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Original Article

Reconstruction of global ex-vessel prices of fished species

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Economic dimensions of global fishery analyses are often limited by unavailable or inconsistent ex-vessel price data from the world's fishing nations. We describe a novel method for estimating ex-vessel price time series for individual species by converting export prices of fishery commodities into ex-vessel prices and pairing these with species. The method relies exclusively on global, publicly-available data from the Food and Agricultural Organization of the United Nations (FAO). National datasets of ex-vessel prices are not used as inputs for the method, but comparisons of reconstructed ex-vessel prices with actual prices from national datasets showed strong correspondence. Correlation coefficients for paired reconstructed prices and actual prices of the same species were typically between 0.60 and 0.75 annually in the past two decades. There was a tendency for reconstructed prices to be less variable than actual prices, over-estimating actual prices at low values of actual prices and under-estimating actual prices at high values, likely the result of incomplete price transmission or assigning a given price time series to multiple species. However, there was no evidence of overall bias between reconstructed prices and actual prices, and correlations were strongest for comparisons involving multiple taxonomic groups. The method described carries advantages of global comprehensiveness and consistency across countries in reconstructed ex-vessel prices, reflecting the comprehensiveness and consistency of export price information. The method described links to species from the global FAO landings database, but can be modified to pair with other species lists or to focus on specific regions or countries. Data tables and source code are publicly available and ex-vessel price estimates can be updated annually following annual releases of the FAO fishery commodities database.

Keywords: environmental economics, fish markets, fisheries revenue, landed value, price transmission, seafood trade.

Introduction

Economic dimensions of global fishery analyses are often limited by unavailable or inconsistent ex-vessel price data from the world's fishing nations. Landed value, the product of landed tonnage and price per tonne received at the point of landing, is an important measure of gross economic benefit for a fishery, region, or country (Doll, 1972). These data are essential for any analysis that seeks to accurately evaluate the economic implications of fishery management decisions (Sumaila *et al.*, 2007; Pinkerton and Edwards, 2009), the driving forces behind fisheries development (Sethi *et al.*, 2010), or influences of revenues on effort dynamics and fleet behaviour (Fletcher *et al.*, 1987; Kaplan *et al.*, 2014). Ex-vessel prices may even be used as an index of stock status (Pinnegar *et al.*, 2006). Landed tonnage data are collected by countries and submitted to the Food and Agricultural Organization of the United Nations (FAO), which maintains a global, publicly-available database (Garibaldi, 2012; FAO, 2016a). A parallel database of ex-vessel prices collected and submitted by countries does not exist.

Many countries, including some of the world's top fishing nations in terms of landed tonnage, do not have publicly-available time series data of ex-vessel prices of fished species or groups of species. Certain countries do have ex-vessel price data available, but even these have limitations or inconsistencies: time series data may be short in duration; units of landed quantities and of prices may vary (e.g. total weight versus gutted weight); taxonomic resolution may vary; and estimates may be available for only one or a few species (Doll, 1972; Gillig *et al.*, 1998). Further, countries that do have price data available tend to be within the developed world, which creates a potential price bias if those prices are applied to the landings of developing countries to estimate landed value for similar species in global fishery analyses. The increasing prominence of aquaculture in the coming decades provides another impetus for collecting and monitoring ex-vessel prices. Aquaculture now produces more seafood than capture fisheries and lower, less volatile prices for farmed fish can influence those of their wild counterparts (Anderson, 1985; Guillotreau, 2004; Dahl and Oglend, 2014).

Previous studies have examined ex-vessel prices for individual species or groups of species in select regions (Doll, 1972; Gillig *et al.*, 1998; McConnell and Strand, 2000; Pinnegar *et al.*, 2002; Baeta *et al.*, 2009; Asche *et al.*, 2015; Guillen and Maynou, 2014; Gordon and Hussain, 2015). Two previous studies have constructed global ex-vessel price databases (Sumaila *et al.*, 2007; Swartz *et al.*, 2013), but these are largely based on national datasets for select countries and thus may not be representative of most countries around the world. Further, these databases are not typically updated each year. Similar to their methodology of interpolating missing values for species and regions, Lam *et al.* (2011) developed a global cost of fishing database by compiling information from national datasets. A global fishery commodities production and trade database published by FAO (2016b) is updated annually, but this contains data that can be used to calculate nominal export or import prices (i.e. after processing and handling) rather than nominal ex-vessel prices (i.e. at points of landing, prior to value-adding measures). Previously, Tveterås *et al.* (2012) used import data from this database to develop the FAO fish price index for comparing seafood performance against other sectors. Because global fishery analyses of economic valuation typically involve pairing the landed catch with prices (Sumaila *et al.*, 2007; Arnason *et al.*, 2009; Kobayashi *et al.*, 2015; Costello *et al.*, 2016), ex-vessel prices are more appropriate than import or export prices for this pairing. The FAO fishery commodities are also separated by product type (e.g. fillets; whole/frozen; canned) and often correspond to broad taxonomic groups rather than individual species. However, a significant advantage of the commodities database is that, like the FAO landings database, it is consistent across countries.

In this article, we present a novel method for estimating nominal ex-vessel price time series for all taxonomic entities in the FAO landings database (i.e. "ASFIS species", *Aquatic Sciences and Fisheries Information System*, which are typically individual species but are occasionally miscellaneous groupings of species). This method relies exclusively on data available from FAO; it does not rely on any national databases of ex-vessel prices, but we validate our reconstructed prices against those from national databases. We include our estimates of ex-vessel prices, and we also publish all source code and linkage tables so that price estimates can be updated as FAO annually updates their fishery commodities database.

Methods

First we outline the approach employed for reconstructing ex-vessel prices; following this paragraph, more detailed descriptions of the method are given. We summed FAO export quantities and values of fishery commodities across countries, aggregated fishery commodities into pooled commodities, and then further aggregated these into ISSCAAP groups (*International Standard Statistical Classification of Aquatic Animals and Plants*; broad taxonomic groupings). Using FAO estimates of mean ex-vessel price at the level of ISSCAAP groups, we calculated an Export:Ex-vessel price expansion factor (*EEPEF*) for each ISSCAAP group and applied these expansion factors to time series of pooled commodity export prices, yielding ex-vessel prices. We assigned each species in the FAO landings database to a particular pooled commodity, allowing us to estimate annual ex-vessel prices by species. We validated these estimates against ex-vessel price data from select countries with publicly-available data.

Data sources

Three data sources published by FAO were used for ex-vessel price reconstructions.

(i) *Global commodities production and trade, 1976–2013* (FAO, 2016b). This database contains export values (USD$) and quantities (t) for 1070 fishery commodities in the 2016 dataset, and 1210 commodities in the 2015 and 2016 datasets combined. Commodities are typically the intersection of species or groups of related species with product types (e.g. fresh; chilled; frozen; salted; oil; meal; dried). Accessed through FishStatJ software (FAO, 2016c).

(ii) *World fishery production—Estimated value by groups of species, 1994–2012* (FAO, 2014). This summary table presents global estimates of mean ex-vessel prices from capture fisheries for each of 33 ISSCAAP groups. The citation is for the 2014 document providing estimates for years 2006–2012, but archived documents providing estimates for earlier years are also available (FAO, 2014).

(iii) *Global capture production, 1950–2014* (FAO, 2016a). This database contains landings data for 2033 species or miscellaneous taxonomic groups (ASFIS species) in the 2016 dataset, and 2039 species in the 2015 and 2016 datasets combined. ASFIS species are nested within 50 possible ISSCAAP groups. Excluding the 14 ISSCAAP groups for which mean ISSCAAP ex-vessel price estimates were not available (four aquatic plant groups; four aquatic mammal groups; frogs and other amphibians; crocodiles and alligators; turtles; corals; pearls/mother-of-pearl/shells; and sponges) left 1861 species. Landings data were not used in this paper, but an important objective of this method is to allow linking of reconstructed ex-vessel prices to landings data. Accessed through FishStatJ software (FAO, 2016c).

