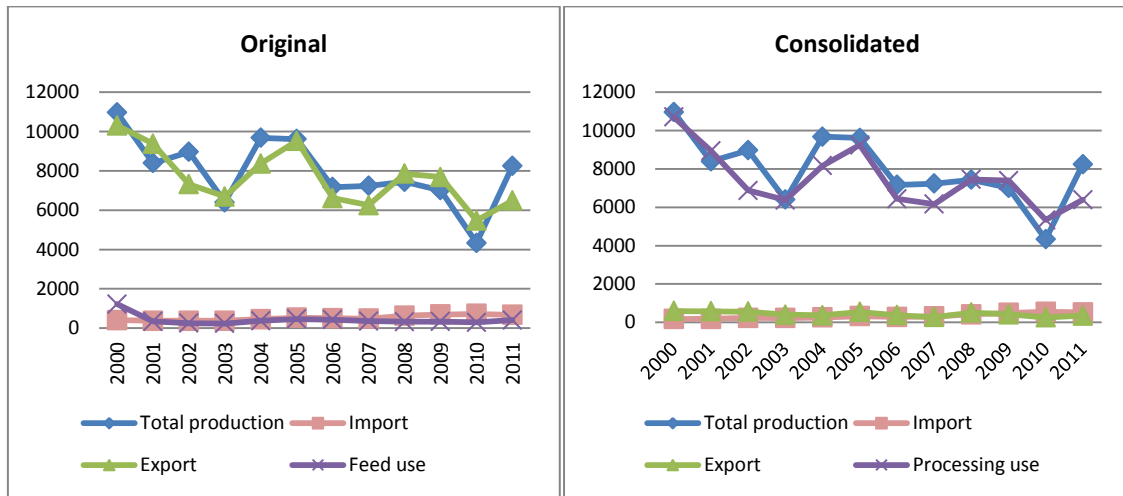
5	Denmark	Japan	Iceland	Iceland	Taiwan	Canada
	241	63	114	60	172	40

Source: FAO FISHSTAT

The effects of the data correction are particularly strong for big exporters and importers including Peru, Chile, China, Iceland and Norway. The correction of demersal fish data shows mainly an impact for countries that capture Norway pouts and blue whiting such as Denmark, Iceland, Norway and Faeroe Islands. We here present the comparison of the original data and consolidated results selected countries namely the region RSA including Peru and other Middle and South American countries, China, Denmark and Iceland.

In Figure 5 the original FAOSTAT data for pelagic fish production, import, export and feed use in the region RSA is contrasted to the data consolidated by the CAPRI system. As shown in the two graphs, the export quantity of live fish drops dramatically due to the deduction of the high export quantity of fishmeal while the import quantity only moves slightly downwards. For instance, in 2005, the exports of pelagic fish stated by FAOSTAT add up to 9,529 thousand tons, and the value drops to 544 thousand tons after the consolidation. In addition, the given feed use from the original data is replaced by processing use. Combining this replacement and the re-assignment of traded live fish to processed fish products, the consolidated processing use in the RSA region amounts to 9,248 thousand tons in 2005 whereas the original feed use is quantified with only 464 thousand tons by FAOSTAT.

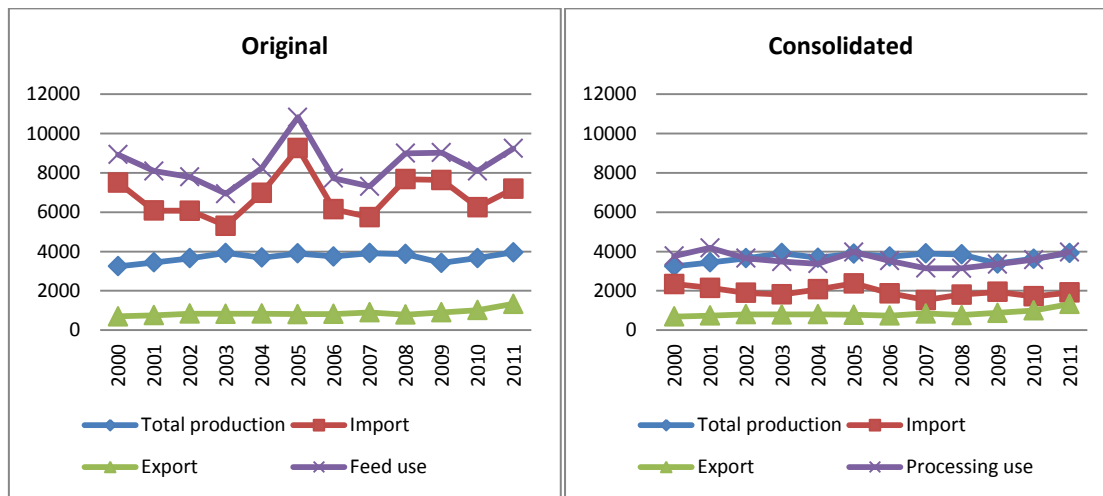
Figure 5 Original and consolidated fish data of region RSA (thousand tons)



