OceanCanada Partnership

Working Paper Series

Working Paper #2017 - 02

Ex-vessel fish price database: disaggregating prices for low-priced species from reduction fisheries

Travis C. Tai, Tim Cashion, Vicky W. Y. Lam, Wilf Swartz and U. Rashid Sumaila

Year: 2017

Email: t.tai@oceans.ubc.ca

This working paper is made available by *OceanCanada*
University of British Columbia, Vancouver, BC, V6T 1Z4, Canada.

OceanCanada is generously supported by SSHRC Partnership Grant 895-2013-1009.

Ex-vessel fish price database: disaggregating prices for low-priced species from reduction fisheries

Travis C. Tai[a,b,*], Tim Cashion[c], Vicky W. Y. Lam[c,d], Wilf Swartz[d] and U. Rashid Sumaila[a,b]

a. *OceanCanada* Partnership, Institute for the Oceans and Fisheries, The University of British Columbia, Vancouver, B.C., Canada V6T 1Z4
b. Fisheries Economics Research Unit and Global Fisheries Cluster, Institute for the Oceans and Fisheries, The University of British Columbia, Vancouver, B.C., Canada V6T 1Z4
c. *Sea Around Us* and Global Fisheries Cluster, Institute for the Oceans and Fisheries, The University of British Columbia, Vancouver, B.C., Canada V6T 1Z4
d. Nippon Foundation-Nereus Program, Institute for the Oceans and Fisheries, The University of British Columbia, Vancouver, B.C., Canada V6T 1Z4

* Corresponding author at: Institute for the Oceans and Fisheries, The University of British Columbia, Vancouver, B.C., Canada V6T 1Z4

E-mail addresses: ttai2@alumni.uwo.ca (T.C. Tai), t.cashion@oceans.ubc.ca (T. Cashion), v.lam@oceans.ubc.ca (V.W.Y. Lam), w.swartz@oceans.ubc.ca (W. Swartz), r.sumaila@oceans.ubc.ca (U.R. Sumaila).

This paper has not been submitted elsewhere in identical or similar form, nor will it be during the first three months after its submission to the publisher.

ABSTRACT

Ex-vessel fish prices are essential for comprehensive fisheries management and socioeconomic analyses for fisheries science. In this paper, we reconstructed a global ex-vessel price database with the following areas of improvement: 1) compiling reported prices explicitly listed as 'for reduction to fishmeal and fish oil' to estimate prices separately for catches destined for fishmeal and fish oil production, and other non-direct human consumption purposes; 2) including uncertainty estimates for each price estimation; and 3) increasing the number of input data and the number of price estimates to match the reconstructed *Sea Around Us* catch database. Our primary focus was to address this first area of improvement as ex-vessel prices for catches destined for non-direct human consumption purposes were substantially overestimated, especially in countries with large reduction fisheries. For example in Peru, 2010 landed values were estimated as 3.8 billion real 2010 USD when using separate prices for reduction fisheries, compared with 5.8 billion using previous methods. This has significant global and country-specific impacts on economic trends over time.

Keywords: Catch destination; fisheries products; fishmeal; fish oil; forage fisheries; landed value; reduction fisheries.

Abbreviations: Price DB, Global Marine Ex-Vessel Fish Price Database; SAU, *Sea Around Us*; DHC, direct human consumption; FMFO, fishmeal and fish oil; PPP, purchasing power parity.

1 INTRODUCTION

Initial construction of a global marine ex-vessel fish price database (hereon after referred to as the Price DB) by Sumaila et al. (2007) was to address the lack of appropriate information required to sustainably manage natural resources, as prices paid to fishers is an integral piece of information since it is a main determinant of fishing behaviour. Ex-vessel prices are the prices that fishers receive directly for their catch, or the price at which the catch is sold when it first enters the supply chain. Therefore, in order to effectively manage the sustainable use of fisheries resources, managers and policymakers need reliable information on ex-vessel prices. The purpose of such a database is to provide ex-vessel prices for fisheries scientists to conduct socioeconomic analyses at various spatial scales—i.e., global, regional, and national-scale analyses. Here, we present an updated version of the database with major improvements by incorporating new estimates for low-priced species caught by reduction fisheries.

The first construction of the Price DB provided a complementary list of fish and market specific ex-vessel prices for each recorded catch in the *Sea Around Us* (SAU) catch database (Watson et al. 2004). It involved collecting data from widely scattered national and regional statistical reports from published and grey literature (e.g., governmental agencies, websites). Sumaila et al. (2007) amassed over 30,000 records of reported ex-vessel prices, but could only directly assign a price to 18% of total tonnage landed from the SAU catch database. They devised a rule-based approach to estimate missing prices, using a combination of various assumptions to relate fish prices across taxa, countries, and years. Such an extensive database, as they first noted, requires continuous updates over time for both the input data (e.g., increasing records of reported ex-vessel prices and increasing the diversity and evenness of the country sources for the data) and price estimation methodologies (i.e., revising the underlying assumptions to provide more accurate estimates).

The Price DB was next updated by Swartz et al. (2013) to address various limitations with the methodologies for estimating ex-vessel prices. For example, the rule-based approach could match prices from one species to a profoundly different species (e.g., from herring to tuna) in countries with few reported ex-vessel prices. Additionally, price estimates were also derived from data across multiple years, failing to account for inter-annual differences in market prices. To address these concerns, Swartz et al. (2013) devised a methodology to estimate ex-vessel prices using the country-product-dummy model (Summers 1973), a multilateral method used by the International Comparison Programme to deal with incomplete matrices and estimate price level and missing commodity prices. The country-product-dummy model addresses year-specific differences in market prices and prioritizes taxonomy for price estimation, where estimates are derived from price data sourced from other countries.

The Price DB has contributed to recent global and regional fisheries economic analyses (e.g., Börger et al., 2014; Nunoo et al., 2014; Teh and Sumaila, 2015), which underscores the importance of providing updated and accurate ex-vessel prices for research related to fisheries management and policy. First, we address a major concern identified by Swartz et al. (2013) where prices for low-value fishes destined for reduction were not distinguished from fishes for human consumption and thus were likely overestimated. We constructed a separate database of ex-vessel prices of fisheries catches destined for purposes other than human consumption. These price estimates are a result of the work of a recent effort to disaggregate catches by product usage: direct human consumption (DHC), fishmeal and fish oil (FMFO) production, and other uses including bait, direct feeding, and industrial uses (Cashion et al. 2017). Together, fish destined for FMFO and other uses are some of the largest fisheries globally in terms of catch in weight, such as the Peruvian anchoveta fishery, and account for approximately 20 million tonnes of annual landings presently (Pauly and Zeller 2016). While the ten largest taxa for FMFO account for 77% of landings destined for this purpose historically, there is a growing diversity of species used for FMFO and especially for direct feed in aquaculture and thus accounting for this diversity of end uses and prices is an important development (Cashion et al. 2017).