Three linkage tables were constructed to specify the aggregation of fishery commodities and the linkages between fishery commodities and species.

(i) *Linkage Table 1: Commodities to pooled commodities*. The 1210 fishery commodities were aggregated into 213 pooled commodities, aggregating across product types. Some pooled commodities are specific to single species, some are specific to families or groups of closely-related species, and others represent miscellaneous species groups. Excluding the commodities for which mean ISSCAAP ex-vessel price estimates were not available left 1168 fishery commodities aggregated into 210 pooled commodities. Taxonomic groupings were generally maintained during aggregation, but in some cases miscellaneous species groups were pooled as well. For example, the three commodities "Sandeels, dried, unsalted", "Sandlance, fresh or chilled", and "Sandlance, frozen" were aggregated into the pooled commodity "Sandlance". Commodities involving oil derived from small pelagic fishes were assigned the pooled commodity "Fish for reduction" to separate them from other small pelagic fish commodities. The full *linkage* Table 1 is given in the online Supplementary Table S1.

(ii) *Linkage Table 2: Pooled commodities to ISSCAAP groups*. The 210 pooled commodities were further aggregated into ISSCAAP groups. The assigned ISSCAAP groups were occasionally modified from default values to better align with the mean ISSCAAP ex-vessel price estimates. For example, there were no mean ex-vessel price estimates for the ISSCAAP group "King crabs, squat-lobsters", so the two pooled commodities "King crabs" and "Squat-lobsters" were instead assigned to the "Crabs, sea-spiders" ISSCAAP group. Similarly, there was no "Krill, planktonic crustaceans" ISSCAAP group available for pairing, so the "Krill" pooled commodity was instead assigned to the "Miscellaneous marine crustaceans" ISSCAAP group. A "Fish for reduction" ISSCAAP group was manually created to contain the single "Fish for reduction" pooled commodity in order to better pair prices with the "Fish for reduction" group from the FAO mean ISSCAAP ex-vessel price estimates. The full *linkage Table 2* is given in the online Supplementary Table S2. The numbers of commodities and pooled commodities within each ISSCAAP group are listed in Table 1.

(iii) *Linkage Table 3:* Species *to pooled commodities*. The 2039 ASFIS species from the FAO landings database were each linked to one of 206 pooled commodities (the remaining 7 pooled commodities were not paired with any species because better fits were available). Best matches were performed manually within each ISSCAAP group. Some matches were at the species level, some matched a species to a pooled commodity at a higher taxonomic level, and some were between miscellaneous groups; in all cases we determined the best match for each ASFIS species. Excluding the species for which mean ISSCAAP ex-vessel price estimates were not available (as well as frogs, crocodiles, and turtles, which were not in the FAO commodities database) left 1861 species each linked to one of 204 pooled commodities. Some (15) of the pooled commodities did not have reliable time series of export prices available (e.g. several years missing, or prices based on low annual quantities), so in these cases the next-best pooled commodity was linked to each species, leaving 189 pooled commodities linked to the 1861 species. The full *linkage Table 3* is given in the online Supplementary Table S3. The number of species in each ISSCAAP group is listed in Table 1.

Ex-vessel price reconstruction

The FAO *Global commodities production and trade database* contains export quantities and values by country and commodity type. In this paper we focus on global weighted mean prices based on summed quantities and values across countries, but the approach outlined could instead be applied to select countries or regions. We used *linkage Table 1* (Supplementary Table S1) to aggregate FAO fishery commodities (faoC) into pooled commodities (poolC) by summing export quantities (L_{export}) and values (V_{export}) within each pooled commodity (Figure 1):

$$L_{\text{export}_{\text{poolC, year}}} = \sum_{\text{faoC}} L_{\text{export}_{\text{faoC, year}}} , \tag{1a}$$

$$V_{\text{export}_{\text{poolC, year}}} = \sum_{\text{faoC}} V_{\text{export}_{\text{faoC, year}}} . \tag{1b}$$

For these summations, we ensured that corresponding L_{export} and V_{export} for the same fishery commodity and year were both present in the dataset so that ratios of summed V_{export} and summed L_{export} represent weighted mean export prices.

We similarly *linkage Table 2* (Supplementary Table S2) to sum export quantities and values of pooled commodities into ISSCAAP groups (Figure 1):

$$L_{\text{export}_{\text{ISSCAAP, year}}} = \sum_{\text{poolC}} L_{\text{export}_{\text{poolC, year}}} , \tag{2a}$$

$$V_{\text{export}_{\text{ISSCAAP, year}}} = \sum_{\text{poolC}} V_{\text{export}_{\text{poolC, year}}} . \tag{2b}$$

Using these export quantities and values of ISSCAAP groups, we calculated a weighted mean export price (P_{export}) for each ISSCAAP group:

$$P_{\text{export}_{\text{ISSCAAP, year}}} = \frac{V_{\text{export}_{\text{ISSCAAP, year}}}}{L_{\text{export}_{\text{ISSCAAP, year}}}} . \tag{3}$$

The above steps (Equations 1–3) were carried out for each year, maintaining time series of export prices for 1976–2013 (Figure 1). Weighted mean P_{export} time series for each ISSCAAP group are given in Table S4. Median values across time series varied widely by ISSCAAP group (Table 2).

We paired calculated mean ISSCAAP export prices with mean ISSCAAP ex-vessel prices (P_{exvessel}) from FAO (2014) to calculate an Export:Ex-vessel price expansion factor (*EEPEF*) for each ISSCAAP group (Figure 1). The overlapping years (1994–2012) of the two data sources were used to calculate annual expansion factors:

$$EEPEF_{\text{ISSCAAP, year}} = \frac{P_{\text{export}_{\text{ISSCAAP, year}}}}{P_{\text{exvessel}_{\text{ISSCAAP, year}}}} . \tag{4}$$

$EEPEF_{\text{ISSCAAP}}$ for earlier years 1976–1993 were estimated by back-extrapolating the median of annual $EEPEF_{\text{ISSCAAP}}$ values over years 1994–2012. Time series of $EEPEF_{\text{ISSCAAP}}$ are given in Table S5. Weighted mean values over years 1994–2012 ranged from 1.1 to 23.2 (Table 2).

We estimated ex-vessel prices from export prices using calculated $EEPEF_{\text{ISSCAAP}}$ values. In applying these price conversions, a key assumption is that the ISSCAAP-specific *EEPEF* applies to all species (and pooled commodities) within each ISSCAAP group. Export prices for each pooled commodity were calculated from their respective quantities and values, and were then divided by their paired $EEPEF_{\text{ISSCAAP}}$ values using linkage Table 2 to estimate an ex-vessel price for each pooled commodity (Figure 1):

$$P_{\text{exvessel}_{\text{poolC, year}}} = \frac{P_{\text{export}_{\text{poolC, year}}}}{EEPEF_{\text{ISSCAAP}_{\text{year}}}} . \tag{5}$$

Finally, we assigned the time series of reconstructed ex-vessel prices for the best-matched pooled commodity to each of the

Table 1. Numbers of fishery commodities, pooled commodities, and species within each ISSCAAP group