Source: Own illustration based on CAPRI database

China has not only the biggest fish production in the world but also a substantial amount of fishmeal production. Furthermore, it is also the biggest fishmeal importing country. Figure 6 shows the data comparison for China. Although China has a large pelagic fish production, it also heavily relies on imports to meet its high demand of feed use. In 2005, the import, export and feed use of pelagic fish of China amount to 9,257, 810 and 10,829 thousand tons, respectively. Distinguished from the previous countries, its imports show a strong decrease from 9,257 to 2,375 thousand tons, and its exports only slightly drop from 810 to 784 thousand tons due to China's high imports and low exports of fishmeal. Feed use in China in the year 2005 is reduced from 10,829 thousand tons and converted to a processing use of only 3,974 thousand tons.

Figure 6 Original and consolidated fish data of China (thousand tons)

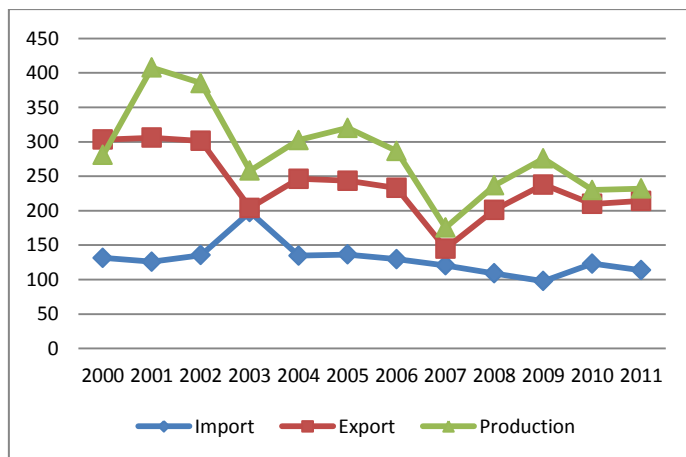


Source: Own illustration based on CAPRI database

Denmark is the fifth biggest producer of fishmeal and the second biggest producer of fish oil that captures a great amount of pelagic forage fish and the two demersal fish species, Norway pout and Blue whiting, which are used as raw material in its fishmeal and fish oil production industry. We therefore demonstrate the comparison of the data from FAOSTAT and the consolidated data from CAPRI for both, pelagic and demersal fish. The same procedure also applies to a couple of countries that capture the two demersal fish such as Iceland and Norway. Figure 8 shows the time series of the data comparison for pelagic fish produced and traded in Denmark. In 2005, the import, export and feed use of pelagic fish in Denmark are 857, 1,229 and 108 thousand tons, respectively. After the consolidation, import and export values are adjusted to 294 and 232 thousand tons, and feed use is replaced by a processing use of 550 thousand tons. Moreover, an interesting phenomenon is found in the graphs of consolidated pelagic fish and demersal fish of Denmark in 2003 and 2007. Regarding the consolidated data for pelagic fish, the export is larger than processing use although the gap is small, which differs from the rest of the shown time period. We conclude that this influence comes from the fishmeal market of Denmark which is presented in Figure 7. The absolute values of net trade of fishmeal in the two years are particularly small. The import and export therefore move downwards to a similar level. Thus, the consolidated trade data of fish follows the trend of the trade data of fishmeal. Note that the original data for the

