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THE END USE OF MARINE FISHERIES LANDINGS

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Glossary of Terms

DHC- Direct Human Consumption

FAO- Food and Agriculture Organization of the United Nations

FCR - Feed Conversion Ratio

FMFO – Fishmeal and Fish Oil

Study Aim and Methods

Globally, the production of fishmeal and fish oil (FMFO) has been reliant on dedicated fisheries since at least the 1950s. While these products formerly found diverse uses, they are now used almost entirely for livestock and aquaculture production (Tacon and Metian 2008). There has also been a growth in the practice of direct feeding of fish to aquaculture operations for various taxa (Funge-Smith *et al.* 2005). Both of these uses are for purposes other than direct human consumption (DHC) and have been criticized as wasteful and unethical (Naylor and Burke 2005; Tacon and Metian 2009b). On the other hand, the market possibility and complete use of all fisheries landings for DHC has been contested (Wijkström 2009, 2010). However, this debate has also been marked by a lack of clarity around what fish are used for fishmeal and fish oil production and for direct feeding, outside of a few major species that have come to characterize the sector, such as the Peruvian anchoveta (*Engraulis ringens*). Furthermore, as the fishmeal/oil sector is thought to represent close to 1/3 of global capture fisheries in recent years (Alder *et al.* 2008; Tacon and Metian 2009a), understanding its dynamics is important to guide future fisheries policy and fisheries research.

We aim to characterize the role of non-DHC fisheries in global capture fisheries, including both reduction fisheries for fishmeal and oil and fisheries for 'trash fish' (i.e., direct feed). Thus, we provide a global coverage of reduction/feed fisheries for each fishing entity (i.e., fishing country or flag country) from 1950-2010, based on the reconstructed global catch database of the *Sea Around Us* (Pauly and Zeller 2016). This will enable us to analyze a sector of capture fisheries that is relatively poorly understood in its global extent and development, and permits the documentation of current trends within reduction fisheries. Additionally, our focus on the full time period back to 1950 enables us to develop an understanding of the use of fisheries landings almost since the beginning of post-WWII industrial fisheries.

Methods

We based our analysis on the reconstructed landings data (i.e., excluding discarded catch) by taxon for each fishing entity for each year present in the *Sea Around Us* database (currently, 1950-2010). We then assembled a wide range of information and data on the relative proportions of landings that were destined for DHC, reduction and other uses, by taxon, fishing country and year, thereby broadly following the 6-step general catch reconstruction concept (Zeller *et al.* 2007; Zeller *et al.* 2015). We focused our study at the level of the fisheries for FMFO and feed rather than on the products (e.g., FMFO and feeds) or use of these products (e.g., aquaculture or livestock production) as quantifying fish inputs to these finished products introduces additional uncertainties. Therefore, we apportioned all fisheries landings to their end uses of: 1) DHC; 2) FMFO production; or 3) other uses including direct feed, bait, direct fertilizer application, and industrial uses. Note that the by-products of DHC landings that can be used for FMFO production were not accounted for in this analysis, as these are separate from dedicated reduction fisheries. As much as possible, we assembled data that were specific to the taxa, fishing entity, and time period under consideration. However, when this was not possible, a proxy was used based on relative similarities of taxa, regional similarities and historical use

of these landings with respect to the functional group or taxon. This analysis is sensitive to annual changes in the end use of these landings, but is not sensitive to geographical variation in the use of landings except as already spatialized in the *Sea Around Us* database. Furthermore, taxa used for DHC or non-DHC purposes are often used for alternative purposes based on market situations and condition of the landings (i.e. high value species when landed in poor condition are reduced to fishmeal).

Data on the end uses of landings were assembled from a variety of sources, including official national statistics, news reports, company press releases, industry information, historical reports, and scientific journal articles. This disparity of sources provided information of variable quality, mainly based on the perceived audience and aim of the original publication. It should also be noted that the 'end use' as determined here is the anticipated end use at the time of landing a given catch, but the ultimate end utilization may differ occasionally.

Fishing entities (fishing countries) were broadly categorized into three types: 1) those possessing dedicated reduction fleets over the study period (e.g., Peru, Denmark); 2) those with fishmeal production that is dominated by by-products, although often not exclusively (e.g., France, Tanzania); and 3) those with no fishmeal and oil production from by-products or reduction fisheries (e.g., Iraq, Sudan). These broad categories were used to simplify the analysis for some fishing entities, and greater consideration was given to those fishing entities with fishmeal production, and especially with dedicated reduction fisheries as this is the major focus of this analysis. Furthermore, as a fishing country's industrial catches of large pelagic fishes were addressed separately in the *Sea Around Us* database, and these catches are generally high-value species, these species were apportioned 100% to DHC.

Determining that a fishing entity has zero landings destined for fishmeal is difficult and a source of uncertainty, although likely for small developing countries with poorly developed port and/or transport infrastructure, and who are not a flag-of-convenience country. Agreement between various sources was sought, but very few publications are produced on the absence of an industry in a fishing country. Therefore, agreement between multiple sources focusing on fishmeal that exclude certain fishing entities was used as supporting evidence of likely absence of reduction fisheries in the given fishing entity.

International trade complicates the issue significantly, as it is more difficult to track the end streams of fisheries landings after trade, although it can be inferred or is explicit in some cases (e.g., foreign landings of small pelagics in Denmark). Thus, major reports on fishmeal production (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968; Macer 1974; Alder and Pauly 2006; Hasan and Halwart 2009; Jackson and Shephard 2012), as well as country FAO Fishery Profiles (see www.fao.org/fishery/countryprofiles/search/en), were used to inform the analysis of the major fishmeal producing entities, as well as the lack of fishmeal production from other entities.

An alternative method to estimate the amount of fish used for fishmeal production is to use fishmeal production statistics. This method requires the use of approximate data for important values such as the percentage of FMFO derived from by-products in a fishing entity, as well as the FMFO yields of fish into fishmeal which varies temporally, based on technology, and species composition used. In addition, the fishmeal production statistics are often calculated by the FAO when they are not provided by the reporting country. Therefore, there are several sources of uncertainty introduced by using this method in comparison to focusing on the fisheries themselves. When necessary to derive information on a country's production of

FMFO, fishmeal was preferred over fish oil, as the yield of fish oil from different taxa, different countries, and using different technologies has a much higher variance than fishmeal, which is concentrated at a yield rate often of 20-25% for whole fish (not by-products). Fish oil, conversely, has a variable oil yield rate as low as 0.8% and as high as 16% (Cashion *et al.* 2016). When this method was used to calculate fish destined for reduction from fishmeal, the average fishmeal yield of 22.5% was employed (Tacon and Metian 2008).

As required, whole fish wet weights (being the default weight unit for global catch reporting) were back calculated based on requirements for fishmeal production, as well as bait and direct feed uses. This alternative method introduces another level of uncertainty when accounting for feed conversion ratios which vary geographically, temporally, by the farmed species, and by feeds employed. Similar factors are present for bait and fishmeal production with amount of bait used per fish caught (e.g., for trap fisheries, or for tuna pole-and-line fisheries), and conversion efficiency or yield of fishmeal per input of whole fish. This procedure was most commonly used for tuna ranching to estimate the amount of small pelagics (mainly European anchovy, *Engraulis encrasicolus* and European pilchard, *Sardina pilchardus*) used for feed. As tuna ranching occurs mainly in the Mediterranean, broad assumptions on the practices were applied for the region, including a conservative feed conversion ratio (FCR) of fish feed inputs to cultured tuna biomass of 10:1 (Ottolenghi 2008; Metian *et al.* 2014), a stocking (i.e., initial) weight of 1/3 of harvest (i.e., final) weight (Anon. 2013), and harvest weights obtained from the peer-review literature that demonstrates current underreporting in this industry to the FAO (Metian *et al.* 2014).

Uses and methods of fishmeal production vary widely around the world. This estimation accounted as much as possible for the diversity of practices in fishmeal production, but some production practices are not clearly fishmeal production or direct feed. For example, fish is often sun-dried in Asia and the Middle East and then used for feeding animals. In India, it is common practice to sun-dry fish and pulverize it as a crude form of fishmeal for use in poultry, aquaculture feeds, and as fertilizer. However, in Yemen, fish are sun-dried and fed directly to camels. The end use of these products is very similar, but does Yemen qualify as producing fishmeal or is it direct feeding? For this analysis, as it was not produced into a 'meal' form, it was apportioned to other uses, while India's fishmeal production method was apportioned to fishmeal. There is ambiguity here, but both of these are separate from DHC. Human consumption of FMFO products is small, but growing due to perceived health benefits (e.g., Omega fatty acids) of fish consumption.

Furthermore, we did our best to account for bait use as a non-DHC utilization, but catches made for use as bait are often not reported. While catch reconstructions addressed this unreported bait catch issue whenever it could be identified (e.g., Palau; Lingard *et al.* 2011), bait catches are likely still under-represented in the global catch data of the *Sea Around Us*. Fisheries known to use baited hooks or bait for traps were the major identifiers used, and therefore assumptions were made broadly along regional bait use. Bait is also difficult to capture in this analysis as some bait is landed before use and thus appears as landings in reported and unreported data, whereas other bait is caught and used directly from the boat and never landed. Where this information was available, it was taken into account whereas some bait use for each fishing entity was assumed to be landed before use.

In various sources and in the *Sea Around Us* database, taxa are often reported at a level above the species level, which was taken into account during the estimation. For example, if a higher grouping of anchovies (e.g., family level Engraulidae) is used to represent catches destined for

fishmeal production, but European anchovy (*Engraulis encrasicolus*) is known to be used for direct human consumption in Norway, then assigning a portion of Engraulidae landings to fishmeal production excludes catches specifically labelled at the species level (i.e., European anchovy). The exception to this is when it is known a certain genus has a particular use that is inclusive of all species within that genus and in these cases, all species within the genus were treated the same.

Results

Individual country findings

European fishing entities

Reduction fisheries in Europe are globally important and are dominated by three major actors: Denmark, Norway and Iceland. Other countries produce FMFO as well, but in smaller quantities, and often heavily supplemented by FMFO production from by-products of DHC fisheries. These fisheries have been variable over time, with some species solely dedicated for reduction, while other taxa have been used for reduction in the past but are now dominantly caught for DHC. This latter group includes Atlantic mackerel (*Scomber scombrus*), capelin (*Mallotus villosus*), and Atlantic herring (*Clupea harengus*). The development of these fisheries over time has been heavily influenced by the boom and bust of previous fisheries in a progression (Macer 1974; Essington *et al.* 2015).

Based on the previous identification of three types of fishing entities, many countries in Europe, besides Denmark, Norway and Iceland are of the first type, but these three countries produce most of Europe's fishmeal from reduction fisheries. Spain, France and Germany all use by-products of DHC fisheries for fishmeal production, although they have had limited reduction fisheries in the past (Newcastle University and Poseidon Aquatic Resource Management 2004). Only Albania and Malta reported no fishmeal production to the FAO between 1976 and 2013 (FAO 2014a). Therefore, FMFO was set to 0 for all landings for Albania and Malta. Assumptions were made about Type 2 countries for the amount of fish that were deemed not fit for human consumption and went towards FMFO production.

Some countries have no dedicated reduction fisheries, and if they have any fishmeal production it is from fish not fit for human consumption or from by-products of the fish processing industry. These fishing entities thus had their landings conservatively apportioned in line with taxa primarily for DHC, with 99.9% assigned as DHC and 0.1% destined to other purposes to account for landings that were not fit for human consumption. To be categorized here, there had to be a consistent lack of evidence for producing fishmeal *or* evidence that any fishmeal production was from by-products. Furthermore, there had to be multiple sources that were in agreement with each other over the study period. The European fishing entities that meet these criteria are:

- Italy (Bureau of Commercial Fisheries 1961; Newcastle University and Poseidon Aquatic Resource Management 2004; SeaFish 2011). Italy, as a tuna ranching country, has 3% of European pilchard and European anchovy landings apportioned to tuna ranching feed ("Other uses") for the period of 2001-2010 as a conservative estimate (Ottolenghi 2008; Metian *et al.* 2014).
- Portugal (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968; Almeida *et al.* 2015). Portugal, as a tuna ranching country, has 3% of European pilchard and European anchovy landings apportioned to tuna ranching feed ("Other uses") for the period of 2001-2010 as a conservative estimate (Ottolenghi 2008; Metian *et al.* 2014).

- The Republic of Cyprus (i.e., South Cyprus) produces no fishmeal (FAO 2014a), however they do farm tuna for export to Japan. South Cyprus is therefore treated in line with other tuna ranching nations.
- North Cyprus has a small fishing sector (Ulman *et al.* 2013b, 2015a), but employs bait for its longline fisheries. However, this bait use is never landed and is thus considered a discard (Ulman *et al.* 2013b). Other fish used as bait are sometimes landed and low-value bycatch is also used, and so the ratio for this group is assumed to apply for North Cyprus.
- Latvia (Newcastle University and Poseidon Aquatic Resource Management 2004; www.fao.org/fishery/facp/LVA/en; Rossing *et al.* 2010c; Lassen 2011; Anon. 2015b)
- Lithuania (Znamenski 1970; Sealy 1974; www.fao.org/fishery/facp/LTU/en; Veitch *et al.* 2010b; Lassen 2011)
- Estonia (Znamenski 1970; Sealy 1974; Matcon 1994; www.fao.org/fishery/facp/EST/en ; Veitch *et al.* 2010a; Lassen 2011)
- Slovenia, Montenegro, and Bosnia & Herzegovina (Sahrhage and Lundbeck 1992; http://www.fao.org/countryprofiles/index/en/?iso3=SVN; http://www.fao.org/fishery/facp/BIH/en; 2014a)
- Bulgaria (Megapesca 2001; www.fao.org/fishery/facp/BGR/en ; Popescu 2011)
- Romania (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968; Sahrhage and Lundbeck 1992; www.fao.org/fishery/facp/ROU/en; Ministry of Agriculture and Rural Development 2013)
- Netherlands (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968; Newcastle University and Poseidon Aquatic Resource Management 2004; www.fao.org/fishery/facp/NLD/en)
- Albania (www.fao.org/fishery/facp/ALB/en ; 2014a)
- Malta had no reported fishmeal production (FAO 2014a), although they began ranching bluefin tuna in 2006 (Metian *et al.* 2014). Based on Malta's landings, they are heavily dependent on imports for the ranching sector and their use of small pelagics was not modified from the primarily DHC taxa rates.
- The Azores likely had no fishmeal production over the study period, but had significant bait use for pole-and-line fisheries (Pham *et al.* 2013). The main taxa utilized for this purpose were European pilchard (*Sardina pilchardus*) and blue jack mackerel (*Trachurus picturatus*), with a lesser contribution from blackspot seabream (*Pagellus bogaraveo*), Atlantic chub mackerel (*Scomber colias*), bogue (*Boops boops*), boarfishes (Caproidae), and longspine snipefish (*Macroramphosus scolopax*). All baitfish were unreported, while other landings of these taxa were reported. Thus, the unreported portion was assigned 100% to bait use.

While only a few fishing entities meet the above criteria, many more European fishing entities started the period with reduction fisheries, but now use by-products of DHC fisheries for 100% of FMFO production. These countries include Germany, Spain, France and Belgium. These had the same anchor ratio as the above fishing entities after they had switched to using by-products only (after 2002 mainly), and were linearly interpolated to these points.

- France's fishmeal production is almost entirely from by-products, although a small portion is still sourced from fish not fit for human consumption (Bureau

of Commercial Fisheries 1961; Newcastle University and Poseidon Aquatic Resource Management 2004; SeaFish 2011). Thus, the amount destined for non-DHC purposes was divided equally between other uses and FMFO for the entire study period. This amount was based on the ratio for 2003, which equaled approximately 1.1% each for FMFO and other uses, with the remaining 97.8% being for DHC(www.fao.org/fishery/facp/FRA/fr). This was applied to all taxa, as some landings are not fit for human consumption.

- Belgium had small amounts of fishmeal production over the study period from trimmings and fish not fit for human consumption (Bureau of Commercial Fisheries 1961; IFOMA 1999). The FAO country profile reports equal production of fish for DHC and not for DHC(http://www.fao.org/fishery/facp/BEL/en), although this is not confirmed by other sources (Bureau of Commercial Fisheries 1961; IFOMA 1999; Lescrauwaet *et al.* 2015). Therefore, the average rate applied to primarily DHC taxa (99.9% DHC, 0.05% FMFO, and 0.05% other uses) was applied to Belgium for the entire study period.
- Germany (See 'Germany')
- Spain (See 'Spain')

With some variability between fishing entities, a number of taxa dominate the amount of FMFO produced from dedicated reduction fisheries. Norway pout (*Trisopterus esmarkii*) and sandlances (*Ammodytes* spp.) are entirely destined for FMFO as reported by all sources (Central Bureau of Statistics 1960; Huntington 2009; Statistics Iceland 2015). Other taxa demonstrate regional disparities in their use for FMFO or DHC, such as blue whiting (*Micromesistius poutassou*) which is used almost entirely for reduction by Denmark, Norway, Iceland and the Faeroe Islands, whereas it is commonly used for DHC by Spain, France, Germany, Netherlands and Portugal (Newcastle University and Poseidon Aquatic Resource Management 2004). Other taxa, such as capelin (*Mallotus villosus*) and Atlantic mackerel (*Scomber scombrus*) have shifted from being almost entirely for reduction in the past to having the majority of landings destined for DHC more recently. Atlantic herring (*Clupea harengus*) has a more nuanced relationship of formerly being a food fish which was then used for reduction in large amounts, but since the late 1990s and early 2000s has increased its share dedicated to DHC. These shifts have been caused by changes in perception towards reduction fisheries, but also by changes in the stocks of different taxa. For example, Atlantic herring was significantly depleted during the 1960s and 1970s, but their biomass and landings have risen since then. The most commonly used taxa for reduction in Europe are: blue whiting, Atlantic herring, capelin, Atlantic mackerel, Atlantic horse mackerel, Norway pout, sandlances, and European sprat. Some more recently exploited taxa include boarfish, Argentines, and roundnose grenadier.

Croatia

Croatia dominated the coast of the former Yugoslavia, and shares characteristics with other former Yugoslavia entities based on their historical relationship. Fishmeal production in the former Yugoslavia appears to be based on by-products of the processing sector, as small pelagics were processed for DHC (Sahrhage and Lundbeck 1992). After the break-up of Yugoslavia, small amounts of fishmeal were reported to be produced by Croatia and Slovenia, whereas Serbia, Macedonia, Kosovo, Montenegro and Bosnia and Herzegovina have no reported fishmeal production (FAO 2014a). It is assumed that Croatia's and Slovenia's production is still sourced from by-products. However, Croatia began tuna ranching which is heavily reliant on small pelagics for feed. They report a high amount of imports of frozen 'bait fish' (Atlantic herring) for this purpose(www.fao.org/fishery/facp/HRV/en). Croatia is reported as having 2.15% of fish production destined for animal feed or other purposes and this was assumed to be 100% for tuna feed(www.fao.org/fishery/facp/HRV/en). However, many other reports discuss the integration of the Croatian fisheries, often trawlers (likely pelagic trawls), with the tuna farming industry (Ottolenghi *et al.* 2004; www.fao.org/fishery/facp/HRV/en). Given this, and the need for large amounts of tuna feed (>40,000 tonnes based on the author's conservative calculations of a 10:1 FCR; Ottolenghi 2008) and production of ~4,000 tonnes annually (Anon. 2013) from an original tuna catch weight of 8-10 kg/individual to a minimum ranch-harvest weight of 30 kg/individual (Anon. 2013), it was assumed at least 50% of the main feed taxa (sardine and anchovy) would be destined for this purpose. This practice began in 1996 and has grown to current rates, and so the use of these taxa was linearly interpolated to these levels from previously being primarily for DHC (99.9%). For an overview of the fisheries of Croatia since 1950, please see Matić-Skoko *et al.* (2014).

Evidence and assumptions:

- European pilchard (*Sardina pilchardus*) and European anchovy (*Engraulis encrasicolus*) were treated as DHC fish until 1996 when tuna ranching began in Croatia (Ottolenghi 2008). After this period, they were linearly interpolated to 50% for other use in 2008 when the ranching industry stabilized at around 4,000 tonnes of annual production (Anon. 2013). This is a conservative estimate for the use of these fish over this period, but total use of feed for tuna farming includes significant imports at some points during the study period(www.fao.org/fishery/facp/HRV/en).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses to account for fish caught for human consumption that are not used for that purpose.

Denmark

Denmark has the largest reduction fisheries in Europe. However, production data and taxonomic breakdown of the reduction fisheries are scarce. Many taxa appear to be solely used for reduction based on their classification in Danish statistics

(http://agrifish.dk/fisheries/fishery-statistics/), EU reports (Newcastle University and Poseidon Aquatic Resource Management 2004; Lassen 2011), historical sources (Bureau of Commercial Fisheries 1961; Macer 1974) and other sources (Green 2012; Byskov 2013). Additionally, many taxa are caught as by-catch by the reduction fisheries in varying amounts, and this resulted in these former by-catch taxa developing their own reduction fisheries, although there is even less specific information available on these fisheries (Macer 1974). For an overview of the fisheries of Denmark since 1950, please see Gibson *et al.* (2014).

Evidence and assumptions:

- Norway pout (*Trisopterus esmarkii*) was assumed to be 100% destined for reduction based on current usage by pelagic fisheries(www.agrifish.dk/fisheries/fishery-statistics/), historical use (Macer 1974), and its quality as an industrial fish deemed not fit for direct human consumption (Huntington 2009; Wijkström 2010).
- Sandeels (*Ammodytes* spp., and more specifically *A. marinus*) were assumed to be 100% destined for reduction based on current usage by fisheries(www.agrifish.dk/fisheries/fishery-statistics), historical use (Macer 1974), and it being deemed as not fit for direct human consumption (Huntington 2009; Wijkström 2010).
- Atlantic horse mackerel (*Trachurus trachurus*) was assumed to be 100% destined for reduction based on current usage by pelagic fisheries(www.agrifish.dk/fisheries/fishery-statistics), and previous use reported for Denmark (Newcastle University and Poseidon Aquatic Resource Management 2004), whereas other fishing entities use this for DHC (including Ireland, and the United Kingdom).
- Boar fish (*Capros aper*) and Roundnose grenadier (*Coryphaenoides rupestris*) are two species that have been exploited more recently for reduction purposes, without a long previous fishing history (www.agrifish.dk/fisheries/fishery-statistics; Peacock and Platt 2012). As this is a relatively new fishery with no evidence for other uses, these were assumed to be 100% for FMFO(www.maring.org/raw-materials).
- Atlantic herring (*Clupea harengus*) was one of the first reduction fisheries in Denmark going back before the study period (Bureau of Commercial Fisheries 1961). However, this fishery historically has had mixed use, being both for reduction and DHC. After the North Sea herring stocks were severely depleted in the 1970s, a ban was placed on herring fisheries for reduction purposes in 1977 (Byskov 2013), but they continued to be used when they were by-catch of other reduction fisheries. The apportioning also took into account that the reconstruction considered the distinction between commercial industrial, and artisanal human consumption. The industrial fishery was thus classified to be entirely for reduction from 1950 to 1977 when the ban on herring reduction fisheries was put in place until the early 1990s (Nielsen 1989; Byskov 2013), when the ban was lifted. Given that herring continued to be caught as by-catch by the sprat reduction fishery, 10% of landings were apportioned to this use from 1977-1991, as a conservative estimate. It was assumed the reduction fishery for Atlantic herring resumed after 1991, and thus industrial landings were again apportioned to 100% FMFO for 1992-2010.
- Blue whiting (*Micromesistius poutassou*) has reported use for DHC in other European markets, but not in Denmark (Newcastle University and Poseidon Aquatic Resource Management 2004). Given this, and its continued use for FMFO by Denmark (Green 2012), this species was listed as 100% for FMFO.

- Haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*) were caught as by-catch and then targeted for reduction in the early 1970s (Macer 1974). Haddock represented ~30% of the fishmeal production of Denmark in 1969 (Macer 1974), which is also when its landings peaked for Denmark. Since Danish production of fishmeal in 1969 was just over 200,000 tonnes (Macer 1974), almost all of this haddock would have to be destined for FMFO to account for this amount. Therefore, haddock was given an FMFO ratio of 100% for the period of 1960-1970 where it is reported to make up a portion of the national fishmeal production (3-30%; Macer 1974). Outside of this period, it was assumed to follow a similar pattern to whiting and European hake detailed below. While whiting is reported to make up a smaller but still significant share of fishmeal production from 1960-1970, it is reported as a DHC species by Denmark(www.fao.org/fishery/facp/DNK/en; www.eurofish.dk). Therefore, whiting was assigned as 90% to FMFO from 1950-1977 where it switched to being 10% for FMFO and 90% for DHC (1978-2010) because of the shift in where the Norway pout was caught to an area with much less by-catch of whiting and haddock (Byskov 2013). As the reports of this use is almost always from by-catch of other industrial fisheries, artisanal landings were excluded from these considerations (i.e., 100% of artisanal catch was assigned to DHC).
- European hake (*Merluccius merluccius*) was also by-catch and used for reduction purposes from at least 1968-1976 (Gibson *et al.* 2014). Based on a lack of other information, it was treated the same as whiting with regards to FMFO use over the study period.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition of landed catch. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses to account for fish intended for DHC but ultimately destined for FMFO or other uses.

Faeroe Islands (Denmark)

Although heavily dependent on fisheries, the Faeroe Islands until very recently only caught a small amount of fish for reduction to FMFO. Taxa that are mentioned as being used for this are Atlantic herring, Atlantic mackerel, Norway pout, argentines, and blue whiting. However, the amount destined for these purposes is highly uncertain in all cases except blue whiting, which is almost entirely used for reduction (95-99%, Mundell *et al.* 2003). For an overview of the fisheries of Faeroe Islands since 1950, please see Gibson *et al.* (2015d).

Evidence and assumptions:

- Argentines (*Argentina* spp.) were caught as by-catch in the Norway pout fishery from at least 1982-1996 (Reinert 2001). These landings were also destined for reduction and therefore 100% went to FMFO.
- Atlantic herring (*Clupea harengus*) has a fluctuating use for DHC and for FMFO. It is processed and exported from the Faeroe Islands, but also has high historical rates (exceeding 80% but highly variable) of reduction in some years for a major herring processing area (Hamilton *et al.* 2004). Atlantic herring was thus treated as being 75%

destined for reduction until the herring stock collapse in 1968, with most catch used for DHC after 1968 (estimated at 75%).

- Blue whiting (*Micromesistius poutassou*) has a constant use for FMFO (Reinert 2001). This was assumed to be the dominant use, with a smaller portion for export as DHC products beginning in the 1980s(e.g. surimi; www.bakkafrost.com/en). Therefore, blue whiting was set at 95% FMFO, with 5% being DHC.
- Sandeels (*Ammodytes* spp., and more specifically *A. marinus*) were assumed to be 100% destined for reduction based on its quality as an industrial fish deemed not fit for DHC (Huntington 2009; Wijkström 2010).
- Norway pout (*Trisopterus esmarkii*) was assumed to be 100% destined for reduction based on its quality as an industrial fish deemed not fit for DHC (Huntington 2009; Wijkström 2010).
- Atlantic mackerel (*Scomber scombrus*) is used for fishmeal production in the Faeroe Islands (Havsbrun 2013). However, it is difficult to confirm how much is used. Based on the capture production of 2010 and 1990, and subtracting the export of Atlantic mackerel may give an indication of the use for FMFO. This is subject to high uncertainty. However, given that it is known there is FMFO produced from mackerel (Havsbrun 2013), and that exports accounted for 75-85% of the capture amount (FAO 2014a), the FMFO production that is reported is assumed to be mainly from wastes of the mackerel industry. Thus 5% of mackerel was apportioned to FMFO, with the other 95% being destined for DHC.
- Atlantic horse mackerel (*Trachurus trachurus*) was assumed to be 100% destined for reduction based on usage by similar fishing entities such as Denmark.
- European sprat (*Sprattus sprattus*) had limited information specific to the Faeroe Islands. However, based on its regional use, it was apportioned 100% to FMFO consistent with other fishing entities in the region, in addition to it likely originating as by-catch in other reduction fisheries (specifically sandeels; Newcastle University and Poseidon Aquatic Resource Management 2004).
- Roundnose grenadier (*Coryphaenoides rupestris*) has limited information specific to the Faeroe Islands. However, based on its regional use, it was apportioned 100% to FMFO consistent with other fishing entities in the region(www.eurofish.dk).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Finland

Finland is a very small producer of FMFO from reduction fisheries. However, a considerable portion of their landings are used for direct feed in their mink farming industry. There are two main taxa used for this purpose and for reduction to FMFO: European sprat and Atlantic herring. For an overview of the fisheries of Finland since 1950, please see Rossing *et al.* (2010a).

Evidence and assumptions:

- European sprat (*Sprattus sprattus*) is confirmed in multiple sources to be 100% destined for direct feed (Setälä *et al.* 1999; www.fao.org/fishery/facp/FIN/en; Lassen 2011).
- Atlantic herring (*Clupea harengus*) has been used for FMFO and direct feeding over the years. The consumption of herring is relatively low in Finland and thus it is likely that the general use pattern over the period of 1996-2010 for which there is data available is consistent with previous years in the study period (1950-1995). The values were linearly interpolated between anchor years of 1996, 2003, and 2005. The 1996 use ratios were assumed to apply to the previous years. The ratios used are supported by various sources (Setälä *et al.* 1999; Newcastle University and Poseidon Aquatic Resource Management 2004; www.fao.org/fishery/facp/FIN/en; Lassen 2011).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% of non-DHC use was apportioned to other uses rather than FMFO.

Germany

Germany formerly had reduction fisheries for Atlantic herring, European sprat, and sandeels (Bureau of Commercial Fisheries 1961). However, fishmeal production from 2003 is reported to be entirely derived from by-products (Newcastle University and Poseidon Aquatic Resource Management 2004; Jackson and Shephard 2012). Therefore all Atlantic herring and European sprat landings were treated as primary DHC taxa after 2003, and had varying amounts destined for non-DHC purposes for earlier years. A modern fishery for sandeels began soon after these earlier reports (Newcastle University and Poseidon Aquatic Resource Management 2004; Poseidon Aquatic Resource Management and Newcastle University 2004), and is used solely for reduction (Huntington 2009). For an overview of the fisheries of Germany since 1950, please see Gibson *et al.* (2015b) and Rossing et al. (2010b).

Evidence and assumptions:

- Atlantic herring (*Clupea harengus*) produced high catches in Germany before the North Sea stocks collapsed in the late 1960s. However, these were concurrent with a large canning industry in Germany (Mulvaney 2015). It was conservatively assumed that 25% of catches went for reduction purposes until the herring fisheries ban in 1977 (Lassen 2011; Mulvaney 2015), when this dropped to solely account for those fish not fit for human consumption (see below for primary DHC taxa).
- European sprat (*Sprattus sprattus*) was assumed to be similar to herring based on regional use (Macer 1974), but was assumed to be a primary DHC taxon in 1990 as no reports after the re-unification of Germany mention sprat fishmeal production from directed reduction fisheries and Germany's later move to solely by-product fishmeal production (Jackson and Shephard 2012). The values from 1970-1990 were linearly interpolated.
- Sandeels (*Ammodytes* spp.) were assumed to be 100% for FMFO based on its regional use (Huntington 2009).

- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Georgia

Georgia (here included under 'Europe') has produced fishmeal both while part of the former-USSR and since independence (van Anrooy *et al.* 2006). However, this production is not reported to the FAO and is thus missing from major data sources (FAO 2014a; Ulman and Divovich 2015; www.fao.org/fishery/facp/). Georgia's fishmeal production is based on the anchovy fishery in the Black Sea (van Anrooy *et al.* 2006; Mothpoulsen 2011). For an overview of the fisheries of Georgia since 1950, please see Ulman *et al.* (2015).

Evidence and assumptions:

- European anchovy (*Engraulis encrasicolus*) is the main reduction fishery of Georgia and was present in both industrial and artisanal fisheries (Mothpoulsen 2011). Reduction is the dominant use (85-90%) of this species. However, this stopped almost completely with the collapse of the USSR subsidies and central planning system, but began rebuilding again in 2005 (van Anrooy *et al.* 2006). Anchovy was assumed to be destined 85% for FMFO from 1960-1991 and 2005-2010. Anchovy was treated as primarily DHC use from 1992-2004. Anchovy was assumed to start as primary DHC taxa in 1950, and was linearly interpolated from this level to 1960 levels from 1951-1960.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Greece

Greece's fishmeal production was not mentioned in major reports (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968; Macer 1974; www.fao.org/fishery/facp/GRC/en; Moutopoulos *et al.* 2015a), although it has previously reported a minor production (FAO 2014a). This minor production was assumed to be sourced from by-products, or landings deemed not fit for human consumption, and therefore a taxa-specific consideration is not given below. However, Greece began ranching Atlantic bluefin tuna (*Thunnus thynnus*) in 2005 and has 5,021 tonnes out of 189,571 tonnes of reported landings destined for animal feed and other purposes(www.fao.org/fishery/facp/GRC/en). This was assumed to consist of small pelagics and be mainly destined for direct feed in the tuna ranching industry (Ottolenghi 2008; www.fao.org/fishery/facp/). This was assumed to originate from the dominant taxa used for this purpose, European anchovy and European pilchard, and 1/6 of their landings of each of these taxa were destined to other uses to equal ~5,000 tonnes for this

purpose(www.fao.org/fishery/facp/GRC/en), with the balance likely being imported. For an overview of the fisheries of Greece since 1950, please see Moutopoulos *et al.* (2015b).Evidence and assumptions:

- European anchovy (*Engraulis encrasicolus*) and European pilchard (*Sardina pilchardus*) were apportioned 16.66% of their landings to other uses (direct feed) from the period of 2005-2010 for the purpose of tuna ranching (Metian *et al.* 2014), based on the amount of fish destined for feed in Greece(www.fao.org/fishery/facp/GRC/en).
  Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Greenland (Denmark)

Greenland (here included under Europe due to its close connection to and orientation towards Denmark) has limited use of fish for purposes other than DHC. All small-scale artisanal and subsistence fisheries were treated as 100% for DHC. However, industrial fisheries exist for capelin with the main uses being bait, and FMFO (Friis-Rødel and Kanneworff 2002). A small portion of this catch is eaten fresh as DHC. Historically, capelin was caught with on-shore fishing methods during the spawning season and dried for human consumption as well as to feed dogs and sheep. The production of FMFO is noted, but acknowledged to be a small part of Greenland's industry, which is mainly geared towards DHC products for export (Friis-Rødel and Kanneworff 2002). For an overview of the fisheries of Greenland since 1950, please see Booth *et al.* (2014).

Evidence and assumptions:

- Capelin (*Mallotus villosus*) was the only dedicated reduction fishery, but was also used for fishing bait. Industrial catches of capelin were thus estimated as 60% other uses including bait and direct feeding, 20% for FMFO, and 20% for DHC including a roe export fishery (Friis-Rødel and Kanneworff 2002; Poseidon Aquatic Resource Management and Newcastle University 2004; Greenland Institute of Natural Resources 2013).

Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% of non-DHC use was apportioned to other uses rather than FMFO as Greenland does not have a major fishmeal industry to absorb these fish.

Iceland

Iceland is the 3rd largest producer of FMFO from reduction fisheries in Europe. From 1950 to 1959, only herring and redfishes are listed as reduction species (Bureau of Commercial Fisheries 1961). From 1960-1963, Atlantic herring was the only species used for FMFO, and thereafter Capelin was also fished to compensate for the herring stock collapse in 1968 (Macer 1974). Iceland's use of fisheries landings was assembled through official government publications (www.fisheries.is; Statistics Iceland 2015), historical reports (Bureau of Commercial Fisheries 1961; Macer 1974; Knutsson and Gestsson 2006), and other literature (Sahrhage and Lundbeck 1992; Hardy and Tacon 2002; Valtýsson 2014). Published official data on the end use of fisheries landings for Iceland are available for the period 1992-2014 (Statistics Iceland 2015). For earlier years, historical reconstructions relied on assumptions based on best available knowledge. For an overview of the fisheries of Georgia since 1950, please see Valtýsson (2014).

Evidence and assumptions:

- Atlantic redfishes (*Sebastes* spp., including *Sebastes marinus*) were used for FMFO before they began to be used for DHC. They are not reported as being used over the period of 1960-1970 for FMFO (Macer 1974), but this could be a discrepancy in sources as they are reported up to 1959 (Bureau of Commercial Fisheries 1961). Therefore, 100% was destined up to 1959, and after this period 100% destined for DHC.
- Beaked redfish (*Sebastes mentella*) was never used for reduction as it was only fished after 1970 and used for DHC(www.fisheries.is).
- Norway pout (*Trisopterus esmarkii*) was assumed to be 100% destined for reduction based on its quality as an industrial fish deemed not fit for human consumption (Huntington 2009; Wijkström 2010). Iceland has low landings of this species compared to Denmark and Norway, but as this is a common use, this assumption was justified.
- Sandeels (*Ammodytes* spp., and more specifically *A. marinus*) were assumed to be 100% destined for reduction based on its quality as an industrial fish not fit for human consumption (Huntington 2009; Wijkström 2010). Iceland has low landings of this species compared to Denmark and Norway, but as this is a common use, this assumption was justified.
- Atlantic mackerel (*Scomber scombrus*) is listed as a high value species used for DHC(www.fisheries.is), but its use over 2005-2010 includes significant landings destined for reduction (Statistics Iceland 2015). The average for the reported period (75% for DHC, 25% for FMFO) was used as there is less evidence of a strong reduction fishery based on Atlantic mackerel in Iceland (Macer 1974).
- Atlantic horse mackerel (*Trachurus trachurus*) was assumed to be 100% destined for reduction based on usage by similar fishing entities.
- Roundnose grenadier (*Coryphaenoides rupestris*) is used 100% for DHC in Iceland, contrary to its use for reduction in other countries (Statistics Iceland 2015).
- Whiting (*Merlangius merlangus*) is listed as solely for DHC (www.fisheries.is; Statistics Iceland 2015) contrary to its use for reduction in other countries.
- Atlantic herring (*Clupea harengus*) is a dominant reduction fishery in Iceland that was negatively impacted by the collapse of herring stocks in the late 1960s. While it made up 100% of Iceland's reduction fishery from 1960-1963 (Macer 1974), there is evidence that during this time a considerable portion was also used for DHC (Bureau of

Commercial Fisheries 1961). An assumption of 60% for FMFO and 40% for DHC was made given a lack of other available information for 1950-1991, except for the years of 1958-1966 where more information was available. 1960-1966 did not have specific information, but the sharp rise in catches would have gone to reduction and this was accounted for in a rise to roughly 95% being used for reduction in 1966. This is based on the DHC amount (~50,000 tonnes) for 1959 (Bureau of Commercial Fisheries 1961; Valtýsson 2014).

- Blue whiting (*Micromesistius poutassou*) has reported use for DHC in other European markets and in Denmark for 1995-2014 (Statistics Iceland 2015). The average use rates over 1995-2014 (87.5% for FMFO, and 12.5% for DHC) were more likely than other estimates (Wijkström 2010), and so these rates were applied to 1950-1994.
- Capelin (*Mallotus villosus*) is an important reduction species in Iceland. The average use over 1993-2002 (95.8% for FMFO, and 4.2% for DHC) was taken as representative of previous years as DHC has grown substantially after this period. The 1992-2014 period was informed by Iceland Statistics and varied by year, where FMFO started as the dominant use at 98% but declined to a low of 47.3% in 2009 with the balance being DHC(Statistics Iceland 2015).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Ireland and the United Kingdom

Ireland and the United Kingdom have limited dedicated reduction fisheries, but there are similarities between the two countries. Most FMFO production in both countries has been mainly from by-products of processed fish including whitefish as well as some pelagics (Bureau of Commercial Fisheries 1961). For an overview of the fisheries of Ireland and the United Kingdom since 1950, please see Miller *et al.* (2013) and Gibson *et al.* (2015a).

Evidence and assumptions:

- Blue whiting (*Micromesistius poutassou*) is primarily a reduction fishery with a small amount destined for DHC in the United Kingdom and Ireland (Newcastle University and Poseidon Aquatic Resource Management 2004; Poseidon Aquatic Resource Management and Newcastle University 2004; Marine Institute 2009). It was therefore assumed to be 95% for FMFO and 5% for DHC over the entire time period.
- Boar fish (*Capros aper*) is a recently developed reduction fishery in both countries. It is apportioned 100% for FMFO production (Marine Institute 2009).
- Atlantic herring (*Clupea harengus*) has been reportedly used for reduction when there is an excess supply for the DHC market (Bureau of Commercial Fisheries 1961), although DHC remains the primary purpose of this fishery (Newcastle University and Poseidon Aquatic Resource Management 2004). Herring was thus treated as 95% for DHC, and 5% for FMFO as an estimate of its use.
- ‘Whitefish’, in addition to its large amounts of by-products used for reduction, is listed as used for reduction in a historical report (Bureau of Commercial Fisheries 1961). This

was assumed to apply to the earlier period as it is not included in more contemporary sources (Macer 1974; Newcastle University and Poseidon Aquatic Resource Management 2004). Therefore, the main whitefishes (haddock [*Melanogrammus aeglefinus*], European hake [*Merluccius merluccius*], whiting [*Merlangius merlangus*], and Atlantic cod [*Gadus morhua*]) were assumed to begin at 5% for FMFO and 95% for DHC, and were linearly interpolated to be the same ratio as primary DHC taxa (see below) by 1970.

- European sprat (*Sprattus sprattus*) has historically been used in reduction fisheries (Macer 1974), as well as currently in small amounts (Newcastle University and Poseidon Aquatic Resource Management 2004). It was thus assumed to be 100% destined for reduction to FMFO.
- Norway pout (*Trisopterus esmarkii*) was assumed to be 100% destined for reduction based on current usage by pelagic fisheries (Marine Institute 2009), historical use (Macer 1974), and its quality as an industrial fish deemed not fit for human consumption (Huntington 2009; Wijkström 2010).
- Sandeels (*Ammodytes* spp., and more specifically *A. marinus*) were assumed to be 100% destined for reduction based on current usage by pelagic fisheries (Newcastle University and Poseidon Aquatic Resource Management 2004), historical use (Macer 1974), and its quality as an industrial fish not fit for human consumption (Huntington 2009; Wijkström 2010).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Norway

Norway has the largest reduction fisheries in Europe. The data are based on published national fishery statistics from 1961, 1968, 1975, 1984, 1992, 1999, and 2000-2010 (Central Bureau of Statistics 1960; Director General of Fisheries 1968, 1979; Statistics Norway 1979, 1984, 1996, 1997, 2002; www.ssb.no), in addition to other supplemental sources that document changes in these fisheries for Norway and the North Atlantic fisheries in general. Landings are often aggregated for different uses to include fishmeal and oil production and animal feed in one category, however, fishmeal production is the dominant use, and this was addressed for some taxa detailed below. For an overview of the fisheries of Norway since 1950, please see Nedreaas *et al.* (2015).

Evidence and assumptions:

- Norway pout (*Trisopterus esmarkii*), and sandeels (*Ammodytes* spp., and more specifically *A. marinus*) were assumed to be 100% destined for reduction based on current usage by pelagic fisheries(www.sildelaget.no/en/fisheries), historical use (Macer 1974), and reported as 100% of landings (Director General of Fisheries 1968, 1979; Statistics Norway 1984, 1996, 2002), its importance as previous reduction fisheries (1980-2010; Nygaard 2010), certification by the International Fishmeal and Fish Oil Organization (Norwegian Seafood Industry 2013; IFFO 2015), and their quality

as industrial fishes deemed not fit for human consumption (Huntington 2009; Wijkström 2010).

- Blue whiting (*Micromesistius poutassou*) has varying amounts destined for reduction, but was primarily a reduction species from 1974 onwards. In 1992, 96% was for FMFO production (the rest being DHC), and for 2003-2005, 99.2% was destined for FMFO production. However, it is noted as a food fish in other sources and in 2011, DHC made up a larger portion of the catch than FMFO production (64% to 33%, with the balance being other use). As Norway had no landings of blue whiting before 1972, the following time periods and corresponding FMFO/DHC are used (1972-1983- 93% FMFO; 1984-2007- 99% FMFO; 2008- 91% FMFO; 2009; 78% FMFO; 2010- 61% FMFO).
- European sprat (*Sprattus sprattus*) became an important reduction fishery in the 1980s and remains so today (Nygaard 2010). However, there was a base level of DHC which is given priority in years with low landings as shown in the 1984 statistics where DHC use was more than FMFO use. Therefore, this landings information was used to inform when it would switch back to primarily a reduction fishery which is estimated to occur in 1991 based on increased landings. Linear interpolation was used between 1992 and 1999 to reflect the minor changes over this period. The only report that separated FMFO and direct feed was used as a base level where 0.75% of the sprat catch was destined for direct feed (Director General of Fisheries 1979).
- Capelin's (*Mallotus villosus*) use for FMFO varied, but it was likely used almost entirely for FMFO until the mid-1990s or even into the 2000s. In 1999, Norway reported that 51% went towards FMFO and 49% for DHC, whereas in 1992 and earlier years, it was between 99% and 100% for FMFO. The annual landings were taken into account for a non-linear interpolation between the years of 1992 and 1999 based on a consistent demand for DHC of ~40,000 tonnes and excess going towards FMFO production; thus, 1994 is set to 99%, 1996 and 1997 set to 75%, and 1998 set to the same as 1999 as it has similar landings. The 2000s mark a shift that is much more volatile caused by increased human demand and low landings for 2003-2008, and annual variation was applied here (Statistics Norway 2015).
- Atlantic herring (*Clupea harengus)* is a very large reduction fishery which has had several stock collapses in the Northeast Atlantic. These have often triggered a change in patterns of consumption to more being destined for DHC than FMFO. The national fisheries statistics data were linearly interpolated between these points, except for the sharp change occurring between 1968 and 1975, where 1972 to 1976 were kept static at the 1976 levels because of the crash in the population of the North Sea stocks and halting of some fisheries in this time period. 1968 to 1972 were linearly interpolated. The time period started at 60% being destined for reduction based on Wijkstrom (2012). The only report that separated FMFO and direct feed was used as a base level where 0.75% of the sprat catch was destined for direct feed (Director General of Fisheries 1979). In the absence of better information, Atlantic herring landings were treated this way and had 0.75% of their catch destined for other uses from the period of 1950-1999 to the other category to account for direct feeding.
- Atlantic mackerel (*Scomber scombrus*) is a relatively small reduction fishery. The periods 1977-1984 and 1984-1992 were linearly interpolated (from 81% in 1977 to 66% in 1984 to 10% in 1992 for FMFO use) because of a gradual change over this period in the proportions that were sent to FMFO and DHC. This was confirmed by the switch from a reduction fishery to a DHC fishery (Nedreaas *et al.* 2015), a lack of mention in

the 2000s of mackerel as a reduction species, and confirmed use of mainly DHC by Nygaard (2010).