ISSCAAP division	ISSCAAP group	Number of FAO fishery commodities [a]	Number of pooled commodities	Number of species [b]
Marine Fishes				
	Cods, hakes, haddocks	179	23	75
	Flounders, halibuts, soles	73	17	60
	Herrings, sardines, anchovies	92	12	50
	Sharks, rays, chimaeras	40	7	176
	Tunas, bonitos, billfishes	78	14	49
	Marine fishes not identified	87	2	2
	Miscellaneous coastal fishes	70	24	433
	Miscellaneous demersal fishes	68	18	188
	Miscellaneous pelagic fishes	70	16	135
	(Fish for reduction)[c]	6	1	5
Diadromous Fishes				
	River eels	7	2	5
	Salmons, trouts, smelts	67	12	33
	Shads	2	2	24
	Sturgeons, paddlefishes	2	1	9
	Miscellaneous diadromous fishes	22	3	8
Freshwater Fishes				
	Carps, barbels and other cyprinids	4	1	62
	Tilapias and other cichlids	5	1	21
	Miscellaneous freshwater fishes	42	6	148
Crustaceans				
	Crabs, sea-spiders	14	3	37
	Lobsters, spiny-rock lobsters	41	6	39
	King crabs, squat-lobsters [d]	5	2	20
	Shrimps, prawns	33	6	76
	Krill, planktonic crustaceans [e]	1	1	2
	Miscellaneous marine crustaceans [f]	17	2	10
	Freshwater crustaceans	7	2	16
Molluscs				
	Abalones, winkles, conchs	13	4	24
	Clams, cockles, arkshells	12	2	56
	Scallops, pectens	7	1	15
	Mussels	13	3	12
	Oysters	14	2	9
	Squids, cuttlefishes, octopuses	39	8	35
	Miscellaneous marine molluscs	15	2	1
	Freshwater molluscs			2
Miscellaneous Aquatic Animals				
	Sea-urchins and other echinoderms	10	2	14
	Horseshoe crabs and other arachnoids [g]			1
	Sea-squirts and other tunicates [g]			5
	Miscellaneous aquatic invertebrates	13	2	4
Total commodities or species available for pairing [h]		1168	210 [i]	1861

[a]fishery commodities from *Global commodities production and trade* database (FAO, 2016b).

[b]ASFIS species from *Global capture production* database (FAO, 2016a).

[c]Commodities involving oil derived from small pelagic fishes were assigned to the pooled commodity "Fish for reduction" and to the manually-created ISSCAAP group "Fish for reduction" to separate them from other small pelagic fish commodities and to better pair prices with the "Fish for reduction" group from the FAO mean ISSCAAP ex-vessel price estimates (FAO, 2014). All five species are menhaden species.

[d]Species of "King crabs, squat-lobsters" were paired with the price expansion factor for "Crabs, sea-spiders" because a mean ISSCAAP ex-vessel price estimate was not available for "King crabs, squat-lobsters".

[e]Species of "Krill, planktonic crustaceans" were paired with the price expansion factor for "Miscellaneous marine crustaceans" because a mean ISSCAAP ex-vessel price estimate was not available for "Krill, planktonic crustaceans".

[f]The commodity "Miscellaneous crustaceans, not frozen, nei" was excluded due to suspected decimal place errors in the fishery commodities database.

[g]Species of "Horseshoe crabs and other arachnoids" and "Sea-squirts and other tunicates" were paired with the price expansion factor for "Miscellaneous aquatic invertebrates" because a mean ISSCAAP ex-vessel price estimate was not available for the former two groups.

[h]Commodities, pooled commodities, and species within some ISSCAAP groups were not included because there were no mean ISSCAAP ex-vessel price estimates in FAO (2014) available to pair for price conversions. ISSCAAP groups excluded were: miscellaneous aquatic mammals (7 commodities/1 pooled commodity/88 species); aquatic plants (18/1/39); corals (2/1/16); sponges (3/1/6); pearls, mother-of-pearl, shells (7/1/5); frogs and other amphibians (1 species); crocodiles and alligators (16 species); and turtles (7 species).

[i]7 pooled commodities were not assigned to any species because better fits were available, and 15 pooled commodities did not have reliable time series of export prices available (in these cases the next-best pooled commodity was linked to each species), leaving 189 pooled commodities linked to the 1861 species.

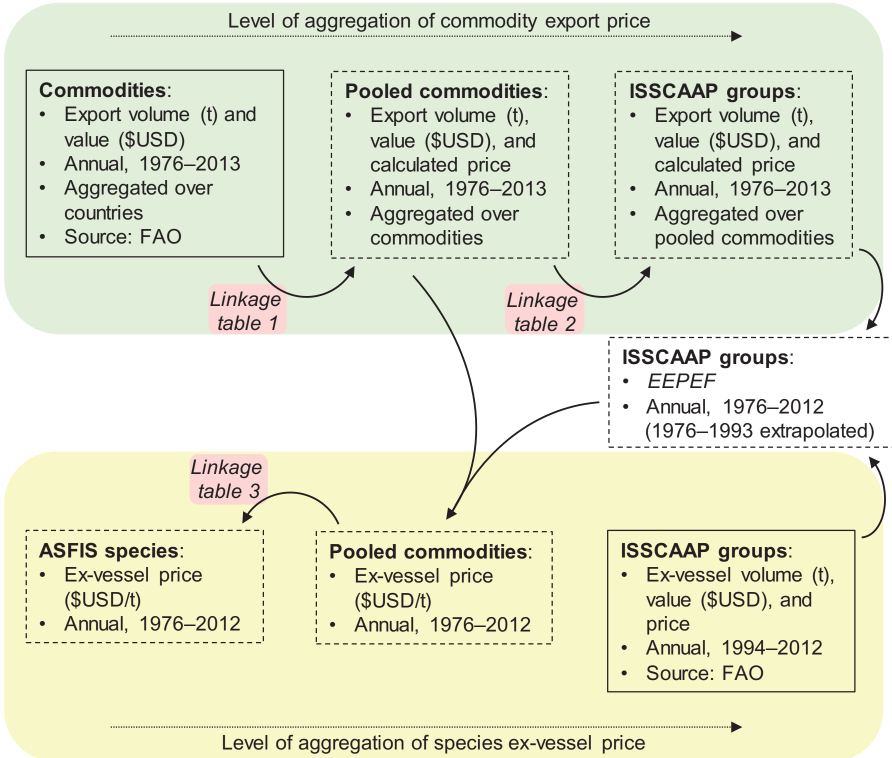

Figure 1. Summary of approach used to reconstruct ex-vessel prices and link these prices to species. Upper shaded region represents export prices and lower shaded region represents ex-vessel prices. Boxes with solid outlines represent input data and boxes with dotted outlines represent derived quantities. Arrows show the sequence of steps taken, with use of linkage Tables 1–3 (Supplementary Tables S1–S3) indicated.

species from the FAO landings database (Figure 1) using *linkage Table 3* (Supplementary Table S3). This resulted in 189 unique time series of reconstructed ex-vessel prices assigned to one or more of 1861 species from the FAO landings database. Source code is available at the following GitHub site: https://github.com/SFG-UCSB/price-db-sfg

Validation of reconstructed prices

We compared reconstructed ex-vessel prices with those for corresponding species from national datasets of ex-vessel prices. Datasets used for comparisons were from countries of the European Union (European Market Observatory for Fisheries and Aquaculture Products), Norway (Directorate of Fisheries), United States (National Marine Fisheries Service; Atlantic Coastal Cooperative Statistics Program; Pacific Fisheries Information Network; Alaska Department of Fish and Game; Washington Department of Fish and Wildlife; and California Department of Fish and Game), Canada (Fisheries and Oceans Canada), New Zealand (Ministry of Fisheries), Philippines (CountrySTAT), and Mexico (National Commission of Aquaculture and Fishing). For each country, we paired ex-vessel price estimates by species and year with our reconstructed ex-vessel price estimates (again, which were derived from FAO export price data and not from national ex-vessel price datasets). We plotted paired estimates separated by year, country, or taxonomic grouping, and calculated correlation coefficients between the two datasets for these subsets. We restricted comparisons to species with >100 t of landings for a given year and country.

We also compared reconstructed ex-vessel prices with those for corresponding species from ex-vessel price estimates of Swartz *et al.* (2013). Swartz and co-authors compiled ex-vessel price estimates from national datasets and used regression methods to estimate prices for combinations of species and countries for which ex-vessel price data were not available. We compare our reconstructed ex-vessel prices only to the prices that were likely estimated by Swartz *et al.* (2013), not to the prices that were likely compiled from national datasets.