Aquaculture remains one of the largest consumers of global fishmeal (68%) and fish oil (89%) products (Tacon and Metian 2015). However, there is a growing trend to use alternative sources of feed such as soy protein (Naylor et al. 2009; Salze et al. 2010), and the proportion of catch to FMFO production has decreased in some of the major reduction fisheries (e.g. Christensen *et al.*, 2014). With global fish stocks in decline (Srinivasan et al. 2010; Pauly and Zeller 2016), we may expect changes in supply and demand of reduction fisheries and thus an effect on prices and other substitutable products. Further, rising costs of FMFO feed may support the shift to more ecological and economic plant-based feeds (Tacon and Metian 2008; Naylor et al. 2009; Pikitch et al. 2014).

We further updated the Price DB by providing measures of uncertainty, a valuable addition for researchers looking to use the price database. We were able to revise the use of the country-product-dummy model to provide uncertainty estimates, an important application overlooked by Swartz *et al.* (2013). Other updates included increasing the number of input reported ex-vessel price records and extending the database to 2010 to match the SAU catch database. In addition to the extension of catch records from 2007-2010, the SAU catch database has gone through major reconstruction efforts and includes 2.5 times more records of unique taxon-country-year marine fisheries catch than the previous version of the Price DB (Pauly and Zeller 2016).

2 METHODS

2.1 Data collection

The first step in our data collection effort was to identify additional price data, and obtain updated versions from many of the same sources used by Sumaila et al. (2007) and Swartz et al. (2013). We sourced data from governmental agencies, web sites, published and grey literature, and contacted partners around the world who helped locate data in their particular regions. Ex-vessel prices were either explicitly reported or calculated from reported landed values and landings. Over 60,000 reported prices were collected spanning the years from 1950 to 2010 (Table S1 and S2). We filtered out the top 0.5% of data to remove any extremely high reported prices (exceeding 38,000 real 2010 USD tonne^{-1}) that would interfere with the estimation model, and prices that were calculated to be \$0 tonne^{-1} to exclude erroneous price reports—in many instances landed value was recorded as $0 and thus a price of $0 tonne^{-1}. In total, less than 500 reported price records were removed on these premises.

Reported ex-vessel prices of fish destined for non-DHC uses were collected from similar sources and many reports specifically on FMFO production. Reported prices were explicitly listed as for 'reduction to fishmeal and fish oil'. We attempted to find reported prices covering the years from 1950 to 2010 on major reduction taxa and taxa used for direct feed in aquaculture. We estimated prices of taxa by applying the reported price of 'trash fish' to known taxa used for this purpose in the reporting country (Cashion 2016). We collected a total of over 2,600 prices of fish for non-DHC uses providing adequate regional, temporal, and taxonomic coverage of major reduction species and taxa used for other non-DHC uses (Table S1 and S2). Again, we filtered out the top 0.5% of data to remove extremely high reported prices (exceeding 3,280 real 2010 USD tonne^{-1}) and any prices calculated to be $0 tonne^{-1}. Fourteen reported price records were removed from the analysis.

The *Sea Around Us* (SAU) catch database (http://www.seaaroundus.org/; Pauly and Zeller, 2015, 2016) was used to create a list of prices to be estimated. Our goal was to provide an estimated ex-vessel price for each listed catch in the SAU catch database. This newly reconstructed version of the catch database provides a detailed list of catches from 1950-2010.

We determined market exchange rates and purchasing power parities from the Penn World Tables, Version 7.1 (http://www.rug.nl/research/ggdc/data/pwt/; Heston et al., 2012). Purchasing power parity (PPP) is a measure of the relative price level in a particular country, and accounts for the fact that the relative cost of goods in a country may not be fully reflected in market exchange rates. We use PPP to convert domestic prices into 'real' prices for a direct international comparison of value, a method used by the International Comparison Program. For years where a country's PPP was unavailable (i.e., earlier years where price level data was scarce for developing countries), we carried data back from the nearest year. Regional averages of the price level were calculated for countries with no PPP data (see Swartz et al., 2013). We accounted for inflation by standardizing all ex-vessel prices to a reference year using the United States (US) Consumer Price Index (CPI) prepared by the US Bureau of Labour Statistics (http://www.bls.gov/cpi/).

2.2 Price estimation with the country-product-dummy model

Reported ex-vessel prices were assigned to a matching taxon-country-year specific catch where possible. However, ex-vessel prices were estimated for the majority of reported catch records in the SAU catch database, as prices were 'missing' and they were not reported with an associated price or landed value. As in the previous version of the Price DB we estimated prices using the country-product-dummy model (for details on the country-product-dummy model, see Swartz *et al.*, 2013). Here we describe a revised application for the use of the country-product-dummy model to estimate 'missing' prices and confidence intervals (Rao 2004; Silver 2009); confidence intervals were not estimated in the previous version.

Ex-vessel prices (denoted by p_{ijt}) of each unique commodity-country-year combination were estimated based on three factors: the price level of the *i*-th commodity (fish taxa) in year *t* relative to other commodities, also referred to as the international price (denoted by IP_{it}); the general price level of the *j*-th country in year *t* relative to other countries, also referred to as the purchasing power parity (denoted by PPP_{jt}); and a random normal error (denoted by μ_{ijt}). Using these determinants, the country-product-dummy model can be stated as (Summers 1973):

$$p_{ijt} = IP_{it} \cdot PPP_{jt} \cdot \mu_{ijt} \quad (1)$$

and taking the natural logarithm yields a linear model equation in the form:

$$\ln(p_{ijt}) = \ln(IP_{it}) + \ln\left(PPP_{jt}\right) + \ln(\mu_{ijt}) \quad (2)$$

To estimate 'missing' ex-vessel prices we first matched the known reported price data (p_{ijt}) from various countries within year *t* to the taxonomic category of interest. Next, we matched known purchasing power parity (PPP_{jt}) values to reported ex-vessel prices from each *j*-th country. We then fit a linear regression model for each year *t* using equation (2) to estimate international prices (IP_{it})—expressed in a common currency, US dollars—for each *i*-th taxon with a 'missing' price. Linear models were run independent of year to maintain intraspecific year-to-year variability and eliminate any effects of ex-vessel price data from other years. Using equation (2) to estimate international prices allowed us to obtain uncertainty estimates. Finally, we calculated 'missing' ex-vessel prices (p_{ijt}) for each *i*-th commodity in country *j* in year *t* by rearranging equation (1) and using the estimated international price (IP_{it}) and PPP_j.