- Atlantic horse mackerel (*Trachurus trachurus*) began to be fished for reduction by Norway in the 1970s but had switched over almost completely to a DHC fishery by the mid-1990s. In the 1990s, there was a sudden shift between 1992 and 1999 from being overwhelmingly used for FMFO to overwhelmingly DHC (Nedreaas *et al.* 2015). Therefore, Atlantic horse mackerel was linearly interpolated from 92% for FMFO in 1992 to 3% destined for FMFO in 1999. Other *Trachurus* spp. were treated the same as Atlantic horse mackerel, and catches are generally low outside the period when Atlantic horse mackerel were used solely for reduction.
- Norway had two short-term fisheries for common reduction taxa: chub mackerel (*Scomber japonicus*) and Antarctic krill (*Euphausia superba*) and based on a lack of information these taxa were assumed to be 100% destined for FMFO production based on other reports of their use during their respective time periods (Tacon 2005; Huntington 2009; Parker 2011).

Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. Therefore, these were accounted for through an average usage rate of all primarily DHC taxa for both FMFO and other uses over the study period. This was informed by the same fisheries statistics reports as were used for the other taxa. Therefore, 0.063% and 0.086% from all other taxa were destined for reduction and other uses, respectively.

Poland

Poland previously only reported fishmeal production from whitefish (FAO 2014a), likely originating from by-products of processing. However, after trade liberalization allowed exports of raw materials to the EU, significant amounts of sprat and herring were used for reduction through landings made directly in Denmark. However, there are conflicting reports on this and there seems to be a lack of reporting of fishmeal production from 2007-2010 to the FAO and other agencies (Lassen 2011; FAO 2014a). Over 90% of sprat, and 80% of herring is fished with pelagic trawlers (Lassen 2011). For an overview of the fisheries of Poland since 1950, please see Bale *et al.* (2012).

Evidence and assumptions:

- Atlantic herring (*Clupea harengus*) was often landed in Denmark for fishmeal production. Poland uses all of their Baltic herring for FMFO (Newcastle University and Poseidon Aquatic Resource Management 2004), and this represents 80% of their Atlantic herring landings (Lassen 2011). Thus, Atlantic herring was apportioned 80% to FMFO and 20% to DHC.
- European sprat (*Sprattus sprattus*) was landed in Denmark for fishmeal production after 1996 (Newcastle University and Poseidon Aquatic Resource Management 2004; FAO 2014a). This was set at 25% for FMFO as most landings (75%) are still destined for DHC(www.fao.org/fishery/facp/POL/en).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002;

Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Russian Federation

The Russian Federation was apportioned its own catch dating back to 1992, and its share of the USSR catch from 1950-1991. The USSR and Russia have had significant productions of fishmeal, but have limited information available. Recently, it has been estimated that 50% of their production comes from by-product utilization, likely from the large Alaskan pollock fishery (Jackson and Shephard 2012). The use of these by-products is also well documented historically (National Marine Fisheries Service 1968; Znamenski 1970; Sealy 1974), but the taxa that are used solely for reduction are less well detailed (Bureau of Commercial Fisheries 1961; Macer 1974; Alder and Pauly 2006). However, it is clear that there was not a large dedicated reduction fishery in what is now the Russian Federation before 1974 (Sealy 1974), and that in the late 1970s the USSR expanded into the Sea of Japan for the sardine fishery traditionally fished for reduction by Japan (Thomson 1990). In addition to this, the USSR was one of the first to exploit Antarctic krill and used this for fishmeal production as well as DHC products (Sealy 1974; Parker 2011). Many taxa that are commonly used by other European fishing entities for FMFO production are commonly used for DHC in the USSR and Russia such as: blue whiting, herring, mackerel, and sardine (Sealy 1974; Reinert 2001). For an overview of the fisheries of Russia since 1950, please see Russia's catch reconstructions (Pauly and Swartz 2007; Harper *et al.* 2012; Divovich *et al.* 2015b; Sobolevskaya and Divovich 2015).

Evidence and assumptions:

- Pacific sardine (*Sardinops sagax*) was likely fished for reduction beginning in the late 1970s (Thomson 1990). Thus, it was apportioned 100% to FMFO.
- The Antarctic krill (*Euphausia superba*) fishery had been conducted experimentally since the 1960s, but became increasingly commercial in the early 1980s until the dissolution of the USSR (Sealy 1974; Parker 2011). As this species was originally sought for human products, but gradually became more destined for animal use, it was originally apportioned as 50% DHC, 25% FMFO, and 25% other uses, and linearly interpolated to 1980 where DHC increased to 60%, and FMFO and other uses declined to 20% each. The values assumed here for this fishery are based on the predominant uses of krill products over this time period and represent a best estimate (Parker 2011).
- Pacific sandlance (*Ammodytes personatus*) is targeted for fishmeal production by European countries thus this was assumed to be 100% FMFO for Russia (Pauly and Swartz 2007; www.fao.org/fishery/species/3261/en).
- Blue whiting (*Micromesistius poutassou*) is used for fishmeal production as well as DHC. Due to a lack of information, a 50/50 split was applied between DHC and FMFO.
- Capelin (*Mallotus villosus*) had a reduction fishery when landings were very large from 1967-1987 until the fishery was closed (Hopkins and Nilssen 1991; Churchill and Ulfstein 2005). Before and after this period, it is thought that capelin was used for DHC (Jangaard 1976; Poseidon Aquatic Resource Management and Newcastle University 2004) with any excessively high catches in the intervening years likely playing a role in

the use for FMFO. Thus Capelin was apportioned 95% to DHC from 1950-1976 and 1988-2010, with 95% destined for FMFO from 1977-1987.

- Surprisingly, many of the fish used for reduction in European countries have no evidence of use for reduction in Russia. Many reports confirm the high use of by-products by Russia, especially before the collapse of the USSR (National Marine Fisheries Service 1968; Macer 1974; Sealy 1974), but also up to the present when fishmeal production is much lower (Green 2012; Jackson and Shephard 2012).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Spain

Spain formerly had dedicated reduction fisheries (Bureau of Commercial Fisheries 1961), however, fishmeal production after 2003 is entirely derived from by-products (Newcastle University and Poseidon Aquatic Resource Management 2004; Jackson and Shephard 2012). Therefore all reduction fisheries were linearly interpolated to primary DHC taxa levels based on their individual characteristics and landings. There is very limited information on Spain's reduction fisheries; however, based on high landings of the European pilchard and reports of its use for fishmeal production(http://firms.fao.org/firms/fishery/564/en), this was assumed to be the dominant species for Spain's earlier reduction fishery. In addition, Spain has been ranching Atlantic bluefin tuna (*Thunnus thynnus*) since 1985 which is reliant on local pilchard landings in addition to imports (Ottolenghi 2008). Spain's production is similar to Croatia's in the mid-2000s (Metian *et al.* 2014), and so a portion of European pilchard and European anchovy landings were apportioned to this direct feed use in line with other tuna ranching entities. For an overview of the fisheries of Spain since 1950, please see Coll *et al.* (2015) and Villasante *et al.* (2015a).

Evidence and assumptions:

- European pilchard (*Sardina pilchardus*) was a reduction fishery until at least 1996, and closed in 1999(http://firms.fao.org/firms/fishery/564/en). However, there was a consistent demand for pilchard for canning as well, and so the fishmeal proportion was estimated at 20% of total Spanish catches (~140,000 caught in fishery off of Morocco some of which is for canning) of pilchard until 2000 where it was treated as a primary DHC taxa (see below). Most of this catch occurred in Morocco's EEZ. In addition, this species is used for feed for tuna farming (Ottolenghi 2008; Metian *et al.* 2014). As a conservative estimate, other use was set at 1% in 1985 and linearly increased to 3% by 2000 (Metian *et al.* 2014). The remainder after both these uses was destined for DHC in fresh and canned products (Vázquez-Rowe *et al.* 2014).
- European anchovy (*Engraulis encrasicolus*) was also used as direct feed for tuna farming (Ottolenghi 2008) and was treated in line with European pilchard for this purpose from 1985-2010.
- Chub mackerel (*Scomber japonicus*) and jack and horse mackerels (*Trachurus* spp.) are caught as by-catch in the European pilchard fishery

(firms.fao.org/firms/fishery/564/en). It is believed the small amounts of these taxa were thus destined for reduction as well, and this was estimated at 1%.

- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Sweden

Sweden began the study period with no dedicated reduction fisheries (Bureau of Commercial Fisheries 1961), and has recently had a growing portion of landings destined for reduction (EUMOFA 2013). Half of their fishmeal production is reported to come from by-products which would represent a decline over the study period from 100% in 1950 and likely still in 1968 as production remained low (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968). Other fish not fit for human consumption have been used and were reported to be 30,000 tonnes in 1964 including herring, sprat, mackerel, cod, whiting, and others (Statistiska Centralbyrån 1968). From 1960 to 1965, the amount of fish listed as 'trash fish' (i.e. 'skrapfisk') by Sweden increased from ~8,000 tonnes to over 100,000 tonnes (Statistiska Centralbyrån 1960; 1968). In 2010, ~57% of landings were destined for reduction with Atlantic herring and European sprat constituting the majority of these landings (Popescu 2010). Sweden reports its fisheries landings in detail for DHC taxa, but broadly categorizes fish for industrial purposes and fish for reduction, including herring, sprat, cod, whiting, and mackerel, without resolution to the species level (Statistiska Centralbyrån 1960). A small portion of landings are also destined for direct feed and so taxa that are commonly used for reduction were assigned an 'other use' rate of 0.5% over the study period. For an overview of the fisheries of Sweden since 1950, please see Persson (2010) and Persson (2015).

Evidence and assumptions:

- The most important reduction taxa, Atlantic herring (*Clupea harengus*) and European sprat (*Sprattus sprattus*) were assumed to have higher reduction rates and direct feeding rates than other so-called 'trash' fish taxa. The non-DHC portion of the landings were apportioned to FMFO and other uses based on statistical reports with an average of 11.7% for the period of 1964-1966. These levels were assumed to apply to the earlier part of the study period (1950-1963), and were linearly interpolated to the average of 1975 and 1980 of 3.2%. As direct feed use became less common after this period and no longer appears separately in statistics, this was assumed to decline to 1% by 1990 and be stable for the remainder of the study period. The FMFO portion of the non-DHC rates were thus: 88.3% for 1950-1966, linearly interpolated to 96.8% for 1975-1980 and linearly interpolated to 99% in 1990 where it remained until 2010. These were informed by official Swedish fisheries publications (Statistiska Centralbyrån 1960, 1961, 1968, 1975, 1981; 1990).
    - European sprat has landings for FMFO and DHC (Statistiska Centralbyrån 1975). In 2011, 63% of landings went to FMFO (EUMOFA 2013). This fishery began with those fish not fit for DHC being destined for this purpose until Sweden began directed reduction fisheries in 1961. Thus, landings were

apportioned 5% in 1960 increasing linearly to 50% in 1965, as Sweden does have a history of human consumption of sprat (Newcastle University and Poseidon Aquatic Resource Management 2004). Observing the dominance of herring and sprat in Sweden's reduction fisheries, this was assumed to be linearly interpolated for the study period until it reached a peak in 2002 when only 7% of landings were destined for DHC because of a change in public perception of European sprat (Newcastle University and Poseidon Aquatic Resource Management 2004). However, this declined from this point to 63% in 2011, which was linearly interpolated from 2002 levels (EUMOFA 2013).

    - Atlantic herring was approximately 50% for DHC and 50% for FMFO in 2010 (Popescu 2010). This fishery began with those fish not fit for human consumption being re-directed for FMFO purpose until Sweden began directed reduction fisheries in 1961. Thus, landings were apportioned 95% to DHC in 1960 decreasing linearly to 50% in 1965. Observing the dominance of herring and sprat in Sweden's reduction fisheries, this was assumed to be steady for the remainder of the period. The remainder was apportioned to FMFO and other uses as detailed for the reduction taxa below.

- Blue whiting (*Micromesistius poutassou*) is used for fishmeal production as well as DHC in other fishing entities (Newcastle University and Poseidon Aquatic Resource Management 2004). There is not a sizeable DHC market in Sweden and it was assumed to be 95% for FMFO with 5% for DHC (Huntington 2009).
- The other taxa listed as 'skrapfisk', i.e. Atlantic mackerel (*Scomber scombrus*), Atlantic cod (*Gadus morhua*), and whiting (*Merlangius merlangus*) were used occasionally since 1960, but did not make up the majority of reduction fish used by Sweden. Therefore, they were treated separately from other taxa with a higher inclusion rate. Due to a lack of available information, the ratio of other uses to FMFO was estimated based on reported information (Statistiska Centralbyrån 1968, 1975). Therefore, it was simplified to 99%, 0.9% and 0.1% from 1950-1965, 99%, 0.95% and 0.05% for 1966-1989 and 99%, 0.99%, 0.01% for 1990-2010, for DHC, FMFO, and other uses, respectively.
- Norway pout (*Trisopterus esmarkii*) was assumed to be 100% destined for reduction based on current usage by fisheries(www.agrifish.dk/fisheries/fishery-statistics/), historical use (Macer 1974), and its quality as an industrial fish deemed not fit for human consumption (Huntington 2009; Wijkström 2010).
- Sandeels (*Ammodytes* spp., and more specifically *A. marinus*) were assumed to be 100% destined for reduction based on current usage by fisheries(www.agrifish.dk/fisheries/fishery-statistics/), historical use (Macer 1974), and its quality as an industrial fish not fit for human consumption (Huntington 2009; Wijkström 2010).
- Capelin (*Mallotus villosus*), although formerly a common reduction species, was only caught by Sweden recently where it was likely destined for human consumption. It was thus treated as a DHC taxon.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Turkey

Turkey began large-scale fishmeal production from dedicated fisheries in 1960, although there had been less advanced methods of fish oil production before this period (Bureau of Commercial Fisheries 1961). Mackerel and porpoise were the original inputs (note that porpoises and other marine mammals are not covered here, or in general by the *Sea Around Us*), although large catches of anchovy soon were destined for this purpose as well (Bureau of Commercial Fisheries 1961). In addition, pilchards, sprats, and horse mackerel are "used almost exclusively" for this purpose at present(www.eurofish.dk). Anchovy and pilchard are also apportioned to other uses for Atlantic bluefin tuna ranching over the 2002-2010 period as these are the dominant taxa used in its feed (Ottolenghi 2008). For an overview of the fisheries of Turkey since 1950, please see Ulman *et al.* (2013a).

Evidence and assumptions:

- European anchovy (*Engraulis encrasicolus*) was the dominant species used owing to its large annual landings. From 1950-1960, 90% of landings were destined for DHC, with 9.9% being for other uses (mainly fertilizer), and 0.1% for FMFO in the crude production of fish oil (Bureau of Commercial Fisheries 1961; Ulman *et al.* 2013a). From 1961-2001, FMFO increased to 50% in 1984 when the anchovy fishery peaked, with the remainder being split 49.9% for DHC and 0.1% for other uses. This was informed by contemporary use of 56% for FMFO in 2013 (Goulding *et al.* 2014). From 2002-2010 the share of other uses increased to 3% to account for the bluefin tuna ranching in Turkey during this time (Tsikliras *et al.* 2014) and the FMFO decreased to 47% (Ottolenghi 2008).
- European pilchard (*Sardina pilchardus*) is a dedicated reduction fishery in Turkey(www.eurofish.dk). From 1960-2001, 90% was destined for FMFO with the remainder being split 9.9% for DHC and 0.1% for other uses. From 2002-2010 the share of other uses increased to 3% to account for the bluefin tuna ranching in Turkey (Ottolenghi 2008).
- European sprat (*Sprattus sprattus*) began to be caught with pelagic trawl for reduction purposes in the 1990s (Ulman *et al.* 2013a). Therefore, 100% of production was assigned to FMFO, as it does not have a market for DHC in Turkey (Ulman *et al.* 2013a).
- Atlantic mackerel (*Scomber scombrus*) and horse mackerels (*Trachurus* spp.) appear to be treated together in reports on Turkey's fishmeal production. These were treated as 80% for FMFO, 19% for DHC, and 1% for other uses to reflect a small demand for human consumption, but a continued use over the study period for FMFO (Bureau of Commercial Fisheries 1961; www.eurofish.dk).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Ukraine

Ukraine does not report fishmeal production for FAO statistics (FAO 2014a), but they produce substantial amounts of fishmeal(http://www.fao.org/fishery/facp/UKR/en). A major portion of this comes from Ukraine's Antarctic krill fishery. For an overview of the fisheries of Ukraine since 1950, please see Ulman *et al.* (2015b).

Evidence and assumptions:

- European pilchard (*Sardina pilchardus*) was apportioned 50% to FMFO based on a regional average (Huntington 2009), as no other information was available. The remainder was apportioned to DHC. This was assumed to apply only to the period after independence (post-1992), and these were treated as primary DHC taxa from 1950-1991.
- European sprat (*Sprattus sprattus*) was apportioned 50% to FMFO based on a regional average (Huntington 2009), as no other information was available. The remainder was apportioned to DHC. This was assumed to apply only to period after independence (post-1992), and these were treated as primary DHC taxa from 1950-1991.
- Antarctic krill (*Euphausia superba*) was apportioned to various uses in line with Russia from 1950-1991 because of their shared history. For the remainder of the study period, 70% of krill was apportioned to fishmeal production(http://www.fao.org/fishery/facp/UKR/en).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the catch is landed. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

North and South American fishing entities

The reduction fisheries of the Americas are important globally and dominated by Peru, while Chile, the USA, and Canada also had significant fisheries over the 1950-2010 time period (Huntington and Hasan 2009; Sánchez Durand and Gallo Seminario 2009). The dominant taxa remain Peruvian anchoveta (*Engraulis ringens*), with the Gulf (*Brevoortia patronus*) and Atlantic menhaden (*B. tyrannus*), herrings, mackerel, sardines, and other anchovies also contributing a significant portion (Tacon and Metian 2009a). Fishing entities in the Americas broadly have less diversity of taxa in reduction fisheries than Europe and a trend of reduction species to continue to be used almost solely for that purpose (menhadens and anchoveta); however, these dominant taxa mask a trend of some species being redirected to human consumption over time such as Atlantic and Pacific herring, and Chilean jack mackerel.

With some variation between fishing entities, a small number of taxa dominate the total FMFO produced from dedicated reduction fisheries. Peruvian anchoveta is the largest reduction fishery globally, although its annual landings fluctuate greatly. Other important reduction fisheries include Pacific sardine, Chilean jack mackerel, and Atlantic and Gulf menhaden.

The fishing entities were broadly categorized into three types: 1) those possessing dedicated reduction fisheries; 2) those with a fishmeal production that is originating from by-products, although often not exclusively; and 3) those with no fishmeal and oil production from by-products or reduction fisheries. Only Venezuela was a type 2 fishing entity, and the type 1 and type 3 fishing entities for the Americas are listed in Table 1. Type 3 countries generally had no formally reported production of fishmeal (FAO 2014a), and thus FMFO percentage was set to 0%. However, unreported use of some landings for bait or direct feed is possible and this was conservatively estimated at 0.1% for squids, small pelagics, and small tuna-like species, which are commonly used as bait in longline tuna and elasmobranch fisheries in this region (Shing 1999; www.fao.org/fishery/fishtech/1010/en), with the remainder being DHC.

Table 1. Type 1 and type 3 fishing entities of the Americas

Type 1	Type 3
Argentina	Belize (http://www.fao.org/fishery/facp/BLZ/en)
Brazil	Caribbean (see below)
Canada	Costa Rica (http://www.fao.org/fishery/facp/CRI/es)
Chile	Falkland Islands (Falkland Islands Government Fisheries Department 2006)
Colombia	French Guiana (Harper *et al.* 2015)
Cuba	Guatemala (http://www.fao.org/fishery/facp/GTM/es)
Ecuador	Guyana (http://www.fao.org/fishery/facp/GUY/en)
El Salvador	Honduras (http://www.fao.org/fishery/facp/HND/es)
Mexico	Nicaragua (http://www.fao.org/fishery/facp/NIC/es)
Panama	Suriname (http://www.fao.org/fishery/facp/207/en)
Peru	
Saint Pierre & Miquelon	
United States of America	
Uruguay	

The Caribbean, with the exception of Cuba, reported no fishmeal production from 1976-2010 (FAO 2014a). Based on this and other evidence at the country level, there was no apportioning to FMFO purposes for these entities:

- Aruba
- Bahamas
- Barbados
- Bonaire
- British Virgin Islands
- Cayman Islands
- Curaçao
- Dominica
- Dominican Republic
- Grenada
- Guadeloupe
- Haiti
- Jamaica
- Martinique
- Montserrat
- Puerto Rico
- Saba and Sint Eustatius
- Saint Barthélemy
- Saint Kitts and Nevis
- Saint Lucia
- Saint Martin
- Saint Vincent/Grenadines
- Sint Maarten
- Trinidad and Tobago
- Turks and Caicos Islands
- US Virgin Islands

These fishing entities were treated together in a number of aspects including their higher use of bait when fishing for tuna, tuna-like species, and elasmobranchs. Therefore, use of landings for bait or direct feed is possible and this was conservatively estimated at 0.1% for squids, small pelagics, and small tuna-like species (assigned to *Scomber* spp., Scombridae, and Scombroids), which are commonly used as bait in longline tuna and elasmobranch fisheries in this region (Shing 1999; www.fao.org/fishery/fishtech/1010/en).

Argentina

Argentina's fisheries are centered on hake, with substantial amounts of by-products processed into FMFO (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968). Freshwater fishes were used for FMFO production until 1981, but these are not addressed here (Bureau of Commercial Fisheries 1961; FAO 2014a). For an overview of the fisheries of Argentina since 1950, please see Villasante *et al.* (2015b).

Evidence and assumptions:

- Argentine anchovy (*Engraulis anchoita*) caught by the industrial sector is apportioned as a primary DHC taxa after 1970, in contrast to Uruguay (Madureira *et al.* 2009). From 1950-1970, a decreasing portion was used for FMFO as DHC was adopted more heavily. For 1950, 75% was assigned to for DHC and 25% for FMFO, and percentages were interpolated to 100% DHC by 1970 (Bureau of Commercial Fisheries 1961).
- Brazilian menhaden (*Brevoortia aurea*) was assumed to be 100% for FMFO as menhaden is rarely used for other purposes (Wijkström 2010).
- Antarctic krill (*Euphausia superba*) was assumed to be 100% for FMFO as Antarctic krill is commonly used for this purpose (Parker 2011).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Brazil

Brazil's fishmeal production is mostly derived from by-products of fish processing (Lemos *et al.* 2004). While a few sources mention fishmeal coming from dedicated reduction fisheries (Lemos *et al.* 2004; Jackson and Shephard 2012), there is little evidence of this, other than the use of Brazilian sardinella. Therefore, a conservative assumption of 1% of small pelagics not fit for DHC were used for FMFO. As there are elasmobranch and tuna fisheries using live-bait boats, the general assumption for Latin American tuna and elasmobranch fisheries bait use applies here. For an overview of the fisheries of Argentina since 1950, please see Felizola *et al.* (2015).