We conducted a sensitivity analysis to evaluate the influence of the degree of processing on the adherence of reconstructed prices to actual prices. We categorised fishery commodities into high (e.g. fishmeal, cooked, smoked), low (e.g. fresh, whole, chilled), and intermediate/ambiguous (e.g. pickled, dried, roe) processing types. Analyses were repeated for two subsetted datasets—one involving only low-processing types and the other involving low and intermediate-processing types—to compare with the results based on the full dataset.

Our approach provides reconstructed ex-vessel prices by species since 1976, and can be updated annually with the provided source code as FAO releases updates to its export database and ISSCAAP-level average ex-vessel price summaries. However, reported ex-vessel prices from national datasets will generally be more accurate than our reconstructed ex-vessel prices which require down-conversion from export prices. Users desiring the best available ex-vessel price time series for data analyses may wish to use reported ex-vessel prices from national datasets when those are available, and supplement these with

Table 2. Medians of weighted mean export price, weighted mean ex-vessel price, and *EEPEF* for each ISSCAAP group for years 1994–2012

ISSCAAP group	Median export price (US$/t) [a,b]	Median ex-vessel price (US$/t) [c]	Median *EEPEF* [a]
Sturgeons, paddlefishes	155 640	9750	23.13
Miscellaneous aquatic invertebrates	2881	250	11.62
Miscellaneous diadromous fishes	6319	860	7.82
Miscellaneous freshwater fishes	3026	398	7.73
Miscellaneous marine molluscs	2701	430	6.51
Sea-urchins and other echinoderms	12 123	2100	6.15
Fish for reduction	393	85	5.14
Scallops, pectens	7498	1464	5.12
Oysters	3939	750	5.04
Mussels	1388	360	4.68
Sharks, rays, chimaeras	3563	830	4.31
Herrings, sardines, anchovies	1059	267	3.94
Abalones, winkles, conchs	16 731	5400	3.70
Clams, cockles, arkshells	3260	936	3.55
River eels	10 471	4150	2.80
Freshwater crustaceans	5710	2510	2.75
Marine fishes not identified	1099	465	2.72
Cods, hakes, haddocks	2338	916	2.60
Crabs, sea-spiders	5781	2473	2.29
Miscellaneous demersal fishes	2867	1344	2.14
Tilapias and other cichlids	2092	1020	2.09
Carps, barbels and other cyprinids	1802	984	1.92
Salmons, trouts, smelts	4450	2453	1.81
Shrimps, prawns	6270	3520	1.78
Miscellaneous pelagic fishes	691	480	1.70
Tunas, bonitos, billfishes	2162	1400	1.62
Lobsters, spiny-rock lobsters	12 451	8880	1.52
Flounders, halibuts, soles	2985	2250	1.45
Miscellaneous coastal fishes	2757	2034	1.40
Squids, cuttlefishes, octopuses	2309	1670	1.39
Shads	450	640	1.18
Miscellaneous marine crustaceans	3054	2512	1.16

[a]Annual values of weighted mean export price and *EEPEF* by ISSCAAP group for years 1976–2012 are given in Tables S4 and S5, respectively.
[b]Calculated from values and quantities in FAO (2016b). Weighted mean prices for each year 1994–2012 are weighted by quantity.
[c]Calculated from values and quantities in FAO (2014). Weighted mean prices for each year 1994–2012 are weighted by quantity.

our reconstructed ex-vessel prices for the species and countries for which reported ex-vessel prices from national datasets are lacking.

Results

Reconstructed ex-vessel prices

Reconstructed ex-vessel prices over the 210 pooled commodities ranged from as low as 108 $USD/t for brislings or sprats to as high as 18 754 $USD/t for spiny lobsters in the year 2012. After pairing each species from the FAO landings database with its best-matched pooled commodity, the 189 unique time series of reconstructed ex-vessel prices that were assigned to one or more of the 1831 species also shared this range of prices. Time series of reconstructed ex-vessel prices from 1976–2012 are available as Supplementary Materials, both by pooled commodity (Supplementary Table S6) and by species (Supplementary Table S7).

The aggregation of fishery commodity export prices into pooled commodities and then into ISSCAAP groups, along with the disaggregation of ISSCAAP mean ex-vessel prices into pooled commodities and then into species (Figure 1), yielded a diverse set of reconstructed ex-vessel price time series. About 70% of pooled commodities consisted of 5 or fewer fishery commodities, while 13% of pooled commodities contained 10 or more fishery commodities (Supplementary Figure S1); the pooled commodity 'Miscellaneous marine fishes' contained the greatest number of fishery commodities (85, Supplementary Figure S1c). Similarly, most ISSCAAP groups contained up to 90 fishery commodities, with the group 'Cods, hakes and haddocks' containing the most (179; Figure S1d). Aggregating further, half the ISSCAAP groups contained 1 or 2 pooled commodities, though some ISSCAAP groups contained up to 24 pooled commodities (Table 1). Two-thirds of the pooled commodities were assigned to 5 or fewer species though 5% of pooled commodities were assigned to 50–100 species (Supplementary Figure S1); the pooled commodity 'Misc. coastal fishes' was assigned to the greatest number of species (202; Supplementary Figure S1a). Its parent ISSCAAP group of the same name, "Miscellaneous coastal fishes", contained 433 species, over twice as many as other ISSCAAP groups (Table 1; Supplementary Figure S1b). The shape of the distribution of species per pooled commodity (Supplementary Figure S1a) resembled that of the distribution of fishery commodities per pooled commodity (Supplementary Figure S1c).

There is considerable variability in export prices in the FAO commodities database, and the method described maintains this variability in reconstructed ex-vessel prices among the pooled

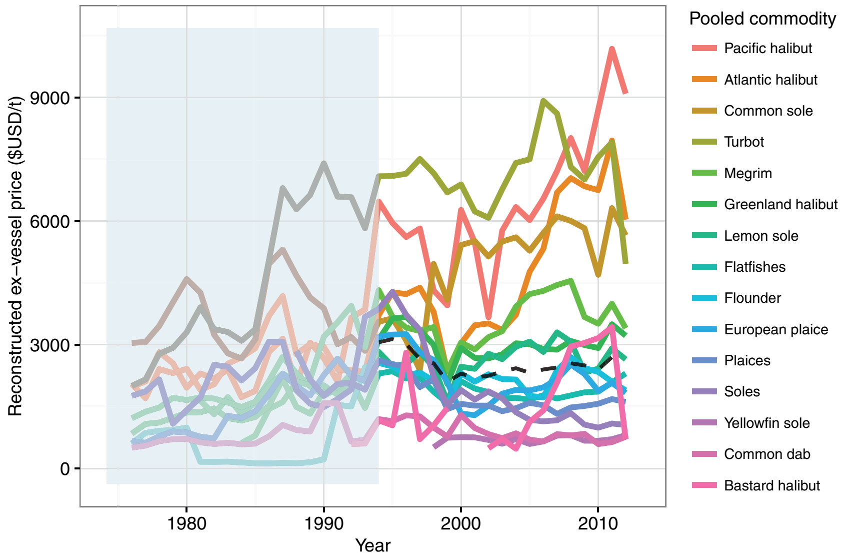

Figure 2. Reconstructed ex-vessel prices of pooled commodities of flatfishes for years 1976-2012. The weighted mean ex-vessel price for the overall ISSCAAP group as reported by FAO (2014) is overlaid as the dashed black line for years 1994–2012. The legend orders pooled commodities according to their reconstructed ex-vessel prices in 2012. The grey-shaded region indicates years for which Export:Ex-vessel price expansion factors were back-extrapolated. Similar plots are shown for each ISSCAAP group in Supplementary Figure S2.

commodities within each ISSCAAP group. An example is shown for pooled commodities of flatfishes (Figure 2). Some species like Pacific halibut, Atlantic halibut and turbot have reconstructed ex-vessel prices approximately 10-fold greater than those of yellowfin sole and common dab, with other flatfishes intermediate. The weighted mean ex-vessel price for this ISSCAAP group published by FAO (2014; black line in Figure 2) does not account for this order-of-magnitude variability in price among species within the ISSCAAP group. Similar plots for each ISSCAAP group are shown in Supplementary Figure S2.