Where there was no specific reported price data for a particular taxon, we matched raw reported price data using higher taxonomic classifications functional groupings and habitat types (as in Sumaila *et al.* (2007) and Swartz *et al.* (2013)) (see Table S3 for more details). For cases with no matching input data for a taxon-year combination, we estimated prices by finding the average international price of the taxa for all years where it was estimated, accounting for inflation using the US CPI. We then used the CPI to back-convert the average price to the year of interest. Finally, the last estimation step was to use the median for all international prices estimated within the year of interest. Our estimation methods prioritize retaining inter-annual variability in market-specific prices.

We used the exchange rates from the Penn World Tables to convert prices from domestic currencies into USD. We used market exchange rates instead of PPP to compare market prices across currencies, and not the "real international" value of ex-vessel prices (Swartz et al. 2013). We converted prices to real 2010 values using the US CPI to account for inflation, and we assume that the relative PPP values capture country-specific inflation. These conversions allowed for comparisons to be made across countries and over time.

Separate ex-vessel prices were estimated for the proportion of catches destined for DHC and for purposes other than DHC (i.e., FMFO and other uses) using separate input data sets. Ex-vessel prices for purposes other than DHC were assigned to the proportions of catch destined for FMFO and "other" uses. We assumed that prices between catch destined for FMFO and other uses are similar and therefore applied the same input reported price data set to both. We estimated an international price for over 87,000 and 77,000 unique taxa-year combinations for catches destined for DHC and FMFO/other uses, respectively.

When comparing average ex-vessel prices, we used weighted-by-catch means instead of normal mean calculations. Weighted-by-catch means were calculated by taking reported catch and multiplying it by price to obtain the landed value, then dividing the sum of all landed values by the sum of all reported catches.

2.3 Landed values

The parallel construction of this Price DB with the global SAU catch database (Pauly and Zeller 2015) allowed us to calculate landed values for each catch. Catches are broken down by product usage and landed values were calculated using ex-vessel prices for DHC, FMFO, and other uses (Cashion 2016). Each catch is designated to a fishing entity and taxonomic group. Therefore, we were able to quantify the landed values by the top fishing nations and major taxonomic groups from 1950-2010. This provided us with the opportunity to determine the distribution of the value of global marine fisheries resources. We compared the landed value by destination type for the specific taxonomic groups that comprise the majority of revenues for uses other than DHC. Additionally, we compared landed values for the top fishing nations for FMFO production value and its relative contribution to the country’s economy.

2.4 Comparing methods and validation of model estimation

We compared ex-vessel price estimates and landed values between methods with and without separate input prices for fisheries destined for FMFO and other uses. Percent differences between non-DHC and DHC prices were shown for the top 12 species for FMFO landed values. We also showed the percent differences in the landed values for these top 12 species using our methods (separate prices for non-DHC purposes) versus pervious methods (one price for all purposes). For each country, we also compared the average price and landed value trends over time between the two methods.

Our model was validated using a k-fold cross validation to determine the accuracy of the model by separating half of the reported prices (training data) to estimate the remaining half of the reported prices (test data). We generated three subsamples, each representing ~50% of the data to measure the strength of the model in estimating prices across countries, taxa, and overall. We removed price data from 35 randomly selected countries, 724 randomly selected taxa, and a random selection of half the data as training data for DHC prices. We did the same for FMFO/Other prices and removed price data from 13 randomly selected countries, 122 randomly selected taxa, and a random selection of half the data. Estimated prices were tested for correlation with the corresponding reported prices.

3 RESULTS

3.1 Ex-vessel prices and landed values

We derived ex-vessel prices for over 667,000 and 364,000 unique taxon-country-year records of catch destined for DHC and FMFO/other uses, respectively, from the SAU reconstructed reported marine fisheries catch database (Pauly and Zeller 2015). About 31,000 catch records were matched directly to reported ex-vessel price data, and 103,000 records were matched by taxon (Table S3). Fisheries catch records span the years 1950-2010, include 197 countries and entities, and over 1,700 different taxon groups.

Ex-vessel prices have generally increased over time. Since the 1950s, prices for DHC have increased by ~54%, while prices for FMFO and other products have increased by 60% and 10%, respectively (Figure 1). Total average ex-vessel price decreased in the 1960s but was much greater than the decrease observed for DHC prices (Figure 1), indicating that seafood was not necessarily getting cheaper. Instead, catches of low-value small pelagic fish, often destined for reduction purposes, increased substantially in the 1960s (Pauly and Zeller 2016). Low average ex-vessel prices of fish destined for FMFO and “other uses” are reflected in the total landed values for each destination type.

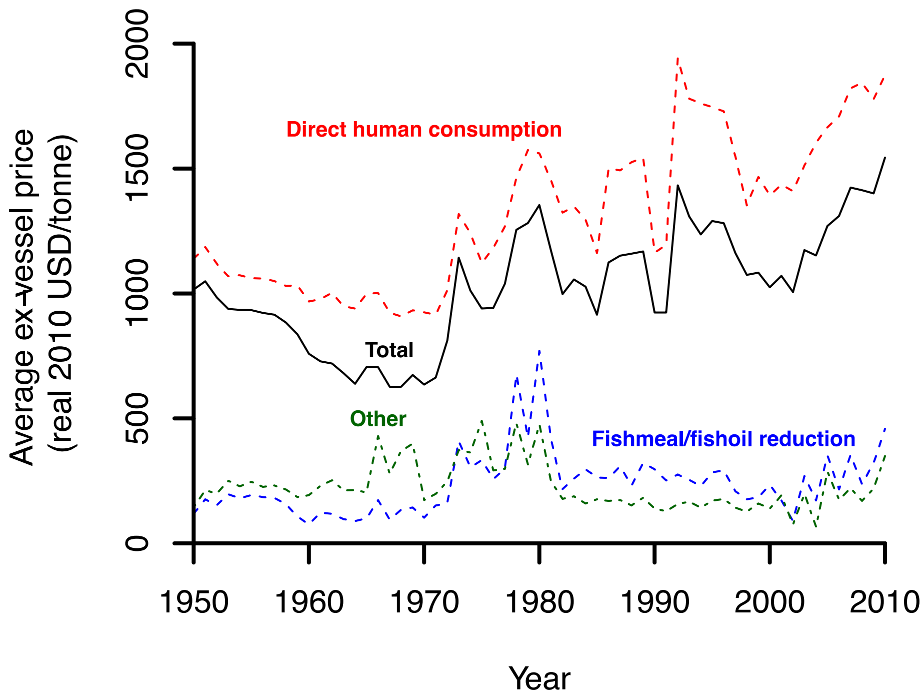

Figure 1. Global marine fisheries weighted-by-catch average ex-vessel prices from 1950-2010 as estimated by our model. Average ex-vessel prices are further disaggregated into product usage: direct human consumption, fishmeal and fish oil reduction, and other uses. (Colour figure available online)