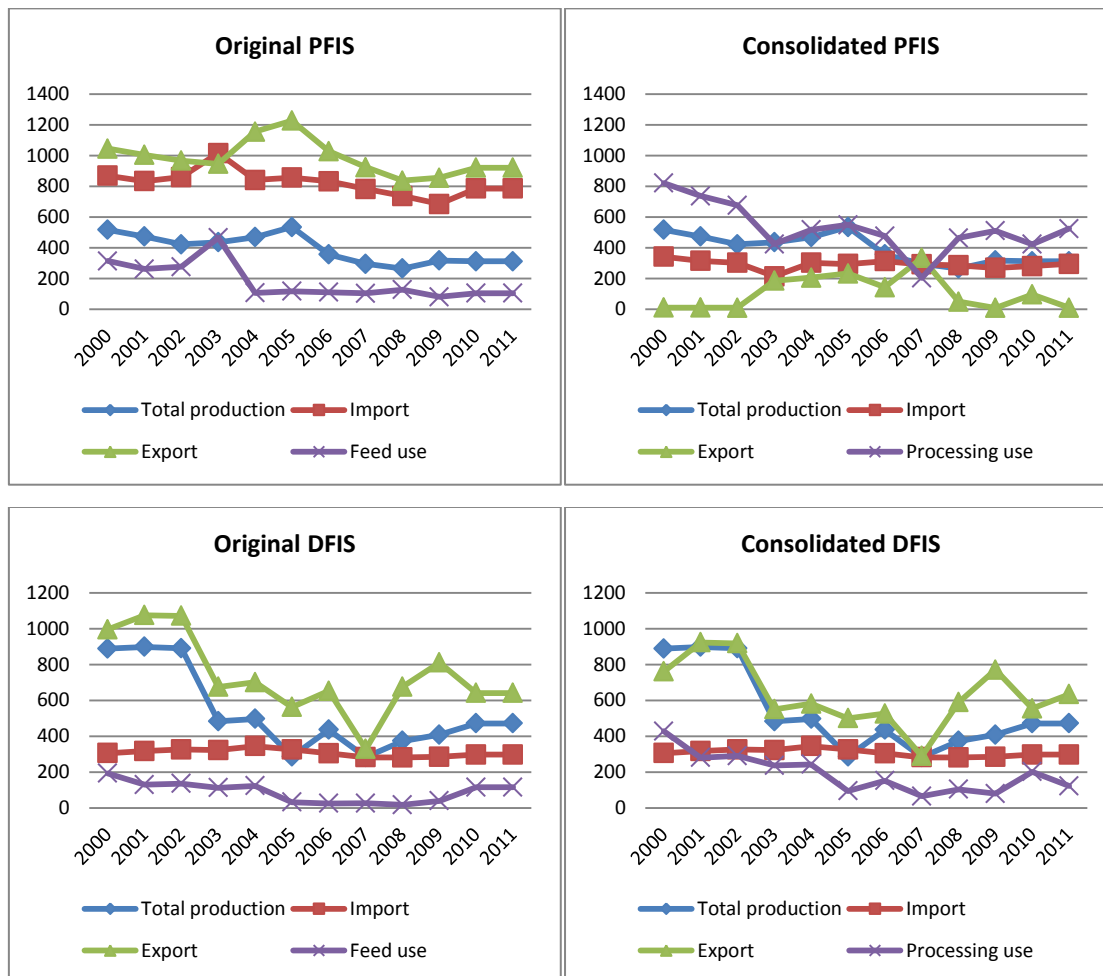
pelagic fish market show hardly any relationship to the fishmeal market even though pelagic fish are the major input used in fishmeal production. As this relationship is present after the data correction, this indicates the data consistency gain from our approach. The movement of the values with respect to demersal is not comparably strong for Denmark. One reason is that the two demersal species used for fishmeal and fish oil production account for only 14% of the total demersal fish production. The adjustment gains for demersal fish data are more explicit for Iceland as shown in Figure 9. The reason is that this country is the fifth biggest fishmeal and fish oil exporting country whose landings of Norway pout and blue whiting account for 35% of the total demersal fish production.