Validation of reconstructed prices

When compared with ex-vessel prices from national datasets (hereafter "actual price"), reconstructed ex-vessel prices did not show consistent bias. There was considerable variability among reconstructed prices and actual prices, but these were centred around the 1:1 line of equal price (Figures 3, Supplementary Figure S3). Correlation coefficients for reconstructed prices and actual prices were variable in earlier years 1976–1993 (0.35–0.73), but were higher and more consistent between 1994 and 2012 (0.55–0.76; Supplementary Table S8). The best-fit lines through paired prices had slopes <1 in most years, suggesting a tendency for reconstructed ex-vessel prices to be over-estimated at low actual prices and under-estimated at high actual prices. This results in a reduced range of reconstructed prices compared with actual prices (Figures 3, Supplementary Figure S3). Among the countries considered for price comparisons, all countries showed positive correlations between reconstructed prices and actual prices, but the strengths of relationships differed. Some countries like the United States, Canada, and Mexico showed slopes <1, again with a reduced range of reconstructed prices compared with actual prices, while other countries like Italy and Spain tended to have slopes near 1 but lower reconstructed prices than actual prices (Figures 4, Supplementary Figure S4). Mexico, the Netherlands, Norway, Denmark, New Zealand, and the United Kingdom had the highest correlation coefficients between paired prices over the full time series (0.87–0.94; Supplementary Table S9). The Philippines, Italy, the United States, Spain, and Canada had relatively low correlation coefficients (0.48–0.61), while those of France and Ireland were intermediate (0.72–0.77; Supplementary Table S9).

Much of the observed variability in reconstructed prices appears to occur among broad taxonomic groups; e.g. invertebrates tend to fetch high prices (Figures 3 and 4). Within broad taxonomic groups, there is less variability among species in reconstructed prices (Figures 5, Supplementary Figure S5). Separating price comparisons by ISSCAAP groups further reveals the tendency of reduced range of reconstructed prices compared with actual prices, with little variability in reconstructed prices of some groups like shrimps/prawns, sharks/rays/chimaeras, or miscellaneous coastal fishes despite considerable variability in actual prices. There was no evidence of consistent bias at the level of ISSCAAP groups with the possible exception of tunas/bonitos/billfishes, which tended to have slightly lower reconstructed prices than actual prices (Figure 5). Over all countries, and with comparisons separated by ISSCAAP groups, correlation coefficients were typically between 0.3 and 0.7 although a few groups were < 0.1 (Supplementary Table S10; Supplementary Figure S6). Correlation coefficients showed similar variability at the level of pooled commodities, in which some pooled commodities had correlation coefficients near 1 while others had slightly negative correlations (Supplementary Table S11; Supplementary Figure S6). When reconstructed prices were instead separated by year, correlation coefficients for paired prices were less variable and higher overall, with most values between 0.60 and 0.75 (Supplementary Figure S6). This suggests that the correspondence of reconstructed prices to actual prices strengthens when comparisons involve multiple ISSCAAP groups over a wide range of actual prices.

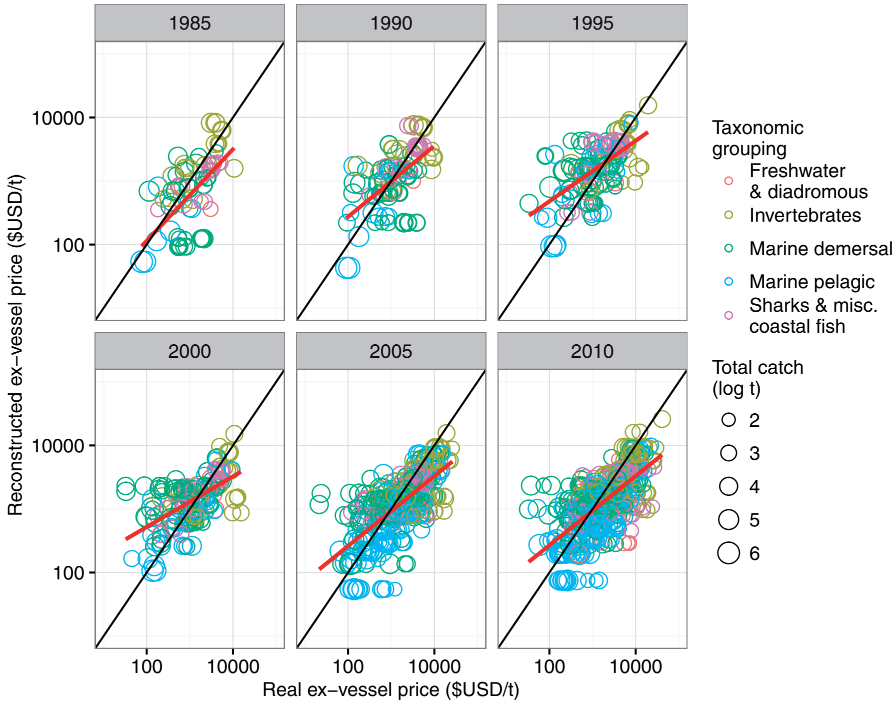

Figure 3. Comparison of reconstructed ex-vessel prices and known ex-vessel prices from national datasets in six calendar years. Symbols show paired species with >100 t of landings, grouped by major taxonomic groupings. Size of symbols is scaled to the log total catch of the species reported to the FAO by the same country in the same year. Thick lines indicate best linear fits. Thin lines indicate 1:1 relationships. Similar plots are shown for each year 1976–2011 in Supplementary Figure S3. Correlation coefficients for individual years are listed in Supplementary Table S8.

Similar to comparisons with prices from national datasets, there was no evidence of consistent bias between reconstructed prices and ex-vessel prices estimated by Swartz *et al.* (2013) for corresponding species (Figures 6, Supplementary Figure S7). There is considerable variation among ISSCAAP groups using both methods, but for any given ISSCAAP group, estimates tended to fall around the 1:1 line on average. Differences of 1–2 orders of magnitude were occasionally observed, however. The largest discrepancies were seen in herrings/sardines/anchovies (Figure 6) from Slovenia, which may result from a decimal place or price conversion error in the Swartz *et al.* (2013) dataset.

Sensitivity analyses showed that excluding more highly processed commodity types before reconstructing ex-vessel prices did not generally lead to greater adherence with actual prices. Most correlation coefficients with actual prices were identical or very similar for subsetted datasets compared with the full dataset, with paired correlation coefficients falling on the 1:1 line (Supplementary Figure S8). A few correlations were slightly improved by excluding the highest-processed commodities (symbols below 1:1 line in Supplementary Figure S8a–c) but more correlations deteriorated by additionally excluding commodity types of intermediate (or ambiguous) processing (symbols above 1:1 line in Supplementary Figure S8d–f); adherence with actual prices was generally greatest for the full dataset.

Discussion

We have presented a novel method to estimate ex-vessel prices at a high taxonomic resolution (generally species) by combining two publicly available datasets: export prices at a high product resolution (FAO fishery commodities; FAO, 2016b) and ex-vessel prices at a low taxonomic resolution (ISSCAAP groups; FAO, 2014). Using this method, the variability in export prices among species is maintained, and prices are converted downwards into ex-vessel prices. The taxonomic resolution of reconstructed ex-vessel prices reflects that of available export price information. If species-specific price information exists in the commodity export database, that is reflected in the ex-vessel price estimate for the species. If there are no species-specific commodities, an ex-vessel price for a taxonomic group of lower resolution is instead assigned to the species.