Global landed values in 2010 were estimated to be almost $150 billion, greater than a five-fold increase since 1950 (Figure 2a). Our confidence limits for price estimates put the range for 2010 global landed values between $80 and 245 billion. Global landed values increased consistently with landings until peak catch rates in the mid-1990s, where landed values continued to increase while landings have decreased. Global landed values have continued to climb, currently (2009-2010) at an all time high. From 1950-2010, global landed values for FMFO have shown an increase from $640 million to over $6.3 billion, and have averaged ~5% in its proportion of global landed values over that period (Figure 2b). In 2010, fish for FMFO production was nearly 18% of global catch (Cashion et al. 2017) but only 5% of global landed value.

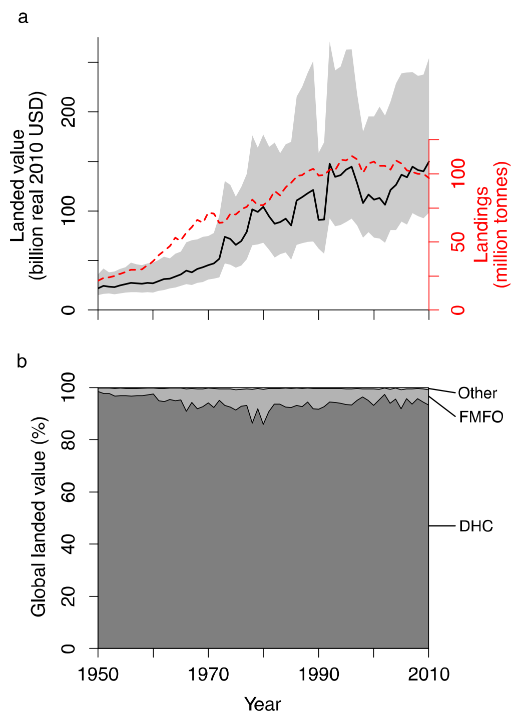

Figure 2. Global marine fisheries a) landed values ± confidence limits (solid line) and landings (dashed line) from 1950-2010, and b) the proportion of landed values derived from fisheries catch destined for direct human consumption (DHC), fishmeal and fish oil production (FMFO), and other uses.

Historically from 1950-2010, forage fishes—which include herring, sardines, and anchovies—accounted for over 70% of the tonnage for FMFO production and over 62% of the landed value of fish for FMFO (Table 1). In 2010 alone, forage fishes accounted for $3.5 billion and 45% of landed value of catch destined for FMFO production. The proportion of forage fish catch destined for FMFO production has averaged 60% every year from 1950-2010, while the proportion of forage fish landed value from FMFO production averaged 41%.

Forage fishes are thus important to both the DHC and FMFO sector. The top 12 species used for FMFO production have historically accounted for over 80% of reduction fisheries landed value. Two species, anchoveta and the Pacific sardine, have together accounted for 40% of reduction fisheries landed values from the period 1950-2010. However, the percentage of landed values in 2010 for anchoveta was larger than its historical average, while they were much smaller for Pacific sardine.

Table 1. Contribution of forage fishes and the top 12 taxa for FMFO landed value production for from 1950-2010.

	% of global FMFO landed value		**% of total taxon landed value destined for FMFO**		**2010 global landed value**	
Taxon name	**1950-2010**	**2010**	**1950-2010**	**2010**	**($ billion)**	**(%)**
Forage fishes (e.g. herrings, sardines, anchovies)	62.3	61.2	8.0	7.9	11.8	45.0
Anchoveta (*Engraulis ringens*)	19.6	25.4	98.1	91.6	2.40	1.6
Pacific sardine (*Sardinops sagax*)	19.5	3.5	73.0	44.0	0.69	0.5
Chilean jack mackerel (*Trachurus murphyi*)	10.0	7.6	75.3	79.6	0.83	0.6
Gulf menhaden (*Brevoortia patronus*)	7.1	4.6	95.7	99.9	0.40	0.3
Capelin (*Mallotus villosus*)	6.2	1.3	84.4	41.9	0.27	0.2
Atlantic herring (*Clupea harengus*)	5.4	3.6	32.6	23.3	1.35	0.9
Sand eels (*Ammodytes* spp.)	4.4	4.3	98.0	99.8	0.37	0.2
Blue whiting (*Micromesistius poutassou*)	3.3	2.4	70.1	55.0	0.38	0.3
Araucanian herring (*Clupea bentincki*)	2.3	9.8	84.2	100.0	0.85	0.6
Norway pout (*Trisopterus esmarkii*)	1.8	1.3	99.8	100.0	0.11	0.1

Chub mackerel (*Scomber japonicus*)	1.8	2.5	23.1	32.6	0.66	0.4
Japanese anchovy (*Engraulis japonicus*)	1.5	3.7	25.3	38.1	0.83	0.6
Total	82.9	69.9			9.1	6.1

The top five countries for FMFO landed value production in 2010 were Chile, China, Peru, Denmark, and Norway, totalling over 5.9 billion real 2010 USD and 68% of landed value destined for FMFO production. The high percentage of reduction fisheries revenues produced by a select few countries indicates that the majority of species fished for FMFO likely come from a few major ecosystems (e.g. Humboldt Current). Proportion of fisheries revenues from catch destined for reduction fisheries were highest in Peru, Denmark, Chile, and other countries including Sweden, Georgia, and Finland, accounting for 29-56% of their total fisheries landed value in 2010. For China and Norway, the proportion of FMFO landed value represents less than 20% of their total fisheries landed values.

Table 2. Top 5 countries for FMFO landed value production in 2010.