Figure 7 Production and trade quantity of fishmeal of Denmark (thousand tons)



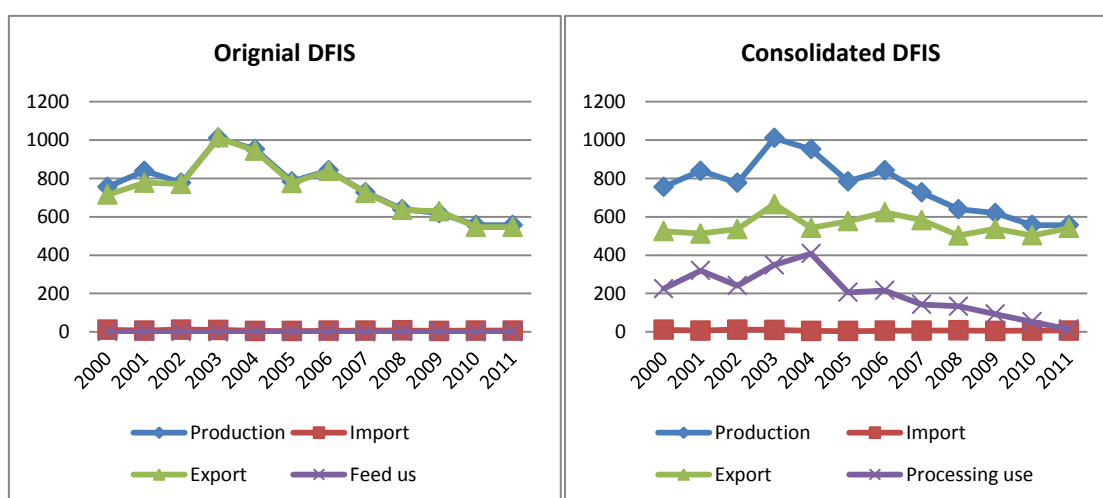
Source: Own illustration based on FAOSTAT database

Figure 8 Original and consolidated fish data of Denmark (thousand tons)



Source: Own illustration based on CAPRI database

Figure 9 Original and consolidated fish data of Iceland (thousand tons)



Source: Own illustration based on CAPRI database

In Table 7, the original data of fish for feed use (1) and the consolidated data of fish for processing use (2) are shown for the top 5 fishmeal producing CAPRI regions for the year 2005. These values are further used as denominators in the computation of reduction ratios. The fishmeal production based on FISHSTAT (3) is referred to as numerator. We compute the two reduction ratios based on the original data (RR(A)) and based on the consolidated data (RR(B)) and compare these to the CAPRI reduction ratio (RR(C)) and the reduction ratios calculated based on Péron et al. (2010) (RR(D)). Table 7, shows the improved accuracy of the conversion between fish and fishmeal due to the consolidation in contrast to the original fish for feed use data. According to the original data, 464 thousand tons of pelagic fish are used to produce 2,048 thousand tons of fishmeal with the reduction ratio of 4.41 in the region RSA. This value is contested and contradicts the reduction ratios stated by Msangi et al. (2013), Péron et al. (2010), and Tacon and Metian (2008). The computed ratio based on the consolidated quantities of processing use is comparably close to the references. Identically, the gaps between the computed reduction ratios and the reference values are reduced for Chile, China and Denmark after the consolidation. Thailand is an extreme case with a reduction ratio of 1.95 that indicates that the fishmeal production of 473 thousand tons would require only 243 thousand tons of pelagic fish. This implies that likely other raw materials are used to satisfy the needs of the fishmeal and fish oil industry, and the gap is likely filled with trash fish (Péron et al., 2010). The data consolidating procedures therefore contribute to filling the gaps in the CAPRI database. The results support that the fish, fishmeal and fish oil markets are better integrated in the CAPRI database after the data consolidation.

Table 7 Comparison of reduction ratios computed based on original and consolidated database and from the literature (Year 2005)

	FAOSTAT Original feed use (1)	RR(A) $\frac{(3)}{(1)}$	CAPRI Consolidated Processing use (2)	RR(B) $\frac{(3)}{(2)}$	FISHSTAT Fishmeal production (3)	RR(C)	RR(D)
RSA	464	4.41	9,248	0.22	2,048	0.23	0.22
Chile	911	0.95	3,939	0.22	866	0.23	0.24
Thailand	200	2.37	243	1.95	473	0.23	1.05
China	10,829	0.04	3,974	0.11	455	0.23	0.37
Denmark (PFIS+DFIS)	140	2.29	644	0.50	320	0.23	0.37