The method developed in this paper depends on the degree to which variations in ex-vessel prices and export prices are transmitted to each other, i.e. the degree of price transmission. If only one input, such as raw fish, is used to produce an export product, then export and ex-vessel price fluctuations are expected to be tightly linked. However, a number of factors can affect price transmission (Gardner, 1975). First, if export products require other inputs like processing, transportation and marketing, the costs of those inputs will also be reflected in export prices. Because these other costs tend to be less variable than raw fish prices, the variability in export prices may be less than that of ex-vessel prices, as was observed. Second, substitution between the raw fish products used to produce exported commodities can alter the dynamics of price transmission. Although our methodology does not explicitly include these processes in our estimation of ex-vessel prices, they likely create a mediating effect on the transmission of variation between export and ex-vessel prices, consistent with our results of reconstructed prices showing less

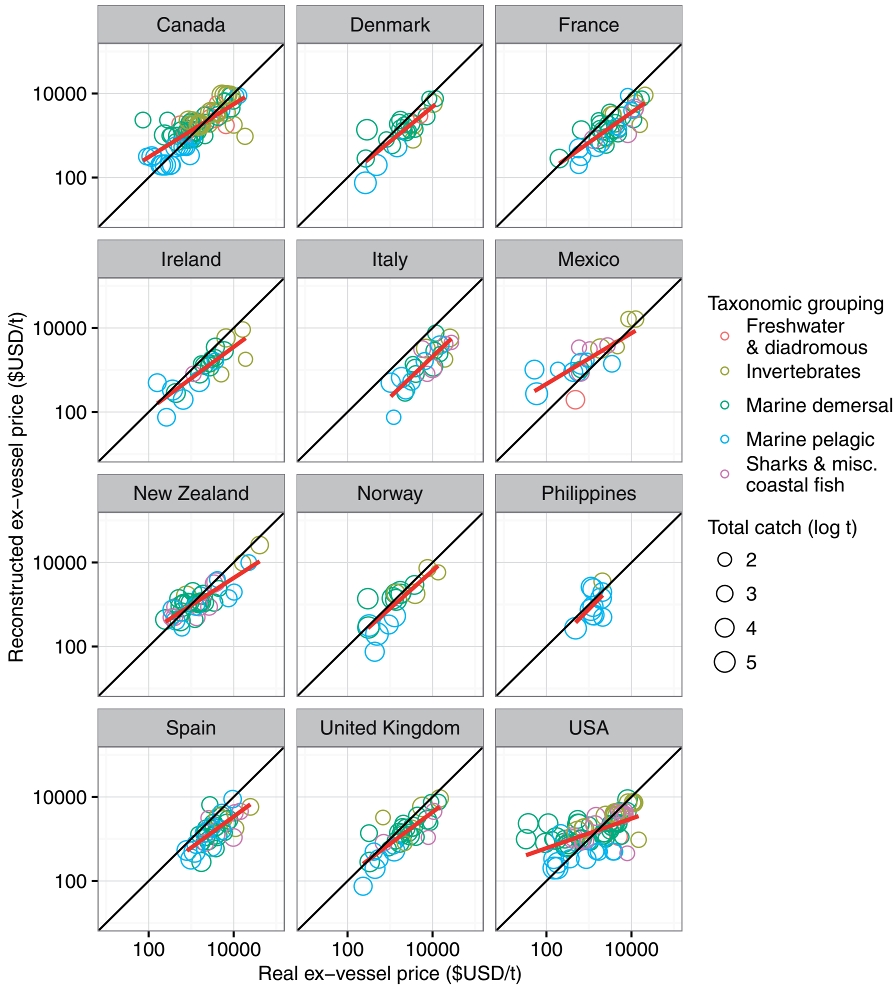

Figure 4. Comparison of reconstructed ex-vessel prices and known ex-vessel prices from national datasets for select countries (6 European Union countries with greatest sample sizes, and 6 non-EU countries). Values for 2010 are shown for paired species with >100 t of landings. Similar plots are shown for other countries in Supplementary Figure S4. Correlation coefficients for individual countries are listed in Supplementary Table S9.

variability than actual ex-vessel prices, especially in comparisons within ISSCAPP groups. Another possible explanation for the reduced range of reconstructed prices compared with actual prices is that ex-vessel prices are first reconstructed at the level of pooled commodities, which is typically more aggregated than the species level (Supplementary Figure S1a), so that several species may be linked to the same pooled commodity and thus share the same reconstructed price time series.

Ex-vessel prices estimated with the described method are advantageous in their global comprehensiveness and consistency across years and countries. Price estimates rely solely on publicly-available data from FAO and thus are more consistent across countries in terms of units, taxonomic resolution, and time series duration than compiling national datasets of ex-vessel prices from several countries. Similarly, because export prices tend to be more available than ex-vessel prices in many developing countries, this method does not extrapolate ex-vessel prices from data-rich countries to similar species of developing countries (we do note, however, that the above price validations mainly involve developed countries). These advantages are important for global studies involving economic aspects of commercial marine fisheries, such as those in Costello *et al.* (2016) which used estimates derived from the method presented here, because it avoids using ex-vessel prices from only data-rich regions. This method allows for flexible linkages to alternate species or stock lists by modifying or replacing *linkage* Table 3 (Supplementary Table S3). This method also allows for analyses specific to certain regions or countries if desired instead of global mean prices, by filtering the original fishery commodities export database to include only those regions or countries. Moreover, the data linkage tables and source code are publicly available and therefore allow users to update ex-vessel price estimates when FAO releases annual updates to the fishery commodities export database and estimated global mean ex-vessel price of ISSCAAP groups.

There are also limitations of the described method. A key assumption of this method is that the same Export:Ex-vessel price expansion factor (*EEPEF*) applies to all species within each ISSCAAP group. This assumption implies that the percentage price increase resulting from added value, or the product recovery ratios during processing, are the same for all species within an ISSCAAP group. This will never be perfectly true because even closely-related species are often processed differently for specific