Country	**% of global FMFO landed value**	**% of country landed value to FMFO**	**2010 FMFO landed value ($ billion)**
Chile	31.0	35.7	2.7
Peru	16.2	51.0	1.4
China	10.2	4.3	0.9
Norway	5.8	11.0	0.5
Denmark	5.1	40.4	0.4
Total	**68.3**		**5.9**

3.2 Comparing methods and model validation

When comparing this third version of the Price DB with the second version (Swartz et al. 2013), model comparison showed that estimation method was a significant variable in average price trends over time (see Supplementary material for more details). Model outputs suggest that weighted average prices were significantly lower using our methods and that prices were likely overestimated in the previous version of the price database ($K = 2$; $DF_{Residual} = 111$; $AIC_{weight} = 0.55$). However, accounting for differences in slope trends of prices over time between the two estimation methods in the model provided a good fit as well ($K = 3$; $DF_{Residual} = 111$; $\Delta AIC = 0.44$; $AIC_{weight} = 0.55$), suggesting price trends may have differed between the two estimation methods.

The differences in average ex-vessel prices between the methods were most pronounced in forage fishes (Figure 3a; for other taxonomic groups see Figure S1). Average prices for forage fish were much lower when using our methods to estimate separate prices for non-DHC purposes, and were much more consistent with FAO prices. When only using one price for all products, average prices for forage fishes increased to over \$1000 tonne^{-1} (Figure 3a). Prices for non-DHC purposes were consistently lower than prices for DHC purposes in the top 12 species used for FMFO production (Figure 3b). With the exception of araucanian herring, landed values using separate prices for reduction fisheries were also much lower than when using one price.

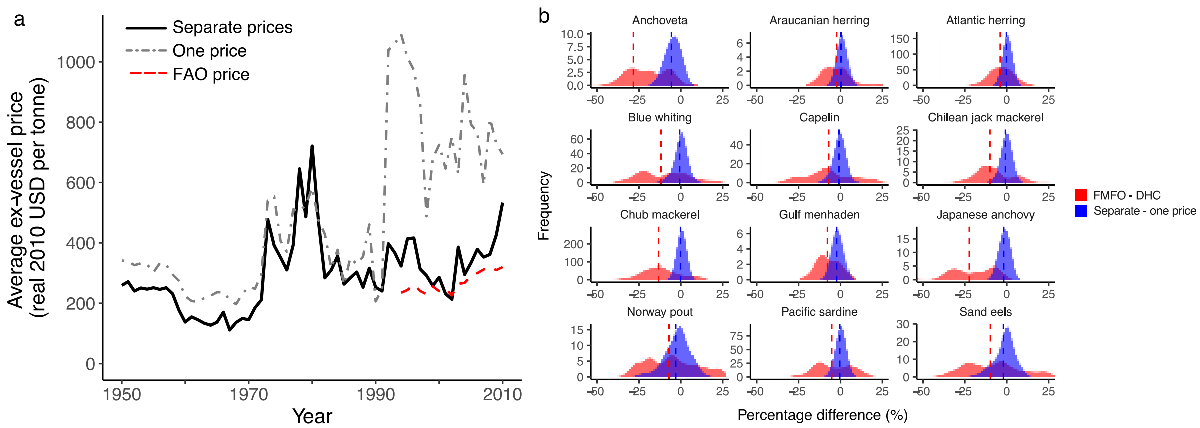

Figure 3. The effects of estimating prices separately for different product types versus one overall price, showing a) average ex-vessel prices for forage fishes, and b) the distribution of the percent differences for the top 12 species by FMFO value production, between prices for fishmeal and fish oil (FMFO) and direct human consumption (DHC) (red), and between landed values using new (separate prices for different products) versus previous (one price for all products) methods (blue). (Colour figure available online)

A cross validation showed that our model did fairly well in predicting reported prices using a subset of reported price data. Our model was able to estimate prices for DHC across country and taxa, with R^2 values greater than 0.43 (Figure 4). Prices estimates for FMFO/Other uses across countries were not as accurate, with an R^2 value of 0.13. This highlights the importance of having adequate coverage of reported prices across countries (Supplementary material). However, our model did fairly well for FMFO/Other price estimates across taxa (Figure 4).

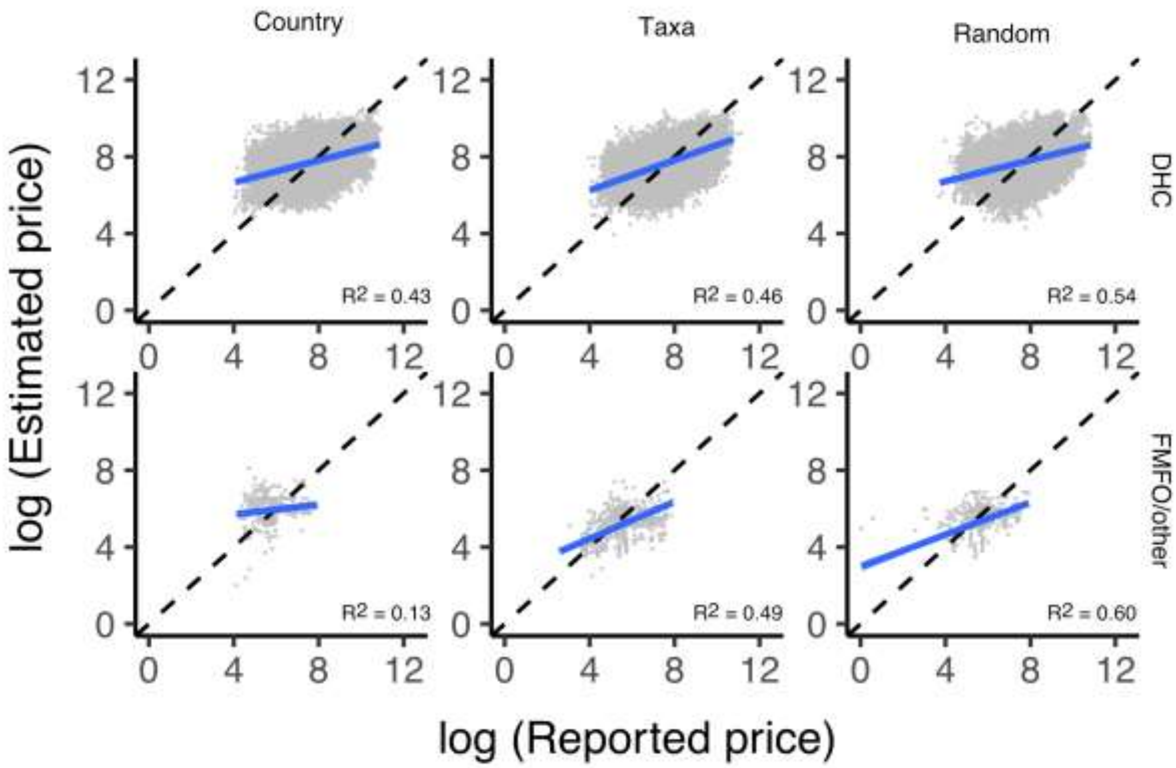

Figure 4. Cross validation where half of the reported prices were removed to estimate the remaining half of the reported prices for DHC (direct human consumption) and FMFO/Other (fishmeal, fish oil and other uses) based on country, taxa, or at random.