Evidence and assumptions:

- Brazilian sardinella (*Sardinella brasiliensis*) is identified as a reduction fishery, with Brazil being the only fishing entity (Tacon 2009). The landings of this taxon were thus apportioned 100% to FMFO.
- Small pelagics were treated as 98.9% destined for DHC, 1% for FMFO, and 0.1% for other uses including bait. Additionally, squids, and tuna-like species are commonly used as bait in longline tuna and elasmobranch fisheries and were conservatively estimated at 0.1% (Shing 1999; www.fao.org/fishery/fishtech/1010/en). The remainder of these exceptions were destined for DHC.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Canada

Canada had sizeable reduction fisheries on both the Pacific and Atlantic coasts from 1950-1985. Reduction fisheries were outlawed in the *Fisheries Act* of 1985 (Government of Canada 2015), but fishmeal production has continued through the use of by-products, and fish not deemed fit for human consumption. Canada also has a sizeable use of Atlantic herring and Atlantic mackerel for bait for its east coast lobster fishery (Harnish and Willison 2009; Driscoll and Tyedmers 2010). All taxa detailed below were given FMFO ratios of 1% after 1985 to account for a large decrease in fish destined for reduction after the *Fisheries Act* (1985), but the increased likelihood of these taxa that are not fit for DHC would be used for FMFO. For an overview of the fisheries of Canada since 1950, please see Canada's catch reconstructions (Cheung *et al.* 2010; Ainsworth 2015; Teh *et al.* 2015b).

Evidence and assumptions:

- Pacific herring (*Clupea pallasii pallasii*) was the dominant species used for fishmeal production on Canada's Pacific coast until 1967 when the fishery was closed (Bureau of Commercial Fisheries 1961; www.pac.dfo-mpo.gc.ca). It was primarily caught with purse seine gear during this period;(>95%; Department of Fisheries of Canada 1968). The fishery was closed from 1968 to 1971 and was re-opened for the purpose of a roe fishery in 1972(www.pac.dfo-mpo.gc.ca). From 1950 to 1967, 97.3% of herring landings went to FMFO, while 2.4% went to bait and 0.3% went to DHC (Department of Fisheries of Canada 1961, 1968; Orth *et al.* 1981). After 1967, this changed drastically with the fishery's closure and conversion to a roe fishery with an estimated 98% of production for roe, 1% for other uses (bait) and 1% for FMFO (Fisheries and Environment Canada 1977).
- Atlantic herring's (*Clupea harengus*) fishmeal production increased with the decline of Pacific herring fishmeal production and was documented through the building of new reduction facilities and increased catches with purse seiners (Power and Savagon 1969; Hodder *et al.* 1972). Data were available to track an early increase in the use of Atlantic herring for bait (Hodder *et al.* 1972); however, they were not available for all years. As

other sources confirm a growing fishmeal industry after 1960 (Stobo *et al.* 1982), it was assumed 95% of landings during 1975-1985 were for FMFO. The proportion of Atlantic herring destined for FMFO was estimated at 7.17% in 1962 from fishmeal production statistics (Power and Savagon 1969) and this rate was assumed to be representative of previous years (1950-1961). Data were interpolated between 1961 and 1975. From 1950-1985, bait use was assumed to be constant at 1% to supply Atlantic cod, lobster, and other bait-based fisheries. After 1985, the landings were split with 1% for FMFO, 5% for other purposes, and 94% for DHC.

- Capelin (*Mallotus villosus*) is mentioned as a major fish for reduction in Canada in one report (Hardy and Tacon 2002), but not confirmed elsewhere. As this source mentions it after whole fish reduction is illegal in Canada, it was assumed to be sourced from by-products of Capelin. Capelin is therefore treated as a primary DHC taxon for the study period.
- Atlantic mackerel (*Scomber scombrus*) is not mentioned as being used for reduction (Department of Fisheries Aquaculture 2012), but has current use as bait in the Lobster fishery (Harnish and Willison 2009). Therefore, 5% of landings were destined for other use as a conservative estimate (in line with the other major bait species, Atlantic herring), and the remainder was apportioned 1% to FMFO for landings not fit for human consumption and 94% was used for DHC.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Chile

Chile's reduction fisheries began in 1957 targeting the Peruvian anchoveta that had previously been used for DHC (Sahrhage and Lundbeck 1992). Chile's reduction fisheries are very diverse, which has made them resistant to declines of individual stocks over the past 40 years. This reconstruction of uses is informed primarily based on annual statistics reports from 1960, 1970, 1980, 1990, 2000, and 2010, with percentages for intervening years being linearly interpolated (Ministerio de Agricultura 1960; 1970; Ministerio de Economia Fomento y Turismo 1980; 1990, 2000, 2010). Many taxa remained fairly consistent in their use over time (1957-2010) with some taxa demonstrating trends of changes in use as market demands shift. All trends were linearly interpolated between anchor years unless otherwise noted. For an overview of the fisheries of Chile since 1950, please see van der Meer *et al.* (2015).

Evidence and assumptions:

- All taxa were assumed to be primarily for DHC before 1957 (1950-1956), and data were linearly interpolated to 1960 levels from 1957-1960. The following taxa were included as reduction species at some point and in percentages as provided for in national statistics (Ministerio de Agricultura 1960; 1970; Ministerio de Economia Fomento y Turismo 1980; 2000, 2010):
    - Peruvian anchoveta (*Engraulis ringens*) was assigned 99.6% destined for FMFO, the average over the period of 1960-2010 as it displayed very little

variation over this period (National Marine Fisheries Service 1968; Hardy and Tacon 2002).
    - Chilean jack mackerel (*Trachurus murphyi*)
    - Pacific sardine (*Sardinops sagax*)
    - Araucanian herring (*Clupea bentincki*)
    - Chub mackerel (*Scomber japonicus*)
    - Patagonian grenadier (*Macruronus magellanicus*)
    - Southern Pacific hake (*Merluccius gayi)* and Southern hake (*Merluccius australis*) were not disaggregated in Chilean statistics and were thus treated together in this analysis.
    - Pacific menhaden (*Ethmidium maculatum*)
    - Pacific bonito (*Sarda chiliensis*) began to be used solely for reduction from 2000 onwards, but with very small landings. It was thus treated as 100% for reduction after this time, and as a primary DHC taxa before this (1950-1999).
    - Cabinza grunt (*Isacia conceptionis*).
    - Medusafish (*Seriolella* spp.) were not disaggregated before 1990 in Chilean statistics. From 1990 to 2010, Palm ruff (*Seriolella violacea*) was the predominant species used for FMFO and so fishmeal from medusafish before 1990 was assumed to be from Palm ruff.
    - *Raja* spp.
    - *Sciaena* spp.
    - Jumbo flying squid (*Dosidicus gigas*) is only reported as FMFO taxon in 2010, but was likely used for reduction as landings rose dramatically from 2000-2010. The 2010 ratio of 71% for FMFO and 29% for DHC was assumed to apply back to 2000.
    - Sauries (Scomberesocidae)
    - Falkland sprat (*Sprattus fuegensis*) was only caught later in the study period intermittently with all landings destined for reduction (Ministerio de Economia Fomento y Turismo 2010). Therefore, all landings were assumed to be destined for reduction.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Colombia

Colombia has fishmeal production dominated by anchovies, with thread herring also contributing. As there are also elasmobranch and tuna fisheries, the general assumption for bait use in Latin American tuna and elasmobranch fisheries applies here. For an overview of the fisheries of Colombia since 1950, please see Lindop *et al.* (2015).

Evidence and assumptions:

- Pacific anchoveta (*Cetengraulis mysticetus*) is used for the production of FMFO (Lindop *et al.* 2015). Therefore, 100% of landings are apportioned to this purpose.
- Pacific thread herrings (*Opisthonema* spp.) are used for the production of FMFO (http://www.fao.org/fishery/facp/COL/es; Lindop *et al.* 2015). Therefore, 100% of landings are apportioned to this purpose.
- Unreported use of landings for bait is likely for fisheries for tuna, tuna-like species, and elasmobranchs. This was conservatively estimated at 0.1% for squids, small pelagics, and tuna-like species (assigned to *Scomber* spp., Scombridae, and Scombroids), which are commonly used as bait in longline tuna and elasmobranch fisheries (Shing 1999; www.fao.org/fishery/fishtech/1010/en). The remainder of these exceptions were destined for DHC.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Costa Rica

Costa Rica has no fishmeal production specifically reported to the FAO; however, their production has been inferred based on export records (FAO 2014a). This is likely from by-products of their tuna canning production(http://www.fao.org/fishery/facp/CRI/es). As the bait used by Costa Rica is considered discarded, Costa Rica had no landings for purposes other than DHC over the entire study period. For an overview of the fisheries of Costa Rica since 1950, please see Trujillo *et al.* (2015).

Evidence and assumptions:

- A small portion of sardines (no species identity given) is used for bait in the tuna fishery while the rest is for DHC(http://www.fao.org/fishery/facp/CRI/es). However, these are considered discards as they were not landed before use as bait. They are therefore not considered in this analysis.

Cuba

Cuba is an island country in the Caribbean with a large amount of by-catch from the shrimp fishery, with by-catch directed towards FMFO production (Au *et al.* 2014). These fish were originally reported as “miscellaneous marine fishes” (or “marine fishes nei”), but have been assigned specific taxa in the *Sea Around Us* catch reconstruction (Au *et al.* 2014). As these industrial landings were destined for FMFO, 100% of these taxa were apportioned to FMFO. Cuba appears to have no other directed reduction fisheries, although it did have a large-scale tuna fishery, and an artisanal elasmobranch fishery (Baisre 2000; Au *et al.* 2014; http://www.fao.org/fishery/facp/CUB/es). For an overview of the fisheries of Costa Rica since 1950, please see Au *et al.* (2014).

Evidence and assumptions:

The following taxa caught by the industrial fleet were apportioned 100% to FMFO, originating from the shrimp fishery's by-catch (Au *et al.* 2014):

- *Acanthurus* spp.
- Balistidae
- Carangidae
- Centropomidae
- Chondrichthyes
- Clupeidae
- Congridae
- Crustaceans
- *Diapterus rhombeus*
- Diodontidae
- *Eucinostomus* spp.
- *Haemulon* spp.
- *Hippocampus* spp.
- *Lepophidium brevibarbe*
- *Lutjanus purpureus*
- *Lutjanus synagris*
- *Micropogonias furnieri*
- Molluscs
- *Ogcocephalus* spp.
- Ostraciidae
- Pleuronectiformes
- *Prionotus* spp.
- *Scomberomorus* spp.
- Serranidae
- Sparidae
- Sphoeroides
- Synodontidae
- Miscellaneous marine fishes ("marine fishes nei") were also included, as a portion of Cuba's by-catch remains aggregated to this level because of a lack of other information

- Unreported use of landings for bait is likely for fisheries for tuna, tuna-like species, and elasmobranchs. This was conservatively estimated at 0.1% for squids, small pelagics, and tuna-like species (assigned *to Scomber* spp., Scombridae, and Scombroids), which are commonly used as bait in longline tuna and elasmobranch fisheries (Shing 1999; http://www.fao.org/fishery/fishtech/1010/en). The remainder of these exceptions were destined for DHC.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Ecuador

Ecuador's reduction fisheries are diverse and all of the associated taxa appear to be used both for DHC and reduction to FMFO, except the 'white fish' fisheries which deliver fish almost entirely for human consumption. Reduction fisheries began in the 1960s and increased significantly in the 1970s and 1980s, and are heavily dependent on chub mackerel and Pacific sardine. There is assumed to be 100% DHC for these small pelagic taxa caught before 1964 when the first fishmeal plant opened (Alava *et al.* 2015). There is a lack of consistent information on the use of small pelagics except that they support both a canning industry and significant fishmeal and oil outputs (Aguilar 1992; Gonzalez and Solis 2010; http://www.fao.org/fishery/facp/ECU/es; SeaFish 2013; Alava *et al.* 2015), with a small portion destined for bait in the tuna fishery. For an overview of the fisheries of Ecuador since 1950, please see Alava *et al.* (2015).

Evidence and assumptions:

- Due to a lack of other information, it was assumed that 49.5% went to FMFO and DHC each, with the remaining 1% destined for bait use from 1964-2010 for all species unless otherwise indicated. The following taxa caught by the industrial fleet were apportioned in this method (Aguilar 1992; Alava *et al.* 2015): Peruvian anchoveta (*Engraulis ringens*), Chilean jack mackerel (*Trachurus murphyi*), chub mackerel (*Scomber japonicus*), harvestfishes (*Peprilus* spp.), longnose anchovy (*Anchoa nasus*), Mexican moonfish (*Selene oerstedii* assigned as Carangidae), Pacific anchoveta (*Cetengraulis mysticetus*), Pacific bumper (*Chloroscombrus orqueta*), Pacific drum (*Larimus pacificus* assigned as Sciaenidae), Pacific sardine (*Sardinops sagax*), red-eye round herring (*Etrumeus sadina*), sea catfishes (Ariidae), and shortfin scad (*Decapterus macrosoma*). Pacific thread herring (*Opisthonema libertate*) was used initially for DHC and fishmeal (apportioned as above) but their use for fishmeal was banned in 1986 (Gonzalez and Solis 2010). It is used primarily for DHC after this period and was thus treated as a primary DHC taxon for 1987-2010.
- 'White fish' was listed as having an increasing role in reduction fisheries as other common stocks have declined. Due to a lack of specific information, a conservative estimate of 5% of small demersals were assumed to be landed for this purpose from 2000-2010 after several of the reduction fisheries described above had declined (Alava *et al.* 2015).
- Unreported use of landings for bait is likely for fisheries for tuna, tuna-like species, and elasmobranchs. This was conservatively estimated at 0.1% for squids, small pelagics, and tuna-like species (assigned to *Scomber* spp., Scombridae, and Scombroids), which are commonly used as bait in longline tuna and elasmobranch fisheries (Shing 1999; http://www.fao.org/fishery/fishtech/1010/en). The remainder of these exceptions were destined for DHC.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

El Salvador

El Salvador has not reported on any dedicated reduction fisheries (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968; http://www.fao.org/fishery/facp/SLV/es). However, they do have fishmeal production reported to the FAO that likely originates from the by-catch of the shrimp fishery (Donadi *et al.* 2015), via *morrallas*. This is reported to be around 0.4% of their landings (www.fao.org/fishery/facp/SLV/es). *Morrallas* are the by-catch of shrimp trawlers which are transferred to artisanal fishing boats and landed by these boats instead of by the trawlers that caught them (Donadi *et al.* 2015).Therefore, in line with the reconstruction of marine fisheries of El Salvador (Donadi *et al.* 2015), 80% of these *morrallas* were assumed to be destined for FMFO, with the remaining 20% destined for DHC. The practice of *morrallas* began in 1979,

and so only the post-1979 period was used as this by-catch was discarded before this period, or only high value species were retained (Donadi *et al.* 2015). For an overview of the fisheries of El Salvador since 1950, please see Donadi *et al.* (2015).

Evidence and assumptions:

- 80% of the unreported industrial landings originating as by-catch from the shrimp fishery were apportioned to FMFO. The remaining 20% was marketed by the artisanal sector for DHC and was apportioned as such. There is one exception to this which had mixed uses which was "miscellaneous marine crustaceans", which were only used for DHC before 1979, and were only caught as *morrallas* after 1990. The period in between was interpolated based on the amount of crustaceans landed by trawlers themselves and that landed through the practice of *morrallas*.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Mexico

Mexico began the study period with fishmeal production mainly from by-products of their canneries, but grew into dedicated reduction fisheries in the 1960s and 1970s (Bureau of Commercial Fisheries 1961; National Marine Fisheries 1980). Mexico began farming bluefin tuna in 2002 (Miyake *et al.* 2010), and therefore has landings of 'baitfish' apportioned to this purpose for the period of 2002-2010 (Cisneros-Montemayor *et al.* 2015). For an overview of the fisheries of Mexico since 1950, please see Cisneros-Montemayor *et al.* (2015).

Evidence and assumptions:

- Pacific thread herring (*Opisthonema libertate*) is a recent fishery for Mexico beginning in 2005. This species was formerly used as bait for tuna fisheries, and it is reported as at least 80% used for fishmeal. Thus, this was apportioned 80% for FMFO, 15% for DHC, and 5% for other uses including bait and possibly direct feeding of tuna.
- Pacific sardine (*Sardinops sagax*) had a high use for fishmeal production in Latin America (Thomson 1990), and Mexico reportedly uses most of their sardine and anchovy landings for this purpose as well (National Marine Fisheries 1980). As anchovies were predominantly used for DHC before 1970, this was apportioned 80% for DHC and 20% for FMFO from 1950-1969, and as catches increasingly switched to FMFO, 75% of landings were apportioned to FMFO and 25% to DHC after 1975. The period of 1970-1975 was linearly interpolated. As tuna farming increased in Mexico in 2002, 3% was apportioned from these landings for other uses for 2002-2010 (FMFO at 73.5%, and DHC at 23.5%).
- Pacific anchoveta (*Cetengraulis edentulous*) is reported as a relatively new reduction fishery in Mexico in a report on fishmeal production (Bureau of Commercial Fisheries 1961). This is apportioned 100% to FMFO.

- Californian anchovy (*Engraulis mordax*) is not separated from Pacific sardine in sources, but most anchovy is used for reduction during the 1970s (National Marine Fisheries 1980). It thus followed the same pattern as Pacific sardine (see above).
- Gulf menhaden (*Brevoortia patronus*) has reported use for fishmeal production, and this is one of the only uses for this fish (Bureau of Commercial Fisheries 1961; Wijkström 2010). It was apportioned 100% to FMFO for Mexico.
- Other small pelagics not considered above were estimated to contribute 1% of landings to feed for bluefin tuna ranching (Miyake *et al.* 2010).
- Unreported use of landings for bait is likely for fisheries for tuna, tuna-like species, and elasmobranchs. This was conservatively estimated at 0.1% for squids, small pelagics, and tuna-like species (assigned to *Scomber* spp., Scombridae, and Scombroids), which are commonly used as bait in longline tuna and elasmobranch fisheries (Shing 1999; http://www.fao.org/fishery/fishtech/1010/en). The remainder of these exceptions were destined for DHC.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Panama

In the early years, Panama drove fishmeal production mainly using Pacific anchoveta (*Cetengraulis mysticetus*) and thread herring (Opisthonema libertate; Bureau of Commercial Fisheries 1961), and only reports anchoveta meal to the FAO from 1976-2010 (FAO 2014a). The fishmeal industry grew in the 1960s (Harper *et al.* 2014), and anchovies and herring are currently listed as being used in their entirety for FMFO production (www.fao.org/fishery/facp/PAN/es). Both of these taxa were originally used as bait for the commercial tuna fishery, and were caught by purse seines (Bureau of Commercial Fisheries 1961). For an overview of the fisheries of Panama since 1950, please see Harper *et al.* (2014).

Evidence and assumptions:

- Pacific anchoveta (*Cetengraulis mysticetus*) was assumed to begin in 1950 with 100% used for other uses such as bait (Harper *et al.* 2014). By 1959, it is likely nearly 100% was destined for FMFO based on landings data compared to fishmeal plant intake (Bureau of Commercial Fisheries 1961), however the tuna fishery's bait demands likely remained. Therefore, 99% was destined for FMFO, with 1% for other purposes (bait), and this was assumed to continue for the remainder of the study period. The period from 1951-1959 was linearly interpolated.
- Pacific thread herring (*Opisthonema libertate*) is the dominant species but other thread herrings were utilized (*O. bulleri*, *O. medirastre*, and *O. berlangai*) (Harper *et al.* 2014). By 1959, it is likely nearly 100% was destined for FMFO based on landings data compared to fishmeal plant intake (Bureau of Commercial Fisheries 1961). However the tuna fishery's bait demands likely remained. Therefore, 99% was apportioned to

FMFO, with 1% for other purposes (bait); this was assumed to continue for the remainder of the study period.
- Round sardinella (*Sardinella aurita*) were canned after the sardine cannery opened in 1971, and was treated as DHC taxon from 1971-2010 (Harper *et al.* 2014), but were assumed to be used for bait and fishmeal production along the same lines as anchoveta and herring before this (1950-1970).
- By-catch of the small pelagics fishery was assumed to follow the same pattern of use as the target species of Pacific anchoveta and Pacific thread herring. Miscellaneous marine fishes were apportioned to account for the proportion caught as pelagic by-catch (the majority) and the different use ratios of this catch compared to other marine fishes.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Peru

Peru has the largest reduction fishery in the world based on Peruvian anchoveta, and has been a major producer of fishmeal since the late 1950s (Bureau of Commercial Fisheries 1961). This fishery, however, has collapsed several times over the last 60+ years due to the combined effects of overfishing and El Niño events(see contributions in Pauly and Tsukayama 1987). This led to the development of other fisheries to supply Peruvian fishmeal production facilities, including Pacific sardine (*Sardinops sagax*); however, many taxa were banned for use for reduction in 2002 (Sánchez Durand and Gallo Seminario 2009; Ministerio de la Producción 2010). The reduction fisheries of Peru can be broken down into three time periods: 1950-1977 where anchovies dominated landings (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968; Macer 1974; Laws 2000); 1978-2002 where reduction fisheries were more diverse and included significant landings of sardine, Chilean jack mackerel and chub mackerel (Anon. 1981; Berrios 1983; FAO 2014a; Ministerio de la Producción 2014); and 2003-2010 when over 99% of fish destined for reduction was anchoveta (www.fao.org/fishery/facp/PER/en). Detailed use data were available from 1991-2010 and data were sampled from this period when landings were similar to the period of 1977-1990 for interpolation. For an overview of the fisheries of Peru since 1950, please see Mendo *et al.* (2014).

Evidence and assumptions:

- Peruvian anchoveta (*Engraulis ringens*) is caught by artisanal and industrial fisheries, with the artisanal fleet being destined for human consumption (Sánchez Durand and Gallo Seminario 2009). Thus, industrial landings were apportioned 100% to FMFO over the study period, and artisanal landings were apportioned as DHC.
- The following three taxa are separated as they had much higher use for FMFO during the 1977-2002 period with very little use outside of this time period (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968; Hardy and Tacon

2002; http://www.fao.org/fishery/facp/PER/en). They are thus modelled based on the time period with detailed data (1991-2010) based on similar landings over a time period; thus, the average use for FMFO over a time period that is known is applied to the period of 1977-1990 when landings were similar.