Remarks: RR(A) = Fishmeal production (3) / Original feed use (1); RR(B) = Fishmeal production (3) / Consolidated Processing use (2); RR(C): Reduction ratios used in CAPRI; RR(D): Reduction ratios calculated based on Péron et al., (2010)

Source: Own compilation

7. Concluding remarks

A detailed description of the data sources used as well as of possible applications and scenario simulations is provided for the IMPACT model (Msangi et al., 2013). However, the problems we found during the process of our data integration have not been mentioned or explained in the IMPACT documentation, presumably because their close interactions with the FAO permitted to rely on a pre-consolidated database incorporating personalized experience of sector experts. In the study at hand the difficulties we faced in the modeling work based on published data alone are addressed in a generic data consolidation strategy applicable to other data needs and raw data availabilities as well. Although there are still elements missing in the integrated time series database, the preliminary consolidation does help to eliminate double counting problems, to reflect the relationships between fish, fishmeal and fish oil markets and to capture the flow from fish to feed and vice versa correctly. The performed data work does not only provide a comprehensive database but it reveals also a consistent data structure of fish and other relevant markets and eases the data integration between fish and other sectors in CAPRI.

Although this study has answered the objectives we proposed in the beginning, there still exist some data issues that have not been addressed. First, the classification of fish into the six groups in CAPRI does not sufficiently explain the complex diet components and the human consumption preferences. In particular, freshwater and diadromous fish, which include both low-value herbivores and high-value carnivores cannot be sufficiently distinguished. Second, nearly all pelagic fish are considered as raw material for the fishmeal and fish oil industry in this study. However, high-value fish like a variety of Tuna species, is grouped to pelagic fish but is too valuable to be used to produce animal feed. This shortcoming has been neglected so far. Third, our data consolidation is not yet including bilateral trade flow data as this would add another layer of complexity that has been deferred to the future. Finally, it has been shown in this study how we generate the data correction for quantity data. However, matching with the quantity relationships in the fish sector there are requirements for suitable price and processing margin data. These have not been imposed at this stage but need to be tackled before proceeding to applications of the extended CAPRI system to fish sector issues that are increasingly gaining weight in the global bio-economy.

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9. Annexes

Aquaculture and fishing related activities and fish and agricultural commodities in the fish module of CAPRI

Table 8

<i>i</i>													
AQTOTL	IMPT	EXPT	FEDM	INDM	PRCM	HCOM	MAPR	EXOG	STCM	FEDAGR	FEDFIS	YLDFML	YLDFOL
AQCRUS	AQMOLS	AQFFIS	AQPFID	AQDFIS	AQOFIS	PrdHCO	PrdRED	YldHCO					

AQTOTL: total aquaculture production, IMPT: import, EXPT: export, FEDM: feed use, INDM: other use, PRCM: processing, HCOM: human consumption, STCM: stock change, FEDAGR: feed use for agriculture, FEDFIS: feed use for aquaculture, PrdHCO: production of FIML and FIOL from human consumption waste, PrdRED: production of FIML and FIOL from reduction fisheries, YldHCOM: yield ratios of production of FIML and FIOL from human consumption waste, MAPR: domestic production, EXOG: captured fisheries, YldFML and YldFOL: yield ratios of production of FIML and FIOL from reduction fisheries

Table 9

<i>j</i>																				
<i>fg</i>						<i>d</i>														
		<i>g</i>				<i>f</i>														
CRUS	MOLS	FFIS	PFIS	DIFS	OFIS	FIML	FIOL	SOYC	MAIZ	WHEA	RYEM	BARL	OATS	PARI	RAPE	SUNF	RAPO	SUNO	SOYO	FIOT

CRUS: crustaceans, MOLS: mollusks, FFIS: freshwater and diadromous fish, PFIS: pelagic fish, DIFS: demersal fish, OFIS: other marine fish, SOYC: soya cake, SOYO: soya oil, MAINZ: corn, WHEA: wheat, RAPO: rapeseed oil, SUNF: sunflower oil, SUNO: sunflower oil, BARL: barley, RARI: paddy rice, RAPE: rape seed, RYEM: rye and meslin, FIOT: other animal waste use in fish feed