Countries with a historically larger proportion of landed values destined for non-DHC purposes were likely to have prices and thus landed values over estimated when prices were not estimated separately for non-DHC purposes. In Peru for example, 2010 landed values were estimated at $3.8 billion when using separate prices for different products versus $5.8 billion using previous methods (Figure S2). Trends in price and landed values also differed for some countries when comparing the two methods (Table 3; Figure S2). A significant difference between slopes indicated over-appreciation, and a significant difference in intercepts indicated overvaluation. Globally, price trends were overvalued, and landed value trends were over-appreciated when using the previous methods.

Table 3. Linear regression analysis showing the countries, and globally, where price and landed value trends over time significantly differed in either their slope[†] or intercept between the two estimation methods.

Consequences of failing to use separate prices for low-value fisheries	**Prices**	**Landed values**
Over-appreciation (slope)[†]	El Salvador Georgia Peru Thailand Turkey	Global Chile El Salvador Georgia Pakistan Panama Peru Thailand Turkey
Overvalued (intercept)	Global Chile Denmark Pakistan Panama South Africa	China Denmark South Africa

[†]Countries with significantly different slopes between the two methods also had significantly different intercepts.

4 DISCUSSION

Average ex-vessel prices for FMFO decreased in the 1960s (Figure 1), likely due to the growing production of FMFO and the increased proportion of low-value species such as the Peruvian anchoveta which rapidly expanded during this period (Bell et al. 1970; Naylor et al. 2000). Following, average ex-vessel prices for FMFO (and across product types) rapidly increased in the 1970s and 1980s, likely due to a combination of multiple global events (Figure 1). First, the cost of fishing likely increased due to the 1973 and 1979 oil crises, which increased fuel costs (Barsky and Kilian 2002). Swartz et al. (2013) also attributes price increases during this time to the establishment of the Third United Nations Convention on the Law Of the Sea, which extended maritime jurisdictions to a 200 nautical mile exclusive economic zone and thus increased the distance travelled and costs. Peruvian anchoveta collapsed in 1972 due to El Niño and overfishing (Lluch-Belda et al. 1989; Pauly et al. 2002) and likely contributed to the rise in prices due to a combination of decreased supply of catch for FMFO production and the growing demand of FMFO for aquaculture production. Production of Peruvian anchoveta remained low until the mid-1990s (Alheit and Niquen 2004), yet ex-vessel prices for reduction fisheries decreased in the 1980s (Figure 1). This may be attributed to the persistent growth of FMFO production and the growing diversity in species used for FMFO production throughout this period (Cashion et al. 2017), despite low anchoveta numbers. Another possible explanation is the 1980s "oil glut" (Ramcharran 2002), where a surplus of oil and a drop in fuel costs likely reduced the cost of fishing and thus ex-vessel prices. Reduction fisheries prices steadily decreased into the 1990s (Figure 1), as Peruvian anchoveta has regained its substantial contribution to FMFO production (Alheit and Niquen 2004). Since the late-1990s, prices for fish for FMFO have steadily increased, likely attributed to the combination of a decrease in global marine fisheries catch and supply (Pauly and Zeller, 2016), increased demand from aquaculture expansion (Shepherd and Jackson 2013), and increasing fuel costs.

Aquaculture has expanded rapidly in the last few decades while forage fisheries production has recently decreased (Shepherd and Jackson 2013). Stricter fisheries management controls (e.g., Aranda, 2009) and increased DHC processing of fish species formerly used as FMFO (Shepherd and Jackson 2013; Cashion et al. 2017) are some of the reasons why reduction fisheries production has not kept up with aquaculture production. While we may expect changes in demand or supply of FMFO to have an effect on ex-vessel prices, there may be other market factors restricting any drastic changes in price. Similar to other land-based farmers, feed will be substituted for other feeds if prices increase and quality is not compromised (Asche and Bjorndal 1999; Asche and Tveterås 2004). Soymeal, a close substitute for fishmeal in terms of crude protein, formerly prevented large changes in price for fishmeal despite the increase in demand (Asche and Tveterås 2004; Asche et al. 2013). However, this price dynamic between fishmeal and soymeal has broken down in recent years (Asche et al. 2013), as fishmeal is substitutable only to a point in aquaculture diets. This recent development (post-2004) can be seen in the uptick in ex-vessel prices of fish destined for FMFO production.

The growing demands for FMFO for aquaculture feed is concerning due to its ecological and socioeconomic impacts. FMFO products are mostly derived from forage fishes (Table 1; Cashion *et al.*, 2017), and many of these stocks are overexploited (Srinivasan et al. 2010; Cao et al. 2015). While many of these fish have favourable traits for exploitation (e.g. high growth rates, fecundity, turnover), their populations are highly vulnerable to collapse. Forage fishes serve an important ecological role as a primary source of prey, and are more valuable to the greater economy in the water than as FMFO (Pikitch et al. 2014). Further, about 90% of non-DHC fisheries catch (~18 million tonnes annually) are food-grade quality (Cashion et al. 2017), and would alleviate global food insecurities.

Global demands for FMFO are mainly driven by aquaculture in China, and FMFO use in aquaculture feed has increased overall despite the decrease in the inclusion of FMFO in aquaculture feed (Naylor et al. 2009). China's aquaculture industry has rapidly expanded and is currently the largest importer of FMFO products (Cao et al. 2015). There is an attempt to shift to more sustainable plant-based feeds, but many companies have already secured future rights to high quality FMFO products (Cao et al. 2015), limiting the capacity for change. However, the change in aquaculture formulations is driven by price (Hardy 2010), and this will continue to incentivize the use of alternative sources of feed to substitute FMFO products. It is possible that the currently depleted reduction fisheries stocks and the higher prices associated with them will drive a decrease in demand for FMFO products as alternative sources of feed are sought. The result of this may be more forage fish for DHC.