  - The use of Pacific sardine (*Sardinops sagax*) for FMFO is concentrated in the second period (1977-2002) as its population was low at other times because of environmental conditions and the combined effects of overfishing and environmental conditions towards the end of this period (Chavez *et al.* 2003). However, as the fishery for this taxon developed, the canning industry and fishmeal industry were its major users (Anon. 1981). Pacific sardine was also caught as by-catch in the Peruvian anchoveta fisheries in other periods and would likely be used for FMFO; therefore, all industrial landings from 1950-1976 and from 2003-2010 were apportioned to FMFO. From 1977-2002, landings and use ratios were highly variable (Ministerio de la Producción 2014), and this was likely to have reached a peak destined for FMFO when anchoveta landings decreased to almost nothing in 1984 (FAO 2014a). The use ratio for 1991-1994 (93.27% for FMFO), with average landings of over 2 million tonnes, was used to inform the use of 1977-1990 when landings were in a similar range (FAO 2014a; Ministerio de la Producción 2014). From 1991-2010, published annual data on its use were applied (Ministerio de la Producción 2014).
  - Chub mackerel (*Scomber japonicus*) was modelled based on 1994-1996 use ratios (53.92% for FMFO) where landings were ~46,000 tonnes annually, compared to ~51,000 tonnes annually over the 1977-1990 period. From 1950-1976, this was assigned as a DHC taxon. From 1991-2010, published annual data on its use were applied (Ministerio de la Producción 2014).
  - Chilean jack mackerel (*Trachurus murphyi*) was modelled based on 1991-1994 with average landings of ~140,000, comparatively close to the 1977-1990 period (~148,000). The average percentage destined for FMFO was 46.61% and this was applied to the 1977-1990 period. From 1950-1976, this was modelled as a primary DHC taxon. From 1991-2010, published annual data on its use were applied (Ministerio de la Producción 2014).

- Pacific menhaden (*Ethmidium maculatum*) is canned for DHC in Peru (Sánchez Durand and Gallo Seminario 2009; www.photolib.noaa.gov/htmls/fish2192.htm), and it is believed that fishmeal sourced from this species is from processing canning by-products (Ministerio de la Producción 2014). Industrial landings are likely by-catch of anchovy and sardine fisheries and thus these are destined 100% for FMFO.
- Longnose anchovy (*Anchoa nasus*) was caught later in the period and reportedly only used for reduction purposes (Ministerio de la Producción FAO 2014a; 2014).
- Jumbo flying squid (*Dosidicus gigas*) is used in unknown amounts in Peru for squid meal production (Tacon 2009). Therefore, Chile's use rate for this taxon (determined by Chilean annual statistics) was applied (Ministerio de Economia Fomento y Turismo 2010).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002;

Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Saint Pierre and Miquelon

Saint Pierre and Miquelon is an island territory off the East coast of Canada that is part of France, which is heavily dependent on fisheries(www.discoverfrance.net; http://atlas.media.mit.edu/en/profile/country/spm/). Their reported fishmeal production likely comes from the by-products of their processing industry of Atlantic cod, and thus has declined in recent years with declines of cod landings (FAO 2014a; Bultel and Zylich 2015). However, it is reported they used many other taxa in substantial amounts as bait for their artisanal cod fisheries. In addition, capelin landings not destined for bait were often used to feed domestic animals and as fertilizer (Bultel and Zylich 2015). For an overview of the fisheries of Saint Pierre and Miquelon since 1950, please see Bultel *et al.* (2015).

Evidence and assumptions:

- The following taxa caught by the artisanal fleet were apportioned 100% to other uses as bait for the Atlantic cod (*Gadus morhua*) fishery: mussels (assigned as blue mussel), softshell clam (assigned as clams), capelin (*Mallotus villosus*), squid, mackerel (assigned as Atlantic mackerel [*Scomber scombrus*]), Atlantic herring (*Clupea harengus*), sand eel (*Ammodytes* spp.), whelk, great scallop (assigned as scallops), and northern propeller clam (assigned as clams).
- Capelin (*Mallotus villosus*) is used for DHC and for other uses when caught in subsistence and artisanal fisheries. Thus, subsistence catches of capelin were apportioned 50% to DHC and 50% to other uses such as feeding domestic animals and fertilizer (Bultel and Zylich 2015).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

United States of America

The USA's reduction fisheries are dominated by menhaden (Gulf and Atlantic) over the study period (NOAA Fisheries 1995). Earlier in the 20th century, Pacific sardine (*Sardinops sagax*) made up the majority of fishmeal production, but the fishery was largely collapsing by 1950 and reduction of this species had largely stopped (Ueber and MacCall 1992). For an overview of the fisheries of the USA since 1950, please see the USA's catch reconstructions (Booth *et al.* 2008; Doherty *et al.* 2015a; Doherty *et al.* 2015b; Gibson *et al.* 2015c; McCrea-Strub 2015).

Evidence and assumptions:

- Pacific herring (*Clupea pallasii pallasii*) was used in small proportions when there were excess landings. Therefore, it was apportion as 99% for DHC, 0.95% for FMFO and 0.05% for other uses (King 1958).
- Atlantic herring (*Clupea harengus*) was used in small proportions for FMFO near the beginning of the study period (King 1958; Bureau of Commercial Fisheries 1961). However, it is also the most common bait used in the American lobster fishery and has been reported to be used in a 2.2:1 ratio of Atlantic herring bait used to lobster landed (Harnish and Willison 2009; Grabowski *et al.* 2010). Therefore, it was apportion as 60% for DHC, 20% for FMFO and 20% for other uses in 1950, and was linearly interpolated to current levels of 30% for DHC, 0% for FMFO, and 70% for other uses (Tyedmers 2004; Grabowski *et al.* 2010; SeaFish 2011).
- Atlantic thread herring (*Opisthonema oglinum*) began as a fishery for bait fish in 1957 and began to be used for fishmeal and animal feed the next year (National Marine Fisheries Service 1968). Due to a lack of information, it was apportioned 100% to other use from 1950-1957, and thereafter as 60% for FMFO and 40% for other uses as the use for fishmeal is documented expanding during the 1960s (National Marine Fisheries Service 1968).
- Californian anchovy's (*Engraulis mordax*) fishmeal production peaked in 1975 and ended around 1983 because of economic factors (Thomson 1990). It was used 100% for bait from 1950-1964, and then a considerable portion was used for FMFO until 1983, so it was assumed to be 80% for FMFO from 1965-1975 (based on 1975 production levels) with this declining to 0.05% in 1983 (Thomson 1990). From 1983-2010, it was assumed that bait use re-emerged as the dominant use with 99.95% of landings.
- Bay anchovy (*Anchoa mitchilli*) is overwhelmingly used for bait (Tacon and Metian 2009a). It was thus apportioned to 100% to this use.
- Gulf menhaden (*Brevoortia patronus*) and Atlantic menhaden (*B. tyrannus*) are used almost entirely for fishmeal production, although some is used for bait and direct animal feed (Thomson 1990). From 1950 to 1988, at least 85% of landings were destined for FMFO with the rest being made up by other uses. This likely increased to nearly 100% (Huntington and Hasan 2009) and therefore the proportion for FMFO was linearly interpolated from 85% in 1950 to 99.9% in 1990 with the remainder (0.1%) being destined for other uses, likely bait in commercial fisheries for blue crab, lobster, crayfish and eel (Tacon and Metian 2009a).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Uruguay

Uruguay produces fishmeal from by-products of processing (Borgstrom 1965; www.fao.org/fishery/facp/URY/es), and through a dedicated reduction fishery for Argentine anchovy (Madureira *et al.* 2009). Uruguay also has very small landings of two taxa used almost entirely for FMFO by other fishing entities. For an overview of the fisheries of Uruguay since 1950, please see Lorenzo *et al.* (2015).

Evidence and assumptions:

- Argentine anchovy (*Engraulis anchoita*) caught by the industrial sector is apportioned 100% to FMFO (Madureira *et al.* 2009).
- Brazilian menhaden (*Brevoortia aurea*) was assumed to be 100% for FMFO as menhaden is rarely used for other purposes (Jablonski *et al.* 2006; Wijkström 2010).
- Antarctic krill (*Euphausia superba*) was assumed to be 100% for FMFO as Antarctic krill is commonly used for this purpose (Parker 2011).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Venezuela

Venezuela's fishmeal appears to be almost entirely derived from by-products (Bureau of Commercial Fisheries 1961; www.fao.org/fishery/facp/VEN/es). For an overview of the fisheries of Venezuela since 1950, please see Mendoza *et al.* (2015).

Evidence and assumptions:

- Atlantic anchoveta (*Cetengraulis edentulus*) has previously been used in small amounts to supplement by-product fishmeal production (Bureau of Commercial Fisheries 1961). 10% of landings were thus apportioned to FMFO.
- Unreported use of landings for bait or direct feeding is possible and this was conservatively estimated at 0.1% for squids, small pelagics, and tuna-like species, which are commonly used as bait in longline tuna and elasmobranch fisheries (Shing 1999; http://www.fao.org/fishery/fishtech/1010/en). The remainder of these exceptions were destined for DHC.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

African fishing entities

Africa is a continent of great diversity in its fishery practices, but there are a few patterns that mark the use of fishery products. Broadly, there are very few countries with dedicated reduction fisheries, and only a handful of countries producing fishmeal from whole marine fish. In addition, many North African countries are involved in the provision of feed for and the practice of ranching of Atlantic bluefin tuna for export (Ottolenghi 2008), but this is not exclusive to this region, as South Africa also provides pilchard for direct feeding of tuna (Hecht and Jones 2009). There are several fishing entities with prominent tuna fisheries using long-lines or pole and line as gear, and thus requiring bait. Therefore, the major uses to account for when reconstructing the end use of fishery landings in Africa are fishmeal, direct feed for tuna, and bait use for tuna and elasmobranch fisheries, although overwhelmingly landings were destined for DHC.

Longline and pole-and-line fisheries for tuna, swordfish, and elasmobranchs use baited hooks, often using frozen whole fish as bait. The most common taxa utilized in the Indian ocean are: bigeye scad (*Selar crumenophthalmus*), blue pilchard (*Sardinops neopilchardus*), chub mackerel (*Scomber japonicus*), mackerel scad (*Decapterus* spp.), milkfish (*Chanos chanos*), Pacific (*Sardinops sagax*), Pacific saury (*Cololabis saira*), and squid (*Ilex* spp.) (Bolaky 2006). Thus, the countries that fished for tuna, swordfish, and elasmobranchs were assumed to have some bait use (until further analysis on gear use in industrial fisheries is completed), and therefore had 0.1% of the previously listed taxa apportioned to this use as a conservative estimate when their fisheries for these taxa were active. However, this was only applicable to fishing entities fishing in the Indian Ocean and this level of resolution is often not available for many of these countries. Where this was not possible, 0.1% of landings of common bait taxa and small pelagics (Clupeidae, Clupeiformes, *Decapterus* spp., Engraulidae, Exocoetidae, Hemiramphidae, Loliginidae, *Loligo* spp., *Sardina pilchardus*, *Sardinella* spp., *Sardinops sagax*, *Scomber japonicus*, *Scomberesox saurus*, *Selar crumenophthalmus*, and *Trachurus* spp.) were apportioned to bait use for these fishing entities when they had industrial landings of tunas, tuna-like species, or elasmobranchs. The fishing entities of Africa that fit this criteria are: Algeria, Angola, Benin, British Indian Ocean Territory, Cabo Verde, Comoros, Congo, Côte d'Ivoire, Egypt, Equatorial Guinea, Eritrea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Libya, Madagascar, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Réunion, Saint Helena, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Tanzania, Togo, and Tunisia.

In addition to the above small pelagic and other taxa being used for bait, many of these same taxa are used for FMFO. Broadly, the taxa targeted for fishmeal and fish oil by reduction fisheries by African fishing entities are: sardines, round sardinella (*Sardinella aurita*), European pilchard (*Sardina pilchardus*), Pacific sardine (*Sardinops sagax*), Southern African anchovy (*Engraulis capensis*), European anchovy (*Engraulis encrasicolus*) chub mackerel (*Scomber japonicus*), and horse mackerels (*Trachurus* spp.) including Cape horse mackerel (*Trachurus capensis*), Atlantic horse mackerel (*Trachurus trachurus*), and Cunene horse mackerel (*Trachurus trecae*).

The following countries are Type 1 fishing entities, and have individual reports to detail their reduction fisheries: Angola, Eritrea, Libya, Madagascar, Mauritania, Morocco, Namibia, and South Africa.

The following fishing entities are Type 2 fishing entities and only produce fishmeal from by-products:

- Cape Verde has fishmeal production from by-products of its mackerel and tuna canning operations (FAO 2008d). As baitfish fisheries are treated separately, these fisheries were apportioned 100% to other uses (Trindade Santos *et al.* 2013).
- Côte d'Ivoire produces fishmeal from by-products of the tuna processing industry (www.fao.org/fishery/facp/CIV/fr; 2014a).
- Egypt produces fishmeal from by-products of canneries for sardine, pilchard, mackerel and tuna (Hecht and Jones 2009; FAO 2010awww.fao.org/fishery/facp/EGY/en).
- Ghana's fishmeal production originates from tuna by-products and freshwater taxa (silver cyprinid [*Rastrineobola argentea*]) and is therefore excluded from this analysis (Hecht and Jones 2009).
- Kenya has fishmeal production from a freshwater silver cyprinid reduction fishery and derived from by-products of Nile perch (*Lates niloticus*) processing and is therefore excluded from this analysis (Hecht and Jones 2009).
- Mauritius produces fishmeal from tuna processing by-products (www.fao.org/fi/oldsite/FCP/en/MUS/; Hecht and Jones 2009). Bait is employed for the pole and line tuna fisheries and sport fisheries (Boistol *et al.* 2011), although the species used by the local fleets are unclear. Therefore, a conservative estimate of 0.1% of small, medium, and large pelagics (bonito and small or juvenile tuna) (www.maranathafishing.com/en), squid, and small demersal fishes were apportioned to other uses for this purpose (Bolaky 2006). This was applied in place of the regional assumption as country-specific information was available.
- Nigeria has a crude form of fishmeal production from freshwater fisheries that are not considered here. There is disagreement on the end use of Nigeria's landings of shrimp by-catch called 'crayfish' but here they were assumed to be for DHC (www.fao.org/fishery/facp/NGA/en; Etim *et al.* 2015).
- Senegal sources its fishmeal production from by-products (www.fao.org/fishery/facp/SEN/fr; Jackson and Shephard 2012) and has no history of reduction fisheries (National Marine Fisheries Service 1968). It may export fish destined as feed for tuna ranching, but there is not robust evidence of this (Hecht and Jones 2009).
- Somalia produces a small amount of fishmeal, likely from by-products of processing, including tuna(www.fao.org/fi/oldsite/fcp/en).
- Tanzania uses fish by-products of Nile perch processing and low quality 'sardines' from Lake Victoria for fishmeal production(www.fao.org/fishery/facp/TZA/en). As these are freshwater fisheries, they are excluded from this analysis.
- The Seychelles' fishmeal production likely originates solely from by-products (Hecht and Jones 2009; FAO 2014a) although this is contested (Jackson and Shephard 2012).
- Tristan da Cunha produces fishmeal from the non-tail portion of spiny lobster and this is classified as a by-product in this analysis (Booth and Azar 2009). Its lobster fishery is dependent on bait use of finish and octopus; therefore, all industrial landings of these taxa were apportioned to bait use (Booth and Azar 2009).

- Tunisia's fishmeal production is assumed to be from by-products of tuna and sardine processing(www.fao.org/fishery/facp/TUN/fr), but they do ranch bluefin tuna for export requiring large amounts of small pelagics for direct feed (Ottolenghi 2008). Therefore, 4920 tonnes were estimated to be used for direct feed in 2009 to produce ~740 tonnes of bluefin tuna (harvest weight with 10:1 FCR, and start weight of roughly 1/3 harvest weight; Anon. 2013; Metian *et al.* 2014).This is assumed to begin in 2002 and increase linearly to 2009 (Metian *et al.* 2014), and therefore European pilchard was apportioned 33% to other uses for the provision of direct feed for this industry in 2009. This is in addition to bait use in line with other African fishing entities that have fisheries for tuna, tuna-like species, and elasmobranchs.

The following fishing entities are Type 3 and reported no fishmeal production to the FAO from 1976-2010 (FAO 2014a). They were therefore apportioned 0% to FMFO for all landings:

- Algeria
- Ascension Island (Booth and Azar 2009)
- Benin
- British Indian Ocean Territory (Zeller and Pauly 2014)
- Cameroon
- Comoros
- Congo
- Democratic Republic of Congo
- Djibouti
- Equatorial Guinea
- Gabon
- Gambia
- Guinea
- Guinea-Bissau
- Liberia
- Mayotte (Doherty *et al.* 2015c)
- Madeira Island had a baitfish fishery to supply its tuna fishery (Shon *et al.* 2015). As fishing entity specific information was available, this was used in place of regional bait use assumptions.
- Mozambique has no reported fishmeal production(www.fao.org/fishery/facp/MOZ/en). Mozambique has industrial landings of elasmobranchs during the study period, but these are by-catch of a pelagic trawl fishery, and thus Mozambique is not considered to have bait use for these fisheries in contrast to other entities in the region.
- Réunion (Le Manach *et al.* 2015)
- Saint Helena (Booth and Azar 2009)
- Sao Tome and Principe
- Sierra Leone
- Sudan (www.fao.org/fishery/facp/SDN/en)
- Togo

Angola

There was a fishmeal industry in Angola during its Portuguese colonial period (pre-1975). Portuguese vessels in what later became Angola made it the third largest fishmeal producing country in the early 1970s (International Trade Centre 2003). In contrast, reported fishmeal production after independence has never been more than ~5,000 tonnes annually (FAO 2014a) and reportedly is 50% derived from by-products (Jackson and Shephard 2012), compared to a production of ~100,000 tonnes in 1957 (Bureau of Commercial Fisheries 1961). Approximately 80% of Angola's catch was used for FMFO in 1960, but this has declined significantly to using ~10,000 tonnes out of ~500,000 tonnes of landings for this purpose (Jackson and Shephard 2012). A small portion of artisanal landings was formerly used for reduction (Bureau of Commercial Fisheries 1961), although this likely no longer occurs. For an overview of the fisheries of Angola since 1950, please see Belhabib & Divovich (2015).

Evidence and assumptions:

- As artisanal landings were used in small proportions during the colonial period, 5% of artisanal landings were apportioned to FMFO for the taxa detailed below as a conservative estimate (Bureau of Commercial Fisheries 1961). The other notes below reflect their use from industrial landings. Due to a lack of other information, Angola was treated in two separate periods: 1950-1975 (colonial period), and 1976-2010 (independent period). Fishmeal production was concentrated in the colonial period. Therefore, the following taxa identified as used primarily for FMFO during this period were apportioned 85% to FMFO, 14% to DHC, and 1% to other uses, likely bait for the tuna fisheries (National Marine Fisheries Service 1968). Independence brought a drastic decline in FMFO production and the following taxa likely became primary DHC taxa: Cunene horse mackerel, cape horse mackerel, Atlantic horse mackerel, and bigeye scad. Sardines continued to contribute a small portion of their landings destined for reduction and this was assumed to be 5% as a conservative estimate (Jackson and Shephard 2012; FAO 2014a; www.fao.org/fishery/facp/AGO/en). While sardinellas were the dominant taxa used for fishmeal, this is accounted for through their substantially higher landings than other taxa during the colonial period. The following taxa were evaluated under this division:
  - Sardinellas (*Sardinella* spp.) were used primarily for fishmeal (Bureau of Commercial Fisheries 1961).
  - Bigeye scad (*Selar crumenophthalmus*) and Atlantic horse mackerel (*Trachurus trachurus*) were reportedly used for fishmeal (Bureau of Commercial Fisheries 1961).
  - Cape and Cunene horse mackerels (*Trachurus capensis* and *T. trecae*, respectively) were used for fishmeal (Lankester 2002), although *T. trecae* is now the main food fish for Angolans (www.fao.org/fishery/facp/AGO/en).
- Bait used in fisheries for tuna, tuna-like species, and elasmobranchs were apportioned in line with other African tuna fishing countries (see 'African Fishing Entities'). These fisheries were active for the whole study period for Angola.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002;

Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Eritrea

Eritrea had reduction fisheries for sardine and anchovy, that were especially prominent in the 1950s and 1960s (Tesfamichael and Mohamud 2012). This fishery was mainly for the production of fishmeal and fish oil, although some was sun-dried and exported to Asia for human consumption (Tesfamichael and Mohamud 2012). Furthermore, Eritrea was a landing site for reduction fisheries based in Yemen (Tesfamichael *et al.* 2012b). However, some fishmeal facilities were destroyed prior to independence, leading to a reduction in production (Tesfamichael and Mohamud 2012), although it is still reported that Eritrea's anchovy and sardine landings are destined primarily for this purpose (www.fao.org/fishery/facp/ERI/en). Fishmeal production also stopped in 1967 due to the closing of the Suez Canal and thus markets for these fish (Tesfamichael and Mohamud 2012). However, this was accounted for through a shift in fisheries to other taxa. For an overview of the fisheries of Eritrea since 1950, please see Tesfamichael and Mohamud (2012).

Evidence and assumptions:

- Bluestripe herring (*Herklotsichthys quadrimaculatus* assigned as Clupeidae) are assumed to be 100% destined for FMFO as they are not retained for other purposes.
- Anchovies (*Encrasicholina heteroloba* and *Thryssa baelama*, assigned as Engraulidae) are assumed to be 100% destined for FMFO as they are not retained for other purposes.
- Indian mackerel (assigned as Scombridae) was used for bait by a modern longline fishery beginning in 1999 (Tesfamichael and Mohamud 2012). Therefore, 0.1% of this was apportioned to bait with the remainder destined for DHC.
- Bait used in fisheries for tuna, tuna-like species, and elasmobranchs were apportioned in line with other African tuna fishing nations (see 'African Fishing Entities'). These fisheries were active for the whole study period for Eritrea.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Libya

Libya has a reported fishmeal production, but has no significant small pelagic fisheries for this purpose. However, it has a requirement of small pelagics for direct feed for Atlantic bluefin tuna ranching (Ottolenghi 2008; Metian *et al.* 2014). This is unaccounted for in national statistics and reports. Libya directs 95% of fish landed for human consumption, and has very small amounts of imports that could be used as feed for bluefin tuna ranching (Ottolenghi 2008; European Commission 2009). It is thus unclear how Libya can supply this industry, but it is

assumed here to derive mainly from unreported imports. For an overview of the fisheries of Libya since 1950, please see Khalfallah *et al.* (2015a).