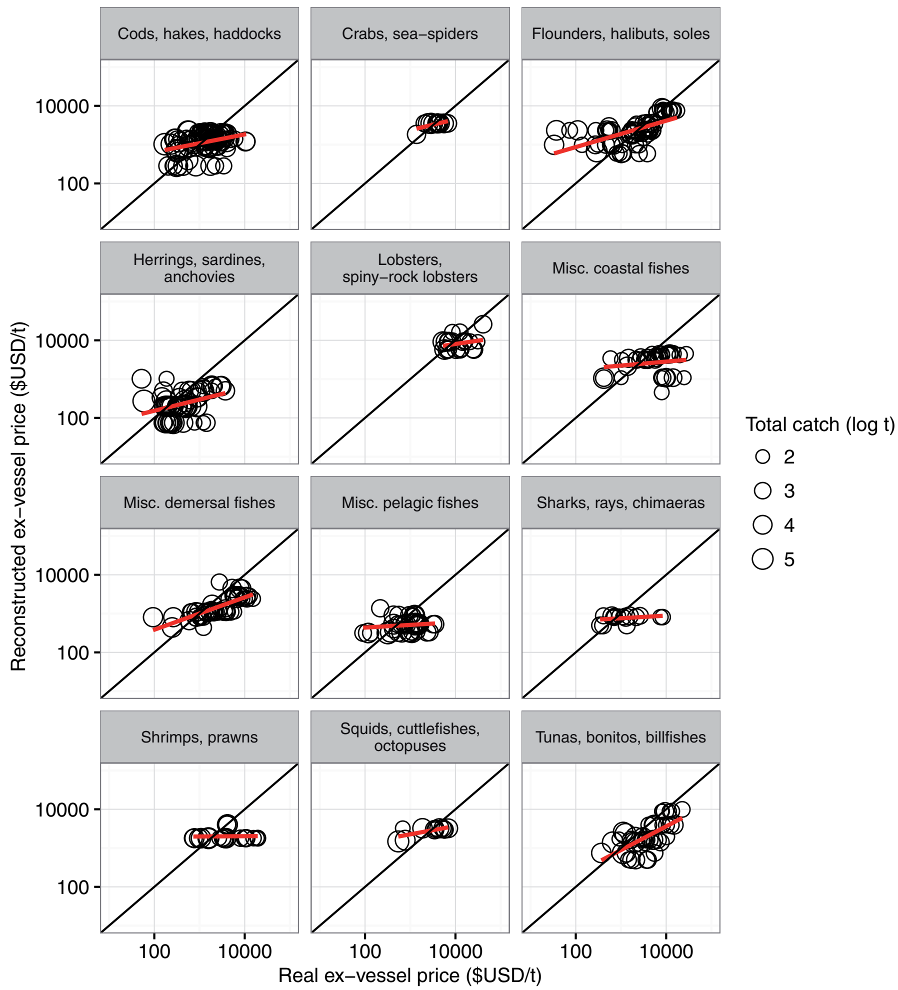

Figure 5. Comparison of reconstructed ex-vessel prices and ex-vessel prices from national datasets for select ISSCAAP groups (12 with greatest sample sizes). Values for 2010 are shown for paired species with >100 t of landings. Similar plots are shown for other ISSCAAP groups in Supplementary Figure S5. Correlation coefficients for individual ISSCAAP groups are listed in Supplementary Table S10.

delivery to markets (McConnell and Strand, 2000), have different product retention proportions (Clucas and Ward, 1996; Asche *et al.*, 2007, 2015; Miyake *et al.*, 2010), and are priced differently based on the size or quality of fish (Gates, 1974; McConnell and Strand, 2000) or the abundance of the species in the given market (McConnell and Strand, 2000; Pinnegar *et al.*, 2002, 2006; Baeta *et al.*, 2009). However it does seem reasonable that, for example, two flatfish species will be more similar to one another than to a tuna species or to a lobster species. Another important assumption involves the annual composition of commodities within each pooled commodity. If some product types within a pooled commodity are over- or under-represented in some years as a result of sampling procedures for exported quantities and values, that will influence the aggregate export price time series, adding interannual variability which will transfer to reconstructed ex-vessel prices. Similarly, as reconstructed prices are based on exported commodities, they will under-represent species that are primarily traded domestically. All else equal, non-export species may reasonably fetch lower ex-vessel prices than exported species, particularly in developing countries. Finally, reconstructed ex-vessel prices using this approach are not expected to be as accurate as those drawn from national datasets; users requiring the best available prices for a given species and country are urged to first seek out official reported prices.

Variation in *EEPEF* values among ISSCAAP groups results from differences among taxa in added value from fish processing or product recovery ratios occurring between the steps of landing fish and exporting fish. The high value for sturgeon and paddlefish (Table 2) is attributable to the high value of caviar, one of the included commodities. Two ISSCAAP groups, shads and miscellaneous marine crustaceans, had values <1 in some years which may have resulted from different subsets of species included in the two data sources, but median values across years were >1. Although invertebrate groups tend to have relatively high prices (Figures 3 and 4), they are represented throughout the range of *EEPEF* values (Table 2). Interannual variability in EEPEF values was generally much less than variability among ISSCAAP groups, supporting the method of back-extrapolating *EEPEF* values for earlier years.

Use of the described method for reconstructing ex-vessel prices appears to be most promising for analyses that involve multiple taxonomic groups. The variation in ex-vessel prices among

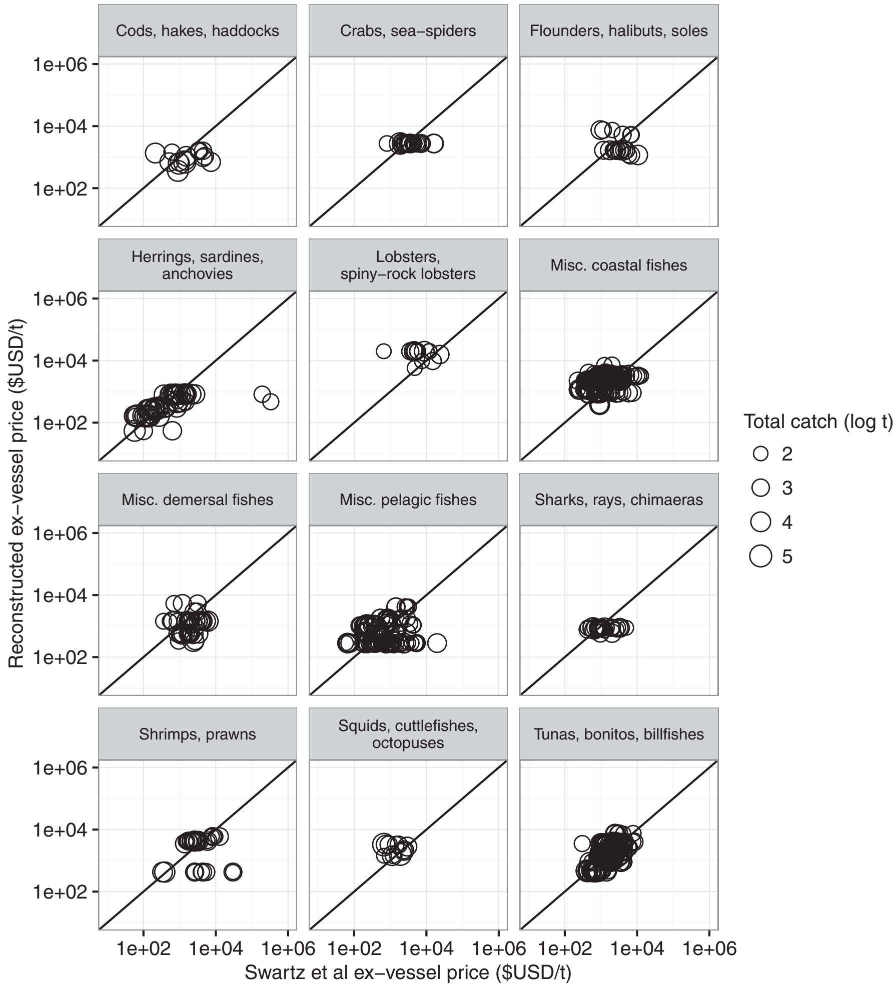

Figure 6. Comparison of reconstructed ex-vessel prices and estimated ex-vessel prices from Swartz *et al.* (2013) for select ISSCAAP groups (12 with greatest sample sizes). Paired values for 2005 are shown for species with >100 t of landings. Comparisons exclude the following countries because their ex-vessel prices may be extracted from national datasets rather than estimated by the regression methods of Swartz *et al.* (2013), such that the remaining values shown are likely all estimated values: Argentina, Australia, Belgium, Brazil, Brunei Darsm, Canada, Chile, Denmark, Estonia, Faeroe Is, Finland, France, Germany, Greece, Greenland, Hong Kong, Iceland, India, Indonesia, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Malaysia, Mauritania, Mexico, Morocco, Namibia, Netherlands, New Caledonia, Norway, Peru, Philippines, Poland, Portugal, Puerto Rico, Seychelles, Singapore, South Africa, South Korea, Spain, Sweden, Thailand, Turkey, United Kingdom, United States, US Virgin Is, and "Other nei". Similar plots are shown for other ISSCAAP groups in Supplementary Figure S7.