There is currently a growing proportion of fish by-catch, often mislabelled as 'trash fish', used for fishmeal production (Cao et al. 2015). The FMFO products from this mixed fish catch are of a lower quality and sell for lower prices to be used for low-value aquaculture species (Chiu et al. 2013). While at first the use of by-catch as aquaculture feed may seem resourceful, it may put further strain on wild fish stocks and ecosystems (Cao et al. 2015). Current production remains relatively low but a rise in price due to a growing demand may increase fishing for these non-targeted species (Cao et al. 2015). What is a concern is that the group of species categorized as 'trash fish' are variable and the growth of non-targeted fisheries will be inherently difficult to manage.

Our paper provides valuable information and tools for researchers to value fisheries catches destined for DHC, FMFO, and other uses. Distinguishing prices between product types showed to have effects on highly aggregated price and landed value trends over time (Table 3; Supplementary material). This Price DB is comparable to other efforts in constructing an ex-vessel marine fish price database. Specifically, Melnychuk *et al.* (2016) used export prices to estimate ex-vessel prices using publicly available FAO data (FAO 2014). They were also able to estimate prices for products destined for FMFO. The authors have strong arguments for their approach, such as the consistency of FAO data and its public availability. However, recent studies have shown that global catch may be much higher than reported by FAO (Pauly and Zeller 2016). Our Price DB has greater temporal coverage (1950-2010) and provides price estimates for the disaggregated catch records from SAU. We also provided price estimates for the various species used for FMFO production and other uses, whereas Melnychuk *et al.* (2016) only provided an aggregate estimate of price for all FMFO catches.

Limitations of our global price database

It should be noted that constructing such an extensive database relies on many assumptions, which creates uncertainties in the estimations. One of the main assumptions we applied is using input prices within the same year rather than prices with a more similar taxonomic match from other years. While this retains year-specific market prices, it assumes that prices can be transferred across higher taxonomic classifications. However, we assume that hard data on ex-vessel prices are available for the major fisheries of the world, and catch data without reported prices were simply 'substitutes' of their related taxa (Swartz et al. 2013). Our methods can also produce conversion errors. Some countries have gone through multiple currency changes (e.g., Chile), and their exchange rates and PPPs may be vastly different at the beginning of the year compared to the end of the year. Therefore, depending on when these prices were recorded, the reported ex-vessel prices may be over- or undervalued when converted to an international price, which can then be carried over to price estimates for other countries.

Price estimates are assigned to each unique taxon-country-year catch, regardless of fishing sector. The SAU catch database disaggregates catch by sector (industrial, artisanal, subsistence) and consequentially, prices and landed values may be underestimated for artisanal fisheries. Artisanal fisheries often have a shortened supply chain, where catches can be transferred directly from fisher to consumer, especially in developing countries. Therefore, artisanal ex-vessel prices are often greater than industrial prices, and our estimates may better reflect industrial prices depending on where the data were sourced. The next steps for an update of the Price DB would be to break down prices and values by fishing sector.

5 CONCLUSION

Future research derived from this database will improve the understanding of the economic contributions and future potential of the different products derived from marine fisheries resources. As global aquaculture has rapidly expanded since the 1990s (Naylor et al. 2000), there are increasing demands for aquaculture feed inputs such as FMFO. However, supply fish destined for FMFO production remained relatively constant (Alder and Pauly 2006) and has more recently declined to a lower proportion of global landings (Cashion et al. 2017). Prices for fisheries products have remained relatively elastic to growing demand (Asche and Tveterås 2004) but have increased in the past few decades, alluding to changes in feed composition, demand and supply, and the structure of product ownership and future rights. If we can get a better understanding of past price trends in response to market factors, we may be able to better predict and manage global fish stocks and the demand for FMFO. Further, our price database contributes to developing a better understanding of the price fluctuations of ex-vessel prices for estimating value chains for reduction fisheries (e.g., Christensen et al., 2014), which are often much longer from production to consumption of final product than fisheries for DHC. Additionally, this Price DB will contribute to the growing literature on socioeconomic scenario development and analyses in fisheries science (e.g. Cheung *et al.*, 2016; Lam *et al.*, 2016).

An update of the Price DB was required as the global SAU catch database has undergone major reconstruction and is now more detailed and refined. However, the production of such large-scale databases does not come without its caveats. Therefore, application of our price database to finer scales of data poor fisheries, such as species- or community-specific analyses, must be exercised with caution. Nonetheless, our Price DB is a valuable resource for assessing large-scale trends. Landed values calculated from our prices can be found on the SAU website (www.seaaroundus.org).

Supplementary material

Supplementary material is available at the *Environmental and Resource Economics* online version of the article.

ACKNOWLEDGEMENTS

We thank *Sea Around Us* for providing data from the extensive work done to reconstruct their database. We would also like to thank Daniel Pauly for contributions to conceptualizing the new material and data that was added to this paper. We thank three anonymous reviewers for providing substantial comments that helped improve this manuscript. TC acknowledges support of the *Sea Around Us* that is supported by The Paul G. Allen Family Foundation and assisted by the staff of Vulcan, Inc., with additional support from the Rockefeller, MAVA, Oak, and Prince Albert II Foundations. This paper was a joint contribution from *OceanCanada* Partnership, *Sea Around Us*, and the Fisheries Economics Research Unit.

Funding: This work was funded by the Social Sciences and Humanities Research Council (SSHRC) of Canada, through support from *OceanCanada* Partnership and MEOPAR. Funding sources did not have a role in study design, collection, analysis, or interpretation of data, writing the report, or the decision to submit the article for publication.

REFERENCES

Alder J, Pauly D (2006) On the multiple uses of forage fish: from ecosystem to markets. Fish Cent Res Reports 14:109.

Alheit J, Niquen M (2004) Regime shifts in the Humboldt Current ecosystem. Prog Oceanogr 60:201–222. doi: 10.1016/j.pocean.2004.02.006

Aranda M (2009) Developments on fisheries management in Peru: The new individual vessel quota system for the anchoveta fishery. Fish Res 96:308–312. doi: 10.1016/j.fishres.2008.11.004

Asche F, Bjorndal T (1999) Demand elasticities for fish and seafood : A review. Bergen, Norway

Asche F, Oglend A, Tveteras S (2013) Regime Shifts in the Fish Meal ⁄ Soybean Meal Price Ratio. J Agric Econ 64:97–111. doi: 10.1111/j.1477-9552.2012.00357.x

Asche F, Tveterås S (2004) On the Relationship Between Aquaculture and Reduction Fisheries. J Agric Econ 55:245–265. doi: 10.1111/j.1477-9552.2004.tb00095.x

Barsky R, Kilian L (2002) Oil and the Macroeconomy Since the 1970s. J Econ Perspect 18:115–134. doi: 10.1007/s13398-014-0173-7.2

Bell FW, Nash DA, Carlson EW, et al (1970) The future of the world's fishery resources: forecasts of demand, supply, and prices to the year 2000 with a discussion of implications for public policy.