Evidence and assumptions:

- Libya farmed 3107 tonnes of bluefin tuna in 2004 (Metian *et al.* 2014), requiring large amounts of pelagics for direct feed (Ottolenghi 2008). Therefore, 20,718 tonnes of small pelagics were needed in 2004 to produce ~3107 tonnes of bluefin tuna (harvest weight with 10:1 FCR, and stocking weight of roughly 1/3 harvest weight; Anon. 2013; Metian *et al.* 2014). This amount of direct feed is greater than Libya's catch of small and medium pelagics, most of which originate from the artisanal sector. Therefore, Libya's feed requirements were assumed to rely entirely on imports and were not apportioned to Libya.
- Bait used in fisheries for tuna, tuna-like species, and elasmobranchs were apportioned in line with other African tuna fishing entities (see 'African Fishing Entities'). These fisheries were active for the whole study period for Libya.
- An average of 1074 tonnes of raw material is needed for fishmeal production in Libya, and this was assumed to apply to the whole study period, as FAO reporting outside this window appears to be missing some data (www.fao.org/fishery/facp/LBY/en; Ottolenghi 2008; FAO 2014a). However, Libya's landings of suitable or likely taxa were relatively low and more likely destined for DHC. Thus, small pelagics were apportioned as 5% to FMFO over the study period to account for variable availability of fresh fish(www.fao.org/fishery/facp/LBY/en). While there is no explicit evidence for this, the majority of Libya's fishmeal production likely originates as by-products of their canneries(www.fao.org/fishery/facp/LBY/en), and hence the low level of use of whole small pelagics for this purpose.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Madagascar

Madagascar's use of fish for fishmeal production began in 1992 to fill some of the demand of the new shrimp aquaculture industry (Laurenti 2004; FAO 2014a; www.fao.org/fishery/facp/MDG/en). There is no indication of what taxa are used for this purpose. Prior to this period (1950-1991), no landings were apportioned to FMFO. For an overview of the fisheries of Madagascar since 1950, please see Le Manach *et al.* (2012).

Evidence and assumptions:

- Only small and medium pelagics were assumed to be consistently used at 10% from 1992-2010. The remaining 90% was apportioned 89.9% to DHC and 0.1% to other uses for bait for elasmobranch and tuna fisheries(www.fao.org/fishery/facp/MDG/en).

- Bait used in fisheries for tuna, tuna-like species, and elasmobranchs were apportioned in line with other African tuna fishing entities (see 'African Fishing Entities'). These fisheries were active for the whole study period for Madagascar.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses when fishmeal was produced (1992-2010) to account for fish caught for human consumption that are not used for that purpose. Before this period (1950-1991), the remainder was apportion 99.95% to DHC and 0.005% to other uses.

Mauritania

Mauritania's fishmeal production is sourced from a small portion of the pelagic catch(www.fao.org/fishery/facp/MRT/fr). Due to a lack of information on taxonomic composition, small and medium pelagics were used for the disaggregation of end uses. For an overview of the fisheries of Mauritania since 1950, please see Belhabib *et al.* (2015).

Evidence and assumptions:

- Pelagics were listed as used in small proportions (1-2%) for fishmeal(www.fao.org/fishery/facp/MRT/fr). Thus small and medium pelagics were assumed to be consistently used at 1.5% for the study period, with changes in fishmeal production (FAO 2014a) caused by changes in landings. The remaining 98.5% was apportioned to DHC.
- Bait used in fisheries for tuna, tuna-like species, and elasmobranchs were apportioned in line with other African tuna fishing entities (see 'African Fishing Entities'). These fisheries were active from 1970-2010 for Mauritania.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Morocco

Morocco's pelagic fisheries use excess landings for FMFO (Bureau of Commercial Fisheries 1961; Hecht and Jones 2009). However, this can be significant in some years because of limited canning infrastructure (www.fao.org/fishery/facp/MAR/fr; Hecht and Jones 2009). In addition, approximately 15% of fishmeal is sourced from by-products (Jackson and Shephard 2012), likely from these same canneries. An estimation was made based on reported fishmeal production (FAO 2014a) taking into account production from by-products. Morocco began the study period with FMFO solely from by-products of sardine canneries, but excess sardine

catches eventually began to be used for reduction. Thus, FMFO was set at 0% for all fish in 1950 and linearly interpolated to the estimate average in 1953 (Bureau of Commercial Fisheries 1961). For an overview of the fisheries of Morocco since 1950, please see Belhabib *et al.* (2013).

Evidence and assumptions:

Morocco's reduction fisheries centered around five taxa, detailed below. These were assumed to be equally apportioned to FMFO. Further, it was assumed that all non-by product FMFO was derived from these five taxa, and the amount needed was calculated based on FAO statistics on fishmeal production for Morocco (1976-2011; (FAO 2014a), and other reports of Moroccan fishmeal production (Bureau of Commercial Fisheries 1961; National Marine Fisheries Service 1968). Years without published statistics on fishmeal production were interpolated for fishmeal production and therefore use of landings. While this does not consider variations in the use of particular taxa for this purpose, it does account for it through a proxy in the variation of landings of particular taxa over time. The amount used for FMFO fluctuated over the period between 47% and 5%, with an average of ~30%. In addition, European pilchard and European anchovy were apportioned to direct feed at roughly ~5,000 tonnes annually over the period of 2002-2010, as its production is comparable to Greece's (Ottolenghi 2008).

- European pilchard (*Sardina pilchardus*)
- Sardinellas (*Sardinella* spp.)
- European anchovy (*Engraulis encrasicolus*)
- Chub mackerels (*Scomber* spp.)
- Horse mackerels (*Trachurus* spp.)
- Other bait used in fisheries for tuna, tuna-like species, and elasmobranchs were apportioned in line with other African tuna fishing entities (see 'African Fishing Entities'). These fisheries were active for the whole study period for Morocco.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Namibia

Namibia has reduction fisheries for Pacific sardine and Atlantic horse mackerel. During its period of South African occupation, much of their data were not disaggregated (Bureau of Commercial Fisheries 1961). However, after independence in 1961, only pilchard (i.e. Pacific sardine) was reported for fishmeal production in the early 1970s. Therefore, it was assumed that sardine was the only reduction species utilized by Namibia until 1975 (Macer 1974). For an overview of the fisheries of Namibia since 1950, please see Belhabib *et al.* (2010).

Evidence and assumptions:

- Pacific sardine (*Sardinops sagax*) was primarily used for fishmeal at the beginning of the study period, as 17% for DHC and 83% for FMFO (Bureau of Commercial

Fisheries 1961). Currently, almost no sardine is used for fishmeal production, but is canned for DHC (www.fao.org/fishery/facp/NAM/en; Metian and Tacon 2009). Therefore, the published rates were assumed to apply until 1978 (1950-1978), when landings dropped precipitously (FAO 2014a), and then pilchard was treated as a primary DHC taxa detailed below for 1979-2010.

- Atlantic horse mackerel (*Trachurus trachurus*) began to be targeted by Namibia for reduction after 1975 (National Marine Fisheries Service 1968; Macer 1974; www.fao.org/fishery/facp/NAM/en), although they were more commonly frozen at sea for export (Metian and Tacon 2009). It was estimated that 85% of the landings were apportioned to DHC after 1975 (1976-2010), with 14.9% destined for FMFO and 0.1% destined for other uses, most notably bait. Before 1975, Atlantic horse mackerel was treated as primary DHC taxa (1950-1975).
- Bait used in fisheries for tuna, tuna-like species, and elasmobranchs were apportioned in line with other African tuna fishing entities (see 'African Fishing Entities'). These fisheries were active from 1968-2010 for Namibia.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

South Africa

For the earlier period, South African data include data for the occupied Namibia, and thus much of their data are not disaggregated for this period (Bureau of Commercial Fisheries 1961; Macer 1974). However, after Namibian independence in 1961, South Africa used Atlantic horse mackerel, Southern African anchovy and chub mackerel (Bureau of Commercial Fisheries 1961; Macer 1974). South Africa is considered here in light of two major historical periods: apartheid-era (1950-1994), and post-apartheid (1995-2010). For an overview of the fisheries of South Africa since 1950, please see Baust *et al.* (2015).

Evidence and assumptions:

- Pacific sardine (*Sardinops sagax*) was primarily used for fishmeal at the beginning of the study period, with 17% for DHC and 83% for FMFO (Bureau of Commercial Fisheries 1961). Currently, almost none is used for fishmeal production, but is canned and used for bait(www.fao.org/fishery/facp/ZAF/en). Approximately 30% is used for bait in tuna fisheries, recreational fisheries, and exported for direct tuna ranching feed (Hecht and Jones 2009). The remaining 70% was destined to DHC. End use rates were assumed to apply to the two periods separately, except that the tuna bait use began only in 1975. The bait use was linearly interpolated as a decrease in FMFO from 1975-1979 to 0.1% (1979) with an increase to current levels over 1997-2002 to reflect the growth in tuna ranching in the Mediterranean (Ottolenghi 2008). DHC was not linearly interpolated between periods, to reflect that fishmeal production drops sharply after the end of apartheid (1994), and a change in pattern of use of this species.

- Atlantic horse mackerel and Cape horse mackerel (*Trachurus trachurus* and *T. capensis*, respectively) were used for reduction during the apartheid-era (National Marine Fisheries Service 1968; Macer 1974), but landings for this purpose were concentrated between 1950 and 1958 at ~80,000 tonnes per year on average (Omari 2007). Juvenile mackerels are caught by purse seines and used for fishmeal, while adult mackerels are caught by mid-water trawls and used for DHC (Omari 2007). Therefore, it was assumed that 90% of landings were destined for FMFO from 1950-1958, but landings were much lower after this, and thus assumed to be 10% of landings from 1959-2010.
- Chub mackerel (*Scomber japonicus*) was used for reduction during the apartheid-era (Macer 1974). It was assumed to follow the same pattern as horse mackerel.
- Southern African anchovy (*Engraulis capensis*) is the only species currently used for fishmeal production, and all of it is landed for this purpose(www.fao.org/fishery/facp/ZAF/en). As it is considered low-value (Omari 2007), it is assumed it was always destined 100% for this purpose.
- Bait used in fisheries for tuna, tuna-like species, and elasmobranchs were apportioned in line with other African tuna fishing entities (see 'African Fishing Entities'). These fisheries were active for the whole study period for South Africa.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Asian fishing entities

Asian fishing entities present great diversity in fisheries, and in comparison to other regions, many of these countries still rely heavily on direct feeding to support their aquaculture sector (Funge-Smith *et al.* 2005; Cao *et al.* 2015b). In addition, many of them produce aquaculture products for export that rely on imports of high quality fishmeal, even when they produce fishmeal domestically (Khemakorn *et al.* 2007). Furthermore, the Southeast Asian region in particular has many fisheries with high levels of by-catch that were often discarded in the past, but have found new markets in direct feed and also as inputs for FMFO production (Khemakorn *et al.* 2007; Teh *et al.* 2015a).

Many Asian countries fish for tuna, tuna-like species, and elasmobranchs. Industrial longlining is common for these taxa and thus bait use was estimated for these countries while these fisheries were active. Bait use for these fisheries was estimated based on the common use of small pelagics and squids (see below) in the Indian and Pacific Oceans for these fisheries (Bolaky 2006; Ardill *et al.* 2012; IPNLF 2012; www.maranathafishing.com/en). Bait use was therefore apportioned to the following taxa: *Anodontostoma chacunda*, Atherinidae, Cephalopoda, Clupeidae, Clupeiformes, *Dussumieria* spp., *Dussumieria acuta*, Engraulidae, *Engraulis encrasicolus*, Exocoetidae, Hemiramphidae, Loliginidae, *Loligo* spp., *Loligo vulgaris*, Miscellaneous marine pelagic fishes, *Nematalosa nasus*, *Sardinella fimbriata*,

Sardinella gibbosa, *Sardinella lemuru*, *Sardinella longiceps*, *Selaroides leptolepis*, Sepiida, *Stolephorus* spp., *Teuthida* spp., *Thryssa* spp., and *Todarodes sagittatus.*

This was conservatively estimated at 0.1% of these taxa. As industrial gears have not been discerned for each fishing entity, taxa, and year combination at the time of writing, fishing entities with industrial landings of these taxa were assumed to have some portion caught with longlines unless there was evidence to the contrary.

The following fishing entities are Type 1, and have individual country summaries: Bangladesh, Cambodia, China, Hong Kong, India, Indonesia, Iran, Japan, Malaysia, Myanmar, Oman, Pakistan, Republic of Korea (South Korea), Singapore, Taiwan, Thailand, United Arab Emirates, Viet Nam, Yemen.

The following fishing entities are Type 2 and only produce fishmeal from by-products. They were therefore apportioned 0% to FMFO for all landings.

- Maldives produces only tuna fishmeal from by-products of their canneries (FAO 2014a).
- Saudi Arabia is believed to have all fishmeal production from by-products of fish and shrimp processing(www.fao.org/fishery/facp/SAU/en). However, they do use fish (mackerel and squid) for direct feed in aquaculture in small quantities as supplemental to commercial feeds (Hecht and Jones 2009). Beginning in 1985, the use of squids and mackerels were linearly interpolated from 0% in 1984 to 1% for other uses in 2000 as the shrimp industry grew rapidly over this period(www.fao.org/fishery/countrysector/naso_saudiarabia/en).

The following fishing entities are Type 3 and had no reported fishmeal production from 1976-2010 (FAO 2014a). They were therefore apportioned 0% to FMFO for all landings. These countries are:

- Bahrain (www.fao.org/fishery/facp/BHR/en)
- Brunei Darussalam
- Gaza Strip
- Iraq (www.fao.org/fishery/facp/IRQ/en)
- Israel (Israel reports bait use but the fish are from freshwater origin, which is not analyzed here; www.fao.org/fishery/facp/ISR/en)
- Jordan (www.fao.org/fishery/facp/JOR/en)
- Democratic People's Republic of Korea (North Korea)
- Kuwait (www.fao.org/fishery/facp/KWT/en)
- Lebanon (FAO Fisheries and Aquaculture 1996)
- Philippines (www.fao.org/fishery/facp/PHL/en)
- Qatar (www.fao.org/fishery/facp/QAT/en)
- Sri Lanka
- Syrian Arab Republic
- Timor-Leste

As Asia covers a very large geographical area (including West Asia, i.e., the Middle East and the Arab World) and covers various different fish habitats, identifying the main taxa targeted for reduction is difficult. However, the taxa exploited for this purpose in dedicated reduction fisheries include: Indian oil sardine, Pacific saury, Japanese anchovy, sandeels, largehead hairtail, jack mackerels, and chub mackerels. Many countries in Southeast Asia use by-catch as the main source of raw material for direct feed ('trash fish') and for fishmeal production and these are detailed in the reports that follow.

Bangladesh

Bangladesh is a small fishmeal producer and relies heavily on freshwater molluscs to supplement aquaculture feeds. In total, very little fish is destined for purposes other than DHC, even though approximately 1/6 of landings are 'low-value fish' (Funge-Smith *et al.* 2005). In addition, there is no evidence of direct feeding for aquaculture in Bangladesh (Funge-Smith *et al.* 2005). A small portion of low-value fish and one other species are the main sources of fishmeal. As low-value fish were rarely landed by industrial fisheries, no fishmeal production was apportioned to industrial landings for Bangladesh (Funge-Smith *et al.* 2005; Ullah *et al.* 2014). For an overview of the fisheries of Pakistan since 1950, please see Ullah *et al.* (2014).

Evidence and assumptions:

- Chewa (*Pseudapocryptes elongatus*) is cited as a source of higher quality fishmeal (Mamun-Ur-Rashid *et al.* 2013), but is included here under its family name, Gobiidae (see below).
- Low value fish (often inappropriately called 'trash fish') were determined from multiple sources (Nowsad *et al.* 1998; Ullah *et al.* 2014) and confirmed by regional similarities (see India and Pakistan country summaries). In 2005, DHC was reportedly the main use of low-value fish at 84.5% leaving the remainder to FMFO (Funge-Smith *et al.* 2005). Production of FMFO was 0 until 1990 (FAO 2014a), and the rise in fishmeal production occurred with semi-intensive shrimp aquaculture beginning in 1993(www.fao.org/fishery/countrysector/naso_bangladesh/en). Therefore, the values were linearly interpolated from 1990-2005, and 2005 levels were assumed to be stable for the remainder of the period (2006-2010). These taxa are:
    - Gobies (Gobiidae; Ullah *et al.* 2014)
    - Sea Catfish (Ariidae; Nowsad *et al.* 1998)
    - Orange ponyfish (*Leiognathus bindus*; Nowsad *et al.* 1998)
    - Panna croaker (*Panna microdon*; Nowsad *et al.* 1998)
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses. This was applied after 1989 when fishmeal production began. Before this period, this remainder of 0.1% was assumed to be destined for fertilizer or livestock feeds.

Cambodia

Cambodia has limited marine fisheries. Fishmeal production is reported after 1995 by the FAO (FAO 2014a), but Cambodia established its first fishmeal production plant in 1993 (Puthy 2007; UNEP 2007), and this earlier date was adopted in this report. Cambodia's inland freshwater fisheries are much larger and a significant supplier of low value 'trash fish' for aquaculture in this region (Nam *et al.* 2007; www.fao.org/fishery/facp/KHM/en) and this was assumed to be the source for almost all FMFO input source in this country. For an overview of the fisheries of Cambodia since 1950, please see Teh *et al.* (2014a).

Evidence and assumptions:

- By-catch of industrial fisheries was the main source of raw material. These landings were disaggregated in the reconstruction of catches based on similar landings in the Gulf of Thailand (Teh *et al.* 2014a). These were thus apportioned to DHC when landed for the years 1950-1992, and split between multiple uses for 1993-2010. Most of these landings were thus apportioned to fishmeal (75%), but a portion remained for DHC which was estimated at 25%. The taxa were: Leiognathidae, Small crabs (Portunidae, *Portunus* spp., *Charybdis* spp.), *Saurida* spp., Apogonidae, Balistidae, Gobiidae, and miscellaneous marine fish (Teh *et al.* 2014a).
- Bait used in fisheries for tuna, tuna-like species, and elasmobranchs were apportioned in line with other Asian tuna fishing entities (see 'Asian Fishing Entities'). These fisheries were active from 1965-1975, and 1999-2010 for Cambodia.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

China

China is the largest fishing country in the world, but also suffers from systemic misreporting in its statistics (Pauly *et al.* 2014). China is the largest aquaculture producer in the world, and its aquaculture industry has consumed large amounts of fishmeal and feeds since the 1980s. In the period from 1950-1978, aquaculture was dominated by algae, bivalve, and carps requiring minimal inputs of fish feed, although some was used for omnivorous carps. As China has no requirement or fishmeal production facilities before 1978 (Hishamunda and Subasinghe 2003), FMFO production was set to 0% for all taxa from 1950-1978. For an overview of the fisheries of China since 1950, please see Pauly *et al.* (2014) and Pauly and Booth(2015).

Evidence and assumptions:

- Artisanal fisheries produced inputs into the aquaculture sector (Krumme *et al.* 2013), for direct feed as well as FMFO production (Mills *et al.* 2011). In a study of artisanal lift-net fisheries, *Clupanodon thrissa, Sardinella gibbosa, Gobiid* spp., *Ambassis* spp.,

Trachinocephalus myops, Thryssa spp., and *Megalops cyprinoides* were all used solely for feed inputs (Krumme *et al.* 2013). Juvenile *Atherinomorus lacunosus, Leiognathus* spp., *Mugil cephalus, Gerres filamentosus, Siganus canaliculatus, Moolgarda perusii, Plotosus lineatus,* and *Stolephorus indicus* were all used for non-DHC purposes, while large individuals were used for DHC (Krumme *et al.* 2013). These taxa used partially for DHC and other similar taxa (see below) were thus apportioned knowing that the proportion of economically valuable adult fish (low value fish) would be higher than the average proportion of fish destined for feed (52%; trash fish) from these fisheries (Krumme *et al.* 2013). These taxa were assumed to be predominantly DHC, and this was applied at 2/3 of landings to DHC, and 1/3 to non-DHC uses (corresponding to the outer estuary area from the source study; Krumme *et al.* 2013). These were assumed to be current rates (1990-2010) that were linearly interpolated from 1980 to 1990 to reflect the changing nature of these fisheries to supply the growing fed aquaculture sector (Krumme *et al.* 2013).

- As direct feed was more likely for the artisanal sector (Asia Pacific Fishery Commission 2007; Krumme *et al.* 2013), and fishmeal production is supplied by some major reduction fisheries (Funge-Smith *et al.* 2005), non-DHC uses were split 2/3 to other uses and 1/3 to FMFO for artisanal landings.
- Artisanal landings of Japanese anchovy (*Engraulis japonicus*) were assumed to be destined for DHC as this fish became more popular for DHC use as a prime food fish (Wijkström 2010).
- The industrial landings of the following taxa were assumed to be destined exclusively for FMFO from 1979-2010 based on various sources:
    - Japanese anchovy (*Engraulis japonicus*) (Funge-Smith *et al.* 2005)
    - Japanese jack mackerel (*Trachurus japonicus*) (Henriksson *et al.* 2014)
    - Blue mackerel (*Scomber australasicus*) (Henriksson *et al.* 2014)
    - Japanese Spanish mackerel (*Scomberomorus niphonius*) (Henriksson *et al.* 2014)
    - Jack mackerels (*Trachurus* spp.) (Cao *et al.* 2015b)
    - Skinnycheek lanternfish (*Benthosema pterotum*) (Cao *et al.* 2015a)
    - Pacific pomfret (*Brama japonica*) (Henriksson *et al.* 2014)
    - Antarctic krill (*Euphausia superba*) (Parker 2011)
    - Chub mackerel (*Scomber japonicas*) (Wijkström 2010)
    - Pacific herring (*Clupea pallasii pallasii*) (Cao *et al.* 2015b)
    - Large head hairtail (*Trichiurus lepturus*) (Cao *et al.* 2015b)
- Low value fish (often inappropriately labelled ‘trash fish’) from industrial fisheries are known to be used for direct feeding for aquaculture and livestock, fishmeal production after 1978, and, if landings are of a high quality also for DHC (Funge-Smith *et al.* 2005; Krumme *et al.* 2013; Cao *et al.* 2015b). Prior to 1980, when aquaculture production was mainly non-fed (Hishamunda and Subasinghe 2003), the market for non-DHC uses for these low value fish was smaller than at present, but discarding was still low because of the DHC potential. In addition, fishmeal production was estimated to have grown slowly in the 1980s and rapidly in the 1990s (Funge-Smith *et al.* 2005; FAO 2014a), although this may be influenced by previous misreporting to the FAO (Watson and Pauly 2001). These general trends were used to determine the end use of industrial trash fish landings over time, as there are no accurate data that distinguish between taxa sources and

different uses. Therefore, DHC and other uses were assumed as 50% of landings each and this remained until 1970. As aquaculture grew in the 1970s, the other uses were assumed to increase to 80% of landings in 1978 before fishmeal production began in China. Fishmeal production was assumed to be 20% of landings in 1989, and 40% of landings in 2000 approximately when fishmeal production was thought to have peaked in China (Funge-Smith *et al.* 2005). As fishmeal production increased and opened up an alternative pathway for feeding fish, direct feeding was assumed to decline from 80% in 1978 to 50% in 2000. DHC similarly declined to 10% of landings in 2000, and all three uses remained at 2000 levels for the remainder of the study period (2001-2010). While this is a simplification, it is believed to be the best estimate of the general trends in the use of low value 'trash' fish in China (Funge-Smith *et al.* 2005; Asia Pacific Fishery Commission 2007; De Silva and Turchini 2009; Cao *et al.* 2015b).

- Bait used in fisheries for tuna, tuna-like species, and elasmobranchs were apportioned in line with other Asian tuna fishing entities (see 'Asian Fishing Entities') except where evidence of direct feeding was already present for the landings. These fisheries were active for the whole study period for China.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Hong Kong

Hong Kong is an autonomous region of the People's Republic of China with a history of heavy overfishing (Cheung 2015). Hong Kong reports no fishmeal production to the FAO (FAO 2014a), although previous reports have a small amount of production for Hong Kong (FAO 1988). As Hong Kong's fisheries changed over time, using by-catch of low value landings for aquaculture feed became common practice (Sadovy 1998; Cheung 2015). For an overview of the fisheries of Hong Kong since 1950, please see Cheung (2015).

Evidence and assumptions:

- Low value fish (often inappropriately labelled 'trash fish') were increasingly used for aquaculture feed, especially for grouper aquaculture, as capture fisheries landings changed to an increasing proportion of low-value taxa (Sadovy 1998; Cheung 2015). This is mainly interpreted as being low-value taxa and juveniles of commercially important species increasing the pressures of overfishing, but nemipterids, sciaenids, clupeids, and leiognathids are mentioned explicitly (Pomeroy 2008). As many of these are aggregated into miscellaneous marine fishes, miscellaneous marine fishes and Nemipteridae were apportioned to other uses at a rate based on grouper and snapper aquaculture production reported to the FAO (FAO 2014a). The feed requirement was estimated with a conservative estimate of an FCR of 5:1, which is below average for this region (Hasan 2012). These 'trash fish' were also assumed to be the source of Hong Kong's fishmeal production (FAO 1988). As none is reported in present reports and

production data were limited to 1979-1988, Hong Kong's fishmeal production was assumed to be 0 in 1949 and 2011 with linear interpolation used from 1950-1979 and 1988-2010. A fishmeal yield of 22.5% was applied for the whole period to calculate the amount of these 'trash fish' required for Hong Kong's estimated fishmeal production.

- Bait use was apportioned in line with other Asian fishing entities for when industrial fisheries for tuna, tuna-like species, and elasmobranchs were landed. For Hong Kong, this was over the entire study period.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

India

India's fisheries are mainly targeted for human consumption (www.fao.org/fishery/facp/IND/en), with a few dedicated reduction fisheries (Ponnusamy *et al.* 2012), and high use of by-catch of other fisheries for both fishmeal (Dineshbabu *et al.* 2014) and direct feeding (Funge-Smith *et al.* 2005). India is the second largest aquaculture producer in the world (De Silva and Turchini 2009), and is thus dependent on substantial amounts of fishmeal (Huntington and Hasan 2009). There is a large discrepancy in the amount of fishmeal reported to be produced, and the reported sources and their relative contributions. The approach taken took these into account and best attempted to model the end uses for the two main sources: pelagic fisheries and shrimp by-catch. For an overview of the fisheries of Pakistan since 1950, please see Hornby *et al.* (2015).

Evidence and assumptions:

- Indian oil sardine (*Sardinella longiceps*) is used for fishmeal production and DHC (www.indiaagronet.com; Ponnusamy *et al.* 2012), but reports vary greatly in the amount used for this purpose, including whether the majority is DHC or FMFO (www.indiaagronet.com; Suresh 2007; Ponnusamy *et al.* 2012). In three states where Indian oil sardine is the main species used (95-99% of total production), total fishmeal production was ~65,000 tonnes (Ponnusamy *et al.* 2012), with the reconstructed catch of this sardine being 346,732 tonnes in 2010 (Hornby *et al.* 2015). At a reduction rate of 22.5%, and assuming a conservative 95% of this fishmeal production is Indian oil sardine, 79% of landings were apportioned to this purpose in 2010. This was assumed to be constant over the study period for landings in industrial fisheries.
- Other *Sardinella* spp. are caught by both industrial fisheries as by-catch, and artisanal fisheries for DHC and FMFO (Bennet *et al.* 1992). Given frequent reporting of sardines use for FMFO (Bennet *et al.* 1992; Ponnusamy *et al.* 2012), the landings of this taxa were apportioned 33% to FMFO, with the remainder destined for DHC.
- Indian mackerel (*Rastrelliger kanagurta*) is reported as a main source of fishmeal (Ayyappan and Ahmad Ali 2007), however the species caught by India are high-value fish(www.indiaagronet.com). Thus, only excess landings are used for fishmeal and

fertilizer(www.indiaagronet.com), and this was conservatively estimated at 1% for each of FMFO and other uses.

- By-catch of shrimp trawl fisheries is landed for both DHC and non-DHC uses (Aswathy *et al.* 2011). When caught as by-catch, some taxa appear to be solely used for food (croakers, goat fishes, lizard fishes, threadfin breams), some are used for both purpose (silver bellies), and some were only used for non-DHC purposes (stomatopods, small crabs, small anchovies (Engraulidae), and *Ambassis* spp.; Aswathy *et al.* 2011). This information was applied to existing information on low and high value species by-caught in these fisheries which leads to higher retention levels for high value species (rather than discarding), and a higher probability that a high-value species would be sold for DHC rather than fishmeal production (Hornby *et al.* 2015). Therefore, low value species (see Table 2) were apportioned 100% to non-DHC uses when there was information confirming their use for non-DHC uses, in contrast to low-value species that were confirmed as used for DHC (Aswathy *et al.* 2011). Unreported industrial landings of silver bellies were divided with half apportioned to DHC, and half apportioned to non-DHC. Non-DHC landings (industrial landings of Ariidae, Carangidae, *Chirocentrus* spp., Clupeidae, and *Sphyraena* spp.) were apportioned 90% to FMFO and 10% to other uses, mainly for direct feed of fish, poultry and for fertilizer based on the scale of fishmeal production over direct feeding (Funge-Smith *et al.* 2005), although some sources assert that all non-DHC by-catch is for FMFO (Dineshbabu *et al.* 2014).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Table 2 Relative value of by-catch in India.

Low-value	**High-value**
Barracuda (Sphyraenidae)	Tunas (Scombridae)
Trevallies (Carangoides)	Cods (Gadiformes)
Catfishes (Ariidae)	Perches (Perciformes)
Wolf herrings (*Chirocentrus* spp.)	Flat fishes (Pleuronectiformes)
Herrings/shads/sardines/menhadens (Clupeidae)	Pomfrets (Bramidae)
Lizardfishes (Synodontidae)	Drums/Croakers (Sciaenidae)
Threadfin/whiptail breams (Nemipteridae)	Skates (Battoidea)
Threadfins (*Polynemus* spp.)	Eels (*Anguilla* spp.)
Ribbonfishes (*Trachipterus* spp.)	Sharks (Elasmobranchii)
Drums/Croakers (Sciaenidae)	Threadfins (*Polynemus* spp.)
Tunas/bonitos/billfishes (Scombroids)	--
Sharks (Elasmobranchii)	--
Soles (*Microchirus* spp.)	--

Indonesia

Indonesia produces a small amount of fishmeal and a significant portion (estimated at 30%) is sourced from by-products of tuna, shrimp and sardine processing (Jackson and Shephard 2012; FAO 2014a). Low value fish (often inappropriately labelled 'trash fish') is still utilized in major quantities and relies on the by-catch of shrimp trawlers (De Silva and Turchini 2009). For an overview of the fisheries of Indonesia since 1950, please see Budimartono and Pauly (2015).

Evidence and assumptions:

- Bali sardinella (*Sardinella lemuru*) is the main species used for fishmeal production in Indonesia, although most of its landing are destined for DHC (Sustainable Fisheries Partnership 2012). Ponyfishes (Leiognathidae), scads (*Decapterus* spp.) and sardines (specifically, spotted sardinella, *Amblygaster sirm* and rainbow sardine, *Dussumieria acuta*) are all used in small amounts for fishmeal (Sustainable Fisheries Partnership 2012). These taxa were assumed to be the only non-by-product sources of fishmeal production reported to the FAO (FAO 2014a). The amount required was apportioned equally to these taxa by the percentage required of the total industrial landings, assuming that 30% of reported fishmeal production was from by-products (Jackson and Shephard 2012), and an average fishmeal yield of 22.5% (Jackson 2009b). As 1976 was the first year this method could be used, the use rates were linearly interpolated to these levels beginning in 1961 (1960= 0% FMFO) when industrial landings started.
- Direct feeding for aquaculture production with 'trash fish' is reported for Indonesia (Nur 2007; De Silva and Turchini 2009), and this originates from landings of by-catch of trawl fisheries in Western Indonesia (Kompiang 1983; Budimartono and Pauly 2015). As a robust breakdown of trash fish was not available, the taxa used for this purpose in Malaysia were assumed to be similarly used in Indonesia although exceptions were made based on local information on consumption of taxa such as *Stolephorus* anchovies and squids (Budimartono and Pauly 2015). Therefore, industrial landings of flatfishes, spinefoots and threadfin breams were apportioned 100% to other uses. Ponyfishes are also used for direct feeding and the remainder that was not apportioned to FMFO (see above) was apportioned to other uses. In addition, many low-value taxa are included in the miscellaneous marine fishes and marine crabs, shrimps and lobsters categories in the *Sea Around Us* database; a conservative estimate of 5% was applied to other uses for this category separately from other 'trash' fish.
- Bait use was apportioned in line with other Asian fishing entities for when industrial fisheries for tuna, tuna-like species, and elasmobranchs were landed. For Indonesia, this was from 1961-2010.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses to account for fish caught for human consumption that are not used for that purpose. All non-DHC landings were apportioned to other uses from 1950-1960 as there was no fishmeal production in this period.

Iran

Iran has fishmeal production disaggregated by source dating to 1979 (FAO 2014a), but likely extends before this period because of Iran's canning industry (Keddie 1971). In line with this, the reported whitefish meal and tuna meal production is assumed to be 100% from by-products of processing and canning. Lanternfish (myctophids; *Benthosema pterotum*) have been viewed as a potential fishmeal resource since the 1970s, but it is undetermined if they have been commercially fished for this purpose to the extent hypothesized (FAO Fisheries and Aquaculture 1996; www.fao.org/fishery/facp/IRN/en). The major reduction fishery for Iran occurs in the Caspian Sea, which is not considered by the *Sea Around Us*. Small pelagics are broadly utilized for FMFO (FAO Fisheries and Aquaculture 1996), but this is likely mainly driven by the Caspian Sea. While Iran is a major fishmeal producer in this region, most of its production falls outside the scope of this analysis (by-products and freshwater fisheries; Jackson and Shephard 2012). For an overview of the fisheries of Iran since 1950, please see Moniri *et al.* (2013).

Evidence and assumptions:

- All landings of skinnycheek lanternfish (*Benthosema pterotum*) were assumed to be used 100% for FMFO based on previous reports of potential use of this resource (FAO Fisheries and Aquaculture 1996).
- Indian oil sardine (*Sardinella longiceps*) was assumed to be destined 100% for FMFO in line with use in this region, and is possible based on location of fishmeal facilities (Anon. 2015a).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Japan

Japan has been producing fishmeal for centuries, although by simpler methods (Bureau of Commercial Fisheries 1961; Macer 1974). Historically, Japan was a leading producer of fishmeal before WWII (Bureau of Commercial Fisheries 1961). Alaska pollock (*Theragra chalcogramma*) is processed at sea into DHC products and the by-products are processed into FMFO (Macer 1974). Thus, Alaska pollock was not considered in this analysis. Small-scale artisanal fisheries in Japan catch a considerable portion of landings and nominal fish catch (Swartz and Ishimura 2014). However, these landings were likely destined for DHC rather than FMFO. It is difficult to confirm the proportions of different taxa used for reduction as there is mixed reporting in the available statistics (Bureau of Commercial Fisheries 1961; FAO 2014a). The largest discrepancy is that for the years where fishmeal is disaggregated to different taxa (1955-1959 and 1976-1998) there is still a large proportion lumped into the 'other' or 'fishmeal nei' category, which in some cases is said to explicitly include some of the listed taxa (Bureau

of Commercial Fisheries 1961). For an overview of the fisheries of Japan since 1950, please see Swartz *et al.* (2014).

Evidence and assumptions:

- We assume that 100% of industrial landings from the following taxa were apportioned to FMFO; natural fluctuations of these taxa will thus affect the overall FMFO production of Japan.
    - Pacific herring (*Clupea pallasii pallasii*) has been a dominant reduction fishery although the stocks declined significantly before the start of the current period of interest (Macer 1974; Swartz and Ishimura 2014).
    - Pacific sardine (*Sardinops sagax*) was the dominant species for fishmeal production while its populations were high in the Japanese EEZ (Macer 1974; Hardy and Tacon 2002). Some artisanal landings of Pacific sardine are used as bait (see below).
- Pacific saury (*Cololabis saira*) was an important reduction species in Japan (Macer 1974) and was apportioned 100% to FMFO from 1950-1962. However, fluctuating landings have caused low fishmeal production levels in the past with only 10% of landings destined for reduction in 1967 (National Marine Fisheries Service 1968), which appears to have marked a change in use for this fishery towards being mainly destined for human consumption (Macer 1974; Bimbo 2014). The low use of this taxon for reduction was assumed to apply to subsequent years (i.e., 1967-2010), with artisanal landings being treated as DHC, and industrial landings apportioned at 83.33% for DHC and 16.67% for FMFO. As the fishery landings declined in the early 1960s, the years 1963-1967 were linearly interpolated.
- Antarctic krill (*Euphausia superba*) has multiple uses in the Japanese market (Parker 2011). The most common use is bait (45%), followed by fishmeal and direct feed (43%), and a small percentage (12%) for DHC (Nicol *et al.* 2000; Parker 2011). The portion destined for use as feed was assumed to be split 50/50 between direct feed and fishmeal production bringing the categories to 66.5% for other uses and 21.5% for FMFO.
- Sandeels (*Ammodytes* spp.) are reported to be used for FMFO later in the period (FAO 2015c), but also reportedly used as direct feed for Japanese amberjack culture (Wijkström 2009). Other reports lump all sandeels into fishmeal production (Wijkström 2010). An assumption was thus made that this would be split evenly between these two uses, with 0% destined for DHC.
- Japanese anchovy (*Engraulis japonicus*) is believed to be utilized for bait, likely in tuna fisheries (Macer 1974). However, 50% of Japan's landings are estimated to be destined for FMFO (Wijkström 2010), and other sources report its use for this purpose in addition to likely small quantities for DHC (http://seafood.edf.org; Bureau of Commercial Fisheries 1961). Therefore, artisanal landings were apportioned to DHC. Industrial landings were split between FMFO and other uses for bait use, with fishmeal estimated to be the dominant use at 90% of industrial landings, and other uses being the remaining 10%.
- Mackerels (*Scomber* spp.) and jack mackerels (*Trachurus* spp.) were used for fishmeal over the study period, but only reported to the FAO for 1976-1986 (FAO 2014a). They are also excluded from major fishmeal reports that cover Japan (Bureau of Commercial Fisheries 1961; Macer 1974). As some of these taxa have a large DHC and export

market, the production of mackerel meal was assumed to be entirely from by-products. This is based on limited information.
- Squids (Teuthida, Loliginidae, Ommastrephidae, and *Illex* spp.) and Pacific sardine are also used for bait for tuna and shark fisheries in Japan (Miyake *et al.* 2010; IPNLF 2012). These were thus apportioned an additional 0.1% to this use.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Malaysia

Malaysia experimented with fishmeal production in the mid-1950s but commercial production only begun in 1977 (Jabatan Perikanan Malaysia 1955, 1978). Malaysia has no dedicated reduction fisheries but relies heavily on by-catch, first from gill net fisheries and later from trawl fisheries. Low value 'trash' fish were originally used as fertilizer and direct feed for livestock production, but as aquaculture grew and fishmeal factories were established, much of it was re-directed for these purposes (Teh and Teh 2014). As the amount of 'trash' fish supplied is significant, it was assumed this fish and by-products of processing were the only sources of raw materials for direct feed, fertilizer, and fishmeal production (Wijkström 2009; Teh and Teh 2014). 'Trash' fish landings were disaggregated in the reconstruction based on trawl survey data (Teh and Teh 2014). Malaysia continues to have a strong demand for both fishmeal and fish for direct feeding (Funge-Smith *et al.* 2005; De Silva and Turchini 2009). For an overview of the fisheries of Malaysia since 1950, see Teh *et al.* (2014).

Evidence and assumptions:

- As Malaysia didn't produce fishmeal until 1977, FMFO was set to 0% for all taxa until 1977 (Jabatan Perikanan Malaysia 1977, 1978). Annual fisheries reports were sampled after this point to capture general trends in the use of low value 'trash' fish from 1977-2010 (Jabatan Perikanan Malaysia 1977, 1978, 1979, 1980, 1986, 1991, 2000, 2006, 2011) and these were applied to associated landings (Teh and Teh 2014). For 1950-1976, 100% of 'trash' fish was apportioned to other uses, being dominated by fertilizer, and direct feed for livestock production (Jabatan Perikanan Malaysia 1955, 1978; Teh and Teh 2014). These taxa were: Cephalopoda. Haemulidae, *Ilisha elongata. Leiognathus* spp., *Loligo* spp., miscellaneous marine crustaceans, miscellaneous marine fishes. *Nemipterus* spp., Pleuronectiformes, *Priacanthus* spp., *Rastrelliger* spp., *Sepia* spp., Sepiidae, *Siganus* spp., *Stolephorus* spp., Synodontidae, *Terapon* spp., and Tetraodontidae.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Myanmar

Myanmar is a small fishmeal producer, but is currently self-sufficient for its growing aquaculture industry. In 2005, Myanmar's fishmeal production was reported as 12,610 tonnes (De Silva and Turchini 2009). The FAO only began reporting fishmeal production in Myanmar in 2005, and it is much higher than other reports (FAO 2014a), although some authors report that Myanmar began operating fishmeal plants in 1999 or 2000 (FAO and NACA 2003). Therefore, Myanmar's fishmeal production is assumed to begin in 1999, and was linearly interpolated from 0 in 1998 to the FAO levels in 2005 (31,700 tonnes). However, Myanmar always had a substantial use of fish for direct feed for aquaculture of grouper, catfish, and fattening crabs (FAO and NACA 2003; www.fao.org/fishery/facp/MMR/en). The fish used for direct feed are known to come from trawl fisheries (FAO and NACA 2003) and from sun dried pelagic fishes (Khin 2008). As the division of taxa for Myanmar are interpolated based on India and Bangladesh, and as the focus of concern for direct feeding and reduction fisheries is on by-catch of trawl fisheries (Booth and Pauly 2011), Myanmar's use of this by-catch was reconstructed in line with these fishing entities. For an overview of the fisheries of Myanmar since 1950, please see Booth *et al.* (2011).

Evidence and assumptions:

- The by-catch of industrial fisheries was treated in line with India and Bangladesh. That is, high value species were assumed to be for DHC, whereas low value species were used for direct feeding or fishmeal depending on the time period. From 1950-1998, Myanmar had no fishmeal production as they had no facilities for its production and no reports of exporting fish to other fishing entities for this purpose (FAO 1988, 2014a).
- Aquaculture began in 1953 (www.fao.org/fishery/countrysector/naso_myanmar/en) and the use of low value fish for direct feeding was linearly interpolated from 0 in 1952 to 20,000 tonnes in 1988 (FAO 1988) and then to 252 208 tonnes used for non-DHC uses in 2003(www.fao.org/fishery/facp/MMR/en). This was assumed to be sourced from both industrial and artisanal fisheries. To isolate the portion for direct feed, the amount destined for fishmeal production (fishmeal production multiplied by a yield of 22.5%) was subtracted from the total amount destined for non-food purposes. The amount destined for non-food purposes was linearly interpolated from 20,000 tonnes in 1988 to 252,208 tonnes in 2003, and the amount for 2003 was assumed to apply forward to 2010 (2003-2010).
- While Myanmar had industrial landings of tuna, tuna-like species, and elasmobranchs from 1953-2010, Myanmar apparently has no longline or pole and line fleets requiring bait. Therefore, taxa commonly used for bait were not apportioned for Myanmar for this purpose.
- Primary DHC taxa had a conservative estimate of 0.05% for each of other and FMFO uses, with the remaining 99.9% destined for DHC during the period when Myanmar had all of these uses present (1999-2010). Before this period, the non-DHC landings were apportioned only to other uses (99.9% for DHC, 0.1% for other uses for 1953-1998), and 100% for DHC before aquaculture production began (1950-1952). This is to capture the amount destined for these uses of fish not fit for human consumption.

Oman

Oman does not report fishmeal production to the FAO (FAO 2014a), but has reported a negligible amount of fishmeal production elsewhere(www.fao.org/fishery/facp/OMN/en). It was reported to be 273 tonnes in 2004 (Poynton 2006). There is no information available on the taxa used for this purpose, and as the amount is negligible and there is processing of fish for export(www.fao.org/fishery/facp/OMN/en), this fishmeal is assumed to be sourced from by-products. In addition, small pelagic fish are sun-dried for direct animal feed (FAO Fisheries and Aquaculture 1996). As direct feed was used for aquaculture and FMFO likely derived from by-products, FMFO was set to 0% for the entire study period (1950-2010). As there is a strong demand for seafood in Oman, almost all fish is destined for DHC (www.fao.org/fishery/facp/OMN/en; Khalfallah *et al.* 2015b) and all landings not detailed below were apportioned 100% to DHC. For an overview of the fisheries of Oman since 1950, please see Khalfallah *et al.* (2015b).

Evidence and assumptions:

- Small pelagic fish are dried for animal feed (FAO Fisheries and Aquaculture 1996). As a conservative estimate, 0.1% of small pelagics were apportioned to this purpose.

Pakistan

Pakistan has produced fishmeal since 1957 from targeted reduction fisheries for anchovies and sardines, as well as large amounts of by-catch of (mostly shrimp) trawl fisheries (Bureau of Commercial Fisheries 1961; Hornby *et al.* 2014). There is variation in how much of the shrimp by-catch is processed for fishmeal, but it is likely around 90% (www.fao.org/fishery/facp/PAK/en; Hornby *et al.* 2014). Pakistan remains one of the major fishmeal producers in the world, but almost all is for domestic consumption in the poultry industry (www.fao.org/fishery/facp/PAK/en; Hornby *et al.* 2014). Half of all landings are destined for reduction (Pritchard *et al.* 2002). For an overview of the fisheries of Pakistan since 1950, please see Hornby *et al.* (2014).

Evidence and assumptions:

- All taxa were set to 0% FMFO for 1950-1956 as there were no operational fishmeal factories during this period (Hornby *et al.* 2014).
- Indian oil sardine (*Sardinella longiceps*) and other small pelagics were used mainly for fishmeal production and are the main dedicated reduction fisheries of Pakistan (www.fao.org/fishery/facp/PAK/en; Metian and Tacon 2009; Hornby *et al.* 2014). The FAO reports 100% of the small-scale seine (*Katra*) fishery being destined for FMFO(www.fao.org/fishery/facp/PAK/en), while other reports confirm that this is the dominant use (Pritchard *et al.* 2002; Hornby *et al.* 2014). As Indian oil sardine and *Thryssa* spp. had significant agreement of the dominant use, these were apportioned 100% to FMFO. For other small pelagics, a conservative estimate of 60% of these taxa were destined to FMFO. The remainder was apportioned to DHC.

- The unreported by-catch of shrimp trawl fisheries (*Arius thalassinus*, Brachyura, Carangidae, Clupeidae, *Himantura uarnak, Thryssa malabarica, Harpadon nehereus, Lactarius lactarius,* Leiognathidae, Mugilidae, *Upeneus vittatus, Nemipterus japonicus, Rhinobatos granulatus, Otolithes ruber,* Scombridae, *Sillago sihama,* Soleidae, *Sphyraena barracuda, Saurida tumbil, Terapon jarbua, Lepturacanthus savala*) was used in varying proportions from 60-90% for fishmeal production (Hornby *et al.* 2014). The higher end of this estimate of 90% was assumed to be destined to fishmeal after 1957 and consistent throughout the period because of the poor handling practices likely ruling out most DHC possibilities (www.fao.org/fishery/facp/PAK/en; Hornby *et al.* 2014). The remaining 10% was divided equally between DHC and other uses. The taxonomic breakdown was applied based on the reconstruction of Pakistan's fisheries (Hornby *et al.* 2014).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses. This was not applied from 1950-1956 when no fishmeal production was present. During this period, the non-DHC landings were apportioned only to other uses (99.9% for DHC, 0.1% for other uses for 1950-1956).

Republic of Korea (South Korea)

South Korea produces a considerable amount of fishmeal (De Silva and Turchini 2009; FAO 2014a). However, much of the fishmeal originates from by-products (Kim and Lee 2007; Jackson and Shephard 2012). For example, Alaska pollock and various squid taxa have fishmeal produced from their by-products (Ayyappan and Ahmad Ali 2007). These are therefore not considered in this report. There is otherwise a lack of information on the dedicated reduction fisheries of Korea. For an overview of the fisheries of South Korea since 1950, please see Shon *et al.* (2010).

Evidence and assumptions:

- Pacific sardine (*Sardinops sagax*) began as a reduction fishery in the late 1970s (Thomson 1990). It was therefore assumed to be 100% destined for FMFO from 1976-2010.
- Industrial landings of small pelagics were used in an unknown amount for fishmeal over the entire time period, and the taxa covered by this group are commonly used by this region's fishing entities. Therefore, these were apportioned 20% to FMFO based on an average of raw material required to produce Korea's reported fishmeal production (FAO 2014a) given that at least 51% is from by-products (Kim and Lee 2007), and the dedicated reduction fishery of Pacific sardine (Thomson 1990).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is

confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Singapore

Singapore is a small island city-state with limited fisheries. Singapore has reported fishmeal production with the FAO from 1976-1990 (FAO 2014a), but earlier references report the use of low-value 'trash' fish for fertilizer, animal feed, and fishmeal (Sinoda *et al.* 1978; Corpus 2014). As no information was available on the breakdown into these three categories, it was assumed the 'trash' fish not fit for human consumption were evenly distributed between fishmeal and other uses. Unfortunately, these fish are currently not brought to a finer taxonomic resolution than 'miscellaneous marine fishes' (or 'marine fishes nei'). As this already represents fish landed not fit for human consumption (Corpus 2014), no further division was necessary and all other landings were assumed to be 100% for direct human consumption. For an overview of the fisheries of Singapore since 1950, please see Corpus *et al.* (2014).

Evidence and assumptions:

- Miscellaneous marine fishes were apportioned 50% to FMFO and 50% to other uses to account for the diversity of use of this category.

Taiwan

Taiwan is a small island country with wide-ranging fisheries. It is known that a considerable portion (>70%) of its fishmeal originates from by-products (Jackson and Shephard 2012). However, there are no reports of other inputs into fishmeal production, and fishmeal production reported in national statistics are significantly lower than FAO reported data (Fisheries Agency 2010; FAO 2014a). The only reported breakdown of fishmeal produced in Taiwan is that it is sourced from pelagic organisms (Tacon *et al.* 2006). Therefore, 30% of the FAO reported fishmeal production was assumed to be sourced from small and medium pelagics. For an overview of the fisheries of Taiwan since 1950, please see Divovich *et al.* (2015a).

Evidence and assumptions:

- For the period of 1976-2010, FAO data on fishmeal production in Taiwan was assumed to be sourced from by-products (70%) and small and medium pelagics (Tacon *et al.* 2006; Jackson and Shephard 2012; FAO 2014a). Therefore, 30% of Taiwan's fishmeal production was assumed to be from small and medium pelagics with a fishmeal yield of 22.5% (Jackson 2009a). The proportion of small and medium pelagics for this purpose was then calculated by dividing the amount required by the total landings (excluding discards) of industrial and artisanal fisheries for small and medium pelagics. For the period before FAO commodity data were available (1950-1975), fishmeal production

was linearly interpolated from 0 in 1949 to 1976 levels. The same calculation method was used for this period.
- Bait use was apportioned in line with other Asian fishing entities for when industrial fisheries for tuna, tuna-like species, and elasmobranchs were landed. For Taiwan, this was over the entire study period.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Thailand

Thailand's fishmeal production is roughly half from by-catch of trawl fisheries and the other half from by-products of fish processing, mainly tuna and surimi (De Silva and Turchini 2009). The overwhelming majority of fish for non-DHC purposes originates as by-catch (95%), and mainly from shrimp trawl by-catch (Funge-Smith *et al.* 2005). The majority of this catch was used for fishmeal and fish oil production (Khemakorn *et al.* 2007). Data were available on the breakdown of low-value fish for 1971 to 2008 with the interpretation of FAO data (Khemakorn *et al.* 2007), and taking an average use breakdown from 2007 (Khemakorn *et al.* 2007), the ratios for this period were applied. FMFO production was much lower before 1975, but this is partially weighted by the higher discard rates before a larger market opened up for these low-value species (Teh *et al.* 2015a). For an overview of the fisheries of Thailand since 1950, please see Teh *et al.* (2015a).

Evidence and assumptions:

- The low-value fish by-caught by trawl fisheries are disaggregated by the *Sea Around Us* database into Nemipteridae, Synodontidae, Leiognathidae, Cynoglossidae, Platycephalidae, Sciaenidae, and Carangidae (Teh *et al.* 2015a). Leiognathidae is considered by some reports as a 'trash' fish family as it has no species of economic value in Thailand (Khemakorn *et al.* 2007). The other families are low-value fish with some of their species being destined for human consumption. Leiognathidae were apportioned 97.78% to FMFO and 2.22% to other uses including direct feed and fertilizer. Low-value fish were apportioned 53.88% to DHC, 22.85% to FMFO, and 23.27% to other uses. These rates were apportioned to industrial landings of 'trash' and low-value fish consistently over the period.
- Bait use was apportioned in line with other Asian fishing entities for when industrial fisheries for tuna, tuna-like species, and elasmobranchs were landed. For Thailand, this was from 1962-2010.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

United Arab Emirates

The United Arab Emirates do not report fishmeal production to the FAO (FAO 2014a), but have reported fishmeal production elsewhere (Hecht and Jones 2009). A small portion of small pelagics is also reported to be dried and used for animal feed and fertilizer(www.fao.org/fishery/facp/ARE/en), separate from the fishmeal production. As these divisions already represent fish landed not fit for human consumption (Hecht and Jones 2009), no further division was necessary and all other landings were assumed to be 100% for direct human consumption. For an overview of the fisheries of the United Arab Emirates since 1950, please see Al-Abdulrazzak (2013).

Evidence and assumptions:

- Some specimens of low-value fish families, also labelled 'trash' fish (e.g., Carangidae, Lethrinidae, Haemulidae, and Sparidae) and tunas (Scombridae) are all reportedly used for fishmeal production (Hecht and Jones 2009), although in reportedly very small quantities (5 tonnes of fishmeal annually in the early 2000s; Poynton 2006). These fish are collected from what was not sold in the Dubai fish market (Hecht and Jones 2009). As this amount is very small, these fish were apportioned 0.1% each to FMFO and other uses, as an approximation of the landings needed to produce the fishmeal in 2004 (landings of these taxa were ~28,000 tonnes). Based on a lack of other information, this was assumed to constant over the study period.

Vietnam

Vietnam uses over 100 species for aquaculture feed, in both direct forms and fishmeal (Edwards *et al.* 2004). In addition, most of these species are also marketable for DHC in the form of 'fish sauce' (Pauly 1995). The *Sea Around Us* catch reconstruction includes 8 families of low-value fish which were previously aggregated in official statistics as miscellaneous marine fishes (Teh *et al.* 2014b). There are additional reports of fish used from various orders including Clupeiformes, Scopeliformes, Anguilliformes, Beloniformes, and Mugiliformes. The low-value fish that were disaggregated were thus apportioned to their various uses: DHC, FMFO, and other uses including direct feed for livestock and aquaculture, and fertilizer (Edwards *et al.* 2004). Vietnam's fishmeal production is still dominated by artisanal methods rather than large-scale industrial methods; only the latter are reported in FAO statistics excluding over 2/3 of national production (Funge-Smith *et al.* 2005; Dao 2007; FAO 2014a). Estimates of Vietnam's current fishmeal production vary greatly as it is highly decentralized and relies on a great diversity of both marine and freshwater species (De Silva and Turchini 2009). For an overview of the fisheries of Vietnam since 1950, please see Teh *et al.* (2014b).

Evidence and assumptions:

- Low-value fish (as assigned in Teh *et al.* 2014b) were apportioned to the three uses based on the Ministry of Fisheries estimates (Funge-Smith *et al.* 2005). First, high-value

species were excluded from consideration (all going to DHC), leaving an even split for low-value catches, 50% for each of DHC (mainly fish sauce) and non-DHC (fishmeal and direct feeding) uses (Funge-Smith *et al.* 2005). Fishmeal production is known to increase over the study period (Funge-Smith *et al.* 2005; FAO 2014a), and was assumed to begin when excessive low-value fish catches began in 1958 with the introduction of otter board trawl fisheries (Teh *et al.* 2014b). For 1990, 10% of low-value fish was apportioned to fishmeal production, as direct feeding was more common at this time (Edwards *et al.* 2004). However, fishmeal production and demand grew to using more fish for fishmeal than direct feeding, and based on production levels was estimated at 40% of low-value fish landings in 2005 (Funge-Smith *et al.* 2005). This was assumed to stay constant for the remainder of the study period (2006-2010). The periods of 1958-1990 and 1990-2005 were linearly interpolated. The other uses of low-value fish declined with the rising importance of fishmeal, while the use for DHC remained constant at 50% for the study period based on the current use estimated by the government (Funge-Smith *et al.* 2005) and the history of low-value fish being used for fish sauce production (Pauly 1995).

- Other fish that were not designated as low-value are currently used as low-value equivalent fish when they are juveniles or of low quality upon landing (Edwards *et al.* 2004). Thus, landings of miscellaneous marine fishes reported as 'trash fish' were apportioned in the same way as low-value fish above.
- Bait use was apportioned in line with other Asian fishing entities for when industrial fisheries for tuna, tuna-like species, and elasmobranchs were landed. For Vietnam, this was from 1990-2010 when longline fisheries began (Teh *et al.* 2014b). Flying fish (Exocoetidae), local squid (Loliginidae), and frozen round scad (*Decapterus punctatus*) are all listed explicitly as being used, while other similar species are likely used (Lewis 2005).
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Yemen

Yemen has mixed reports on its fishmeal production, likely due to misreporting (Hecht and Jones 2009; Jackson and Shephard 2012; FAO 2014a). Yemen has reported fishmeal production from only 1977-1990 in the FAO database (FAO 2014a); however, other sources confirm more recent fishmeal production in the 2000s (Hecht and Jones 2009). The small-scale fisheries of Yemen also contribute to FMFO and direct feed earlier in the study period (Tesfamichael *et al.* 2012a). For an overview of the fisheries of Australia since 1950, please see Tesfamichael *et al.* (2012a).

Evidence and assumptions:

- Indian oil sardine (*Sardinella longiceps*) is used directly as animal feed in Yemen (FAO Fisheries and Aquaculture 1996; www.fao.org/fishery/facp/YEM/en), but is also reportedly used for fishmeal (Tesfamichael *et al.* 2012a; Bimbo 2014). It is caught in the artisanal fishery (Tesfamichael *et al.* 2012a), and is likely the sole source for the 771 tonnes of fishmeal produced in 2008 (Hecht and Jones 2009). Based on 2008 landings, this would be a third of landings. This was linearly interpolated back to 1970. This fish is not used for DHC in Yemen, and so the remainder is made up by other uses for direct animal feed over the study period (100% 1950-1970, and decreased linearly to 67% in 2008).
- Indian mackerel (*Rastrelliger kanagurta*) is used for animal feed directly as well as for DHC(www.fao.org/fishery/facp/YEM/en). A conservative estimate of 5% being destined for other uses was thus applied, with the balance destined for DHC.
- Small pelagics were targeted off the Eritrean coast for fishmeal production in the 1950s and 1960s as well (Tesfamichael *et al.* 2012b). Therefore, 10% of small pelagics were apportioned to FMFO from 1950-1970.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Oceania fishing entities

Oceania, as a broad geographic region composed of many island countries and territories in the southern and central Pacific Ocean, shares many similar characteristics of their fisheries and fishmeal production. Broadly, very few countries in this region produce fishmeal and only Australia has dedicated reduction fisheries. However, tuna fisheries are dominant in this region in almost every fishing entity. The majority of landings are attributed to foreign vessels (distant-water fleets) that are either based out of their home country or have various agreements with host countries.

Tuna fisheries in the region are mainly foreign owned and operated and rely on large imports of bait of pilchard, anchovy, and squid (FitzGerald 2004). Therefore, bait use supplied by local fishing entities is minor but still existent. Milkfish, Carangidae, Clupeidae, and Lutjanidae are noted as used as baitfish in some fishing entities (FitzGerald 2004; Doyle *et al.* 2014; Zylich *et al.* 2014a), but outside these taxa, bait use was not considered further. Milkfish was thus apportioned 100% to other uses as it is not generally considered a food fish in this region (FitzGerald 2004). Carangidae and Lutjanidae were listed as baitfish for the Solomon Islands. Kiribati uses some Clupeidae landings for baitfish. Tuvalu uses delicate round herring (*Spratelloides delicatulus*), hardyhead silverside (*Atherinomorus lacunosus*), and miscellaneous marine fishes for bait as well. Where these taxa were noted to be used for this

purpose, they were apportioned 100% to other uses. All other landings were thus apportioned 100% to DHC.

The following countries are Type 1 and have individual fishing entity reports: Australia and Vanuatu.

The following fishing entities are Type 2 and only produce fishmeal from by-products: Fiji, Solomon Islands, and New Zealand. They were therefore apportioned 0% to FMFO for all landings. Fiji and Solomon Islands both produce fishmeal from by-products of tuna processing (Doyle *et al.* 2014; FAO 2014a). The Solomon Islands' baitfish fishery, which supplies bait to tuna fisheries, was apportioned 100% to other uses (Doyle *et al.* 2014).

New Zealand has mixed reports of fishmeal production. While there are some reports of fishmeal production, it is not stated explicitly that these landings are attributed to New Zealand (i.e., foreign charter vessels producing fishmeal on board; Simmons *et al.* 2015), or that these are not by-products of fish processing. All reports state that New Zealand's fishmeal is produced from by-products of fish processing (Statistics New Zealand 1980; Simmons *et al.* 2012). One report has an estimate that New Zealand produces fishmeal from whole fish (Jackson and Shephard 2012), but this is not supported in the rest of the sources. For an overview of the fisheries of New Zealand since 1950, please see Simmons *et al.* (2015).

Most Oceanic fishing entities are Type 3 and have no reported fishmeal production from 1976-2010 (FAO 2014a). They were therefore apportioned 0% to FMFO for all landings. These countries are: American Samoa, Christmas Island, Cocos (Keeling) Island, Cook Islands, French Polynesia, Guam, Johnston Atoll, Kiribati (Zylich *et al.* 2014a), Marshall Islands, Federated States of Micronesia, Nauru(www.fao.org/fishery/facp/NRU/en), New Caledonia, Niue, Norfolk Island, Commonwealth of the Northern Marianas, Palau (www.fao.org/fishery/facp/PLW/en), Papua New Guinea, Pitcairn, Samoa(has fisheries that use bait although this relies on imported baitfish and is thus not considered here; www.fao.org/fishery/facp/WSM/en), Tokelau, Tonga (www.fao.org/fishery/facp/TON/en), Tuvalu, and Wallis and Futuna Islands.

As only Australia has dedicated reduction fisheries for a few taxa, and bait use in the region is imported, the use of fish for DHC is clearly the dominant use in this region.

Australia

Australia's fisheries landings are relatively low relative to its coastline (Kleisner *et al.* 2015). It has had two minor dedicated reduction fisheries, but the majority of fishmeal originates from by-products of its processing sector (Commonwealth Bureau of Census Statistics 1951; Jackson and Shephard 2012). While Australia is a significant rancher of Southern bluefin tuna, much of the feed is imported(http://asbtia.com.au). For an overview of the fisheries of Australia since 1950, please see Kleisner *et al.* (2015).

Evidence and assumptions:

- Pacific sardine (*Sardinops sagax*) is currently used in large amounts for direct feeding of bluefin tuna. The current disposition is 94% for direct feed, with the remainder destined to DHC, bait, and pet food industries. These other 3 uses were apportioned equally leaving 98% in the 'other uses' category, and 2% in the DHC category in 2010. Values were linearly interpolated to these values starting in 1990 when bluefin tuna ranching began in Australia (Stefano and Heijden 2007).
- Greenback horse mackerel (*Trachurus declivis*) has little commercial value and was previously used to produce relatively large quantities of fishmeal (Rowling *et al.* 2009; FAO 2014a; www.fish.gov.au/). Industrial landings were therefore apportioned 100% to FMFO.
- Australia had a reduction fishery for Clupeoids since around 1970 (Commonwealth Bureau of Census Statistics 1971; Australian Bureau of Statistics 1975). Therefore, landings of Clupeidae and Engraulidae were destined 100% to FMFO from 1970-2010.
- Primary DHC taxa are occasionally used for purposes other than DHC, often because of the poor condition in which the fish is delivered. As a broad assumption, that is confirmed by some fishing entities with detailed statistics (Statistics Norway 2002; Statistics Iceland 2015), these taxa were apportioned 99.9% to DHC. The remaining 0.1% was split evenly between FMFO and other uses.

Vanuatu

Vanuatu has a minor amount of fishmeal production due to its use as a flag-of-convenience via an agreement with Norway for a vessel fishing for Antarctic krill in the Southern Ocean. As fishmeal production was concentrated in one species on a factory trawler (Gascón and Werner 2005), no further division of other DHC taxa was necessary and all other landings were assumed to be 100% for direct human consumption. For an overview of the fisheries of Vanuatu since 1950, please see Zylich *et al.* (2014b).

Evidence and assumptions:

- Antarctic krill (*Euphausia superba*) was apportioned 100% to FMFO for the three years it was fished by Norway under the Vanuatu flag (Gascón and Werner 2005; Parker 2011).
- *Trochus* spp. are fished for the aesthetic quality of their shells and are exported for this purpose (www.fao.org/fishery/facp/VUT/en; Zylich *et al.* 2014b). They are apportioned 100% to other uses (Zylich *et al.* 2014b).

Global results

Globally, fisheries for non-DHC uses are a substantial portion of commercial landings at an average of nearly 20 million tonnes annually (Figure 1), which accounts for around 22% of total global marine fisheries landings in 2010 (Pauly and Zeller 2016). However, the portion destined for FMFO has declined in recent years, in contrast to the growing proportion and nominal use of fish for 'other uses', notably direct feed in aquaculture (Figure 2).

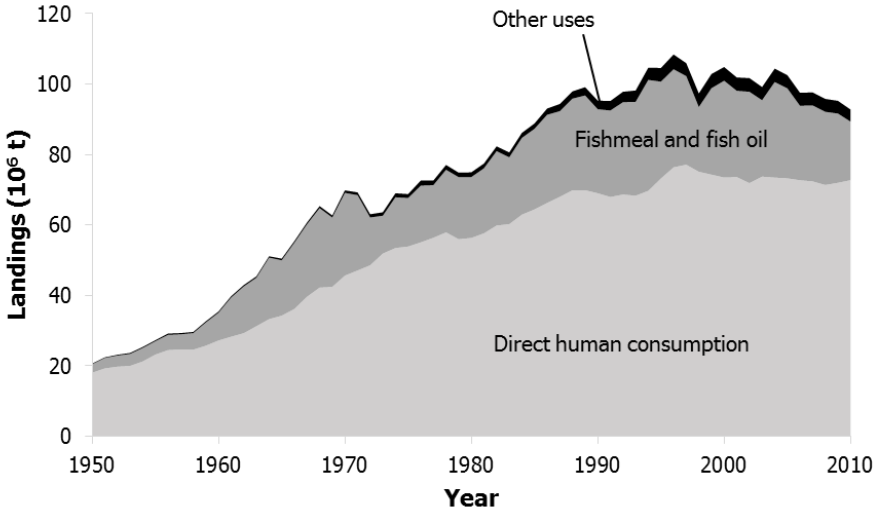

Figure 1. End use of global industrial and artisanal marine landings. Non-commercial subsistence and recreational catches, as well as discarded catches as presented in Pauly and Zeller (2016) are excluded from present consideration.

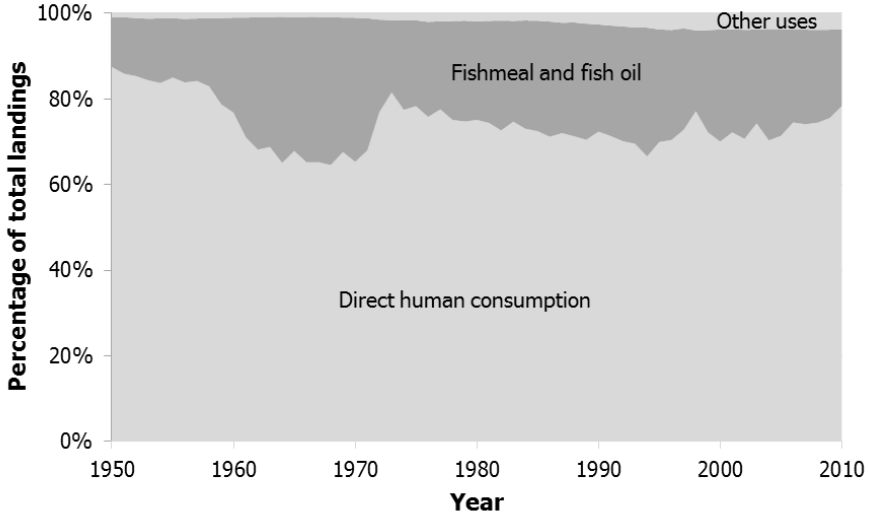

Figure 2. End use of global industrial and artisanal marine landings as percentage.

The largest reduction fisheries are all for forage fish species and are also some of the largest fisheries in the world (Table 3; FAO 2014b). The 10 largest fishing countries (fishing entities) for FMFO account for 85.5% of landings destined for FMFO (Figures 3, 4), with Peru, China (recent years), Norway and Japan (earlier decades) the leading countries (Table 3, Figure 3). While many of the countries listed in Table 3 are unsurprising, South Africa stands out here based on its historical production of fishmeal which has declined significantly since the early 1990s (Figure 3). One hundred and twelve (112) out of 196 examined fishing countries do not produce fishmeal, and another 37 had less than 100,000 tonnes of fish destined for this purpose, while 33 countries caught over 1,000,000 tonnes of fish destined for FMFO from 1950-2010.

Table 3. Top taxon and fishing entities