ISSCAAP groups is considerable (Table 2). In many cases there is also considerable variation among species within ISSCAAP groups (Figures 2, Supplementary Figure S2), but in other cases the variability in reconstructed prices is less than expected compared with actual prices (Figure 5). The reduced range of reconstructed prices compared with actual prices likely results from incomplete price transmission, as discussed earlier, and also because ex-vessel prices for pooled commodities were typically paired with more than one species for which actual ex-vessel prices vary. Different species sharing the same reconstructed price is a limitation of the taxonomic resolution of the FAO fishery commodity export database (FAO, 2016b). For example, the outliers at low actual prices in the panels for USA and Canada (Figure 4) and flounders/halibuts/soles (Figure 5) are Alaskan and British Columbian stocks of arrowtooth flounder and flathead sole. There are no FAO commodities for these particular species, so they are instead assigned the more generic "flounder" and "sole" pooled commodities, which have higher prices than the actual prices of these particular species. In analyses comprising diverse taxonomic groups, however, the relative importance of a reduced range of reconstructed prices diminishes because there is greater overall variation in price across the multiple taxonomic groups. Similarly, analyses involving multiple species will also reduce overall discrepancies that may otherwise result from limited sample sizes. Discrepancies between median reconstructed and actual ex-vessel prices were observed for several countries (Supplementary Table S9), ISSCAAP groups (Supplementary Table S10), or pooled commodities (Supplementary Table S11) when comparisons involved a limited number of species or species × year combinations. In some cases prices were overestimated, in others they were underestimated. As the number of species (or sample size) involved in comparisons increased, however, the discrepancies between median prices were greatly reduced (Supplementary Figure S9).

The described method also appears to be most promising for analyses involving multiple countries or regions. A reduced range of reconstructed ex-vessel prices compared with actual prices can be expected whether price estimates are intended for species in one country (or region) or in many countries (or regions), but the method described is most advantageous for global or multi-region analyses because of its consistency across countries. If interest is instead in obtaining ex-vessel prices for a particular region or country, it is preferable to directly use official ex-vessel price data for those specific areas (as long as they are available, which our searches have indicated may be rare, especially for developing countries). The method proposed here is particularly well-suited for global analyses in which ex-vessel price data are not available for many species or regions of interest.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the article.

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References

Anderson, J. L. 1985. Market interactions between aquaculture and the common-property commercial fishery. Marine Resource Economics, 2: 1–24.

Arnason, R., Kelleher, K., Willmann, R. 2009. The Sunken Billions: The Economic Justification for Fisheries Reform. The World Bank, Washington, DC. pp. 1–130.

Asche, F., Chen, Y., and Smith, M. D. 2015. Economic incentives to target species and fish size: prices and fine-scale product attributes in Norwegian fisheries. ICES Journal of Marine Science, 72: 733–740.

Asche, F., Menezes, R., and Dias, J. 2007. Price transmission in cross boundary supply chains. Empirica, 34: 477–489.

Baeta, F., José Costa, M., and Cabral, H. 2009. Changes in the trophic level of Portuguese landings and fish market price variation in the last decades. Fisheries Research, 97: 216–222.

Clucas, I., and Ward, A. R. 1996. Post-Harvest Fisheries Development: A Guide to Handling, Preservation, Processing and Quality. Natural Resources Institute Marketing Series, Cornell, NY.

Costello, C., Ovando, D., Clavelle, T., Strauss, C. K., Hilborn, R., Melnychuk, M. C., Branch, T. A., et al. 2016. Global fishery prospects under contrasting management regimes. Proceedings of the National Academy of Sciences of the United States of America, 113: 5125–5129.

Dahl, R. E., and Oglend, A. 2014. Fish price volatility. Marine Resource Economics, 29: 305–322.

Doll, J. P. 1972. An econometric analysis of shrimp ex-vessel prices, 1950-1968. American Journal of Agricultural Economics, 54: 431–440.

FAO. 2014. Appendix II – World fishery production: estimated value by groups of species. Summary Tables of Fishery Statistics 2014. UN FAO Fisheries and Aquaculture Department, Rome. ftp://ftp.fao.org/fi/stat/summ_tab.htm.

FAO. 2016a. Fishery Statistical Collections: Global capture production (1950-2014). Accessed through FishStatJ software, UN FAO Fisheries and Aquaculture Department, Rome.

FAO. 2016b. Fishery Statistical Collections: Global commodities production and trade (1976-2013). Accessed through FishStatJ software, UN FAO Fisheries and Aquaculture Department, Rome.

FAO. 2016c. FishStatJ - software for fishery statistical time series. Version 3.00.1. UN FAO Fisheries and Aquaculture Department, Rome.

Fletcher, J. J., Howitt, R. E., and Johnston, W. E. 1987. Management of multipurpose heterogeneous fishing fleets under uncertainty. Marine Resource Economics, 4: 249–270.

Gardner, B. L. 1975. The farm-retail price spread in a competitive food industry. American Journal of Agricultural Economics, 57: 399–409.

Garibaldi, L. 2012. The FAO global capture production database: A six-decade effort to catch the trend. Marine Policy, 36: 760–768.

Gates, J. M. 1974. Demand price, fish size and the price of fish. Canadian Journal of Agricultural Economics, 22: 1–12.

Gillig, D., Capps, O., and Griffin, W. L. 1998. Shrimp ex-vessel prices landed from the Gulf of Mexico. Marine Resource Economics, 13: 89–102.

Gordon, D. V., and Hussain, S. 2015. Price determination and demand flexibilities in the ex-vessel market for tuna in the Republic of Maldives. Aquaculture Economics and Management, 19: 8–28.

Guillen, J., and Maynou, F. 2014. Importance of temporal and spatial factors in the ex-vessel price formation for red shrimp and management implications. Marine Policy, 47: 66–70.

Guillotreau, P. 2004. How does the European seafood industry stand after the revolution of salmon farming: An economic analysis of fish prices. Marine Policy, 28: 227–233.

Kaplan, I. C., Holland, D. S., and Fulton, E. A. 2014. Finding the accelerator and brake in an individual quota fishery: linking ecology, economics, and fleet dynamics of US West Coast trawl fisheries. ICES Journal of Marine Science, 71: 308–319.

Kobayashi, M., Msangi, S., Batka, M., Vannuccini, S., Dey, M. M., and Anderson, J. L. 2015. Fish to 2030: The role and opportunity for aquaculture. Aquaculture Economics and Management, 19: 282–300.

Lam, V. W. Y., Sumaila, U. R., Dyck, A., Pauly, D., and Watson, R. 2011. Construction and first applications of a global cost of fishing database. ICES Journal of Marine Science, 68: 1996–2004.

McConnell, K. E., and Strand, I. E. 2000. Hedonic prices for fish: tuna prices in Hawaii. American Journal of Agricultural Economics, 82: 133–144.

Miyake, M. P., Guillotreau, P., Sun, C. H., and Ishimura, G. 2010. Recent developments in the tuna industry: stocks, fisheries, management, processing, trade and markets. ICES Document, 543: 125. pp.

Pinkerton, E., and Edwards, D. N. 2009. The elephant in the room: The hidden costs of leasing individual transferable fishing quotas. Marine Policy, 33: 707–713.

Pinnegar, J. K., Hutton, T. P., and Placenti, V. 2006. What relative seafood prices can tell us about the status of stocks. Fish and Fisheries, 7: 219–226.

Pinnegar, J. K., Jennings, S., O'Brien, C. M., and Polunin, N. V. C. 2002. Long-term changes in the trophic level of the Celtic Sea fish community and fish market price distribution. Journal of Applied Ecology, 39: 377–390.

Sethi, S. A., Branch, T. A., and Watson, R. 2010. Global fishery development patterns are driven by profit but not trophic level. Proceedings of the National Academy of Sciences of the United States of America, 107: 12163–12167.

Sumaila, U. R., Marsden, A. D., Watson, R., and Pauly, D. 2007. A global ex-vessel fish price database: Construction and applications. Journal of Bioeconomics, 9: 39–51.

Swartz, W., Sumaila, R., and Watson, R. 2013. Global ex-vessel fish price database revisited: A new approach for estimating 'missing' prices. Environmental and Resource Economics, 56: 467–480.

Tveterås, S., Asche, F., Bellemare, M. F., Smith, M. D., Guttormsen, A. G., Lem, A., Lien, K., et al. 2012. Fish is food - The FAO's fish price index. PLoS One, 7: e36731.

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