Börger T, Beaumont NJ, Pendleton L, et al (2014) Incorporating ecosystem services in marine planning: The role of valuation. Mar Policy 46:161–170. doi: 10.1016/j.marpol.2014.01.019

Cao L, Naylor R, Henriksson P, et al (2015) China's aquaculture and the world's wild fisheries. Science (80-) 347:133–135. doi: 10.1126/science.1260149

Cashion T (2016) The end use of marine fisheries landings.

Cashion T, Le Manach F, Zeller D, Pauly D (2017) Most fish destined for fishmeal production are food-grade fish. Fish Fish 1–8. doi: 10.1111/faf.12209

Cheung WWL, Jones MC, Lam VWY, et al (2016) Transform high seas management to build climate-resilience in marine seafood supply. Fish Fish in press:1–10. doi: 10.1111/faf.12177

Chiu A, Li L, Guo S, et al (2013) Feed and fishmeal use in the production of carp and tilapia in China. Aquaculture 414–415:127–134. doi: 10.1016/j.aquaculture.2013.07.049

Christensen V, De la Puente S, Sueiro JC, et al (2014) Valuing seafood: The Peruvian fisheries sector. Mar Policy 44:302–311. doi: 10.1016/j.marpol.2013.09.022

FAO (2014) Fishery and aquaculture statistics.

Hardy RW (2010) Utilization of plant proteins in fish diets: Effects of global demand and supplies of fishmeal. Aquac Res 41:770–776. doi: 10.1111/j.1365-2109.2009.02349.x

Heston A, Summers R, Aten B (2012) Penn World Table Version 7.1 Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania.

Lam VWY, Cheung WWL, Reygondeau G, Sumaila UR (2016) Projected change in global fisheries revenues under climate change. Sci Rep 6:32607. doi: 10.1038/srep32607

Lluch-Belda D, Crawford RJM, Kawasaki T, et al (1989) World-wide fluctuations of sardine and anchovy stocks: the regime problem. South African J Mar Sci 8:195–205. doi:

10.2989/02577618909504561

Melnychuk MC, Clavelle T, Owashi B, Strauss K (2016) Reconstruction of global ex-vessel prices of fished species. ICES J Mar Sci. doi: 10.1093/icesjms/fsw169

Naylor RL, Goldburg RJ, Primavera JH, et al (2000) Effect of aquaculture on world fish supplies. Nature 405:1017–24. doi: 10.1038/35016500

Naylor RL, Hardy RW, Bureau DP, et al (2009) Feeding aquaculture in an era of finite resources. Proc Natl Acad Sci 106:15103–15110. doi: 10.1073/pnas.0910577106

Nunoo FKE, Asiedu B, Amador K, et al (2014) Marine Fisheries Catches in Ghana: Historic Reconstruction for 1950 to 2010 and Current Economic Impacts. Rev Fish Sci Aquac 22:274–283. doi: 10.1080/23308249.2014.962687

Pauly D, Christensen V, Guénette S, et al (2002) Towards Sustainability in World Fisheries. Nature 418:689–695. doi: 10.1038/nature01017

Pauly D, Zeller D (2016) Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nat Commun 7:10244. doi: 10.1038/ncomms10244

Pauly D, Zeller D (2015) Sea Around Us Concepts, Design and Data (seaaroundus.org).

Pikitch EK, Rountos KJ, Essington TE, et al (2014) The global contribution of forage fish to marine fisheries and ecosystems. Fish Fish 15:43–64. doi: 10.1111/faf.12004

Ramcharran H (2002) Oil production responses to price changes: An empirical application of the competitive model to OPEC and non-OPEC countries. Energy Econ 24:97–106. doi: 10.1016/S0140-9883(01)00091-3

Rao DSP (2004) The country-product-dummy method: a stochastic approach to the computation of purchasing power parities in the ICP. Brisbane, Australia

Salze G, McLean E, Battle PR, et al (2010) Use of soy protein concentrate and novel ingredients in the total elimination of fish meal and fish oil in diets for juvenile cobia, Rachycentron canadum. Aquaculture 298:294–299. doi: 10.1016/j.aquaculture.2009.11.003

Shepherd CJ, Jackson AJ (2013) Global fishmeal and fish-oil supply: Inputs, outputs and markets. J Fish Biol 83:1046–1066. doi: 10.1111/jfb.12224

Silver M (2009) The Hedonic Country Product Dummy Method and Quality Adjustments for Purchasing Power Parity Calculations.

Srinivasan UT, Cheung WWL, Watson R, Sumaila UR (2010) Food security implications of global marine catch losses due to overfishing. J Bioeconomics 12:183–200. doi: 10.1007/s10818-010-9090-9

Sumaila UR, Marsden AD, Watson R, Pauly D (2007) A Global Ex-vessel Fish Price Database: Construction and Applications. J Bioeconomics 9:39–51. doi: 10.1007/s10818-007-9015-4

Summers R (1973) International Price Comparisons Based Upon Incomplete Data. Rev Income Wealth 19:1–16. doi: doi:10.1111/j.1475-4991.1973.tb00870.x

Swartz W, Sumaila R, Watson R (2013) Global Ex-vessel Fish Price Database Revisited: A New Approach for Estimating “Missing” Prices. Environ Resour Econ 56:467–480. doi: 10.1007/s10640-012-9611-1

Tacon AGJ, Metian M (2015) Feed Matters : Satisfying the Feed Demand of Aquaculture.

Rev Fish Sci Aquac 23:1–10. doi: 10.1080/23308249.2014.987209

Tacon AGJ, Metian M (2008) Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. Aquaculture 285:146–158. doi: 10.1016/j.aquaculture.2008.08.015

Watson R, Kitchingman A, Gelchu A, Pauly D (2004) Mapping global fisheries: sharpening our focus. Fish Fish 5:168–177. doi: 10.1111/j.1467-2979.2004.00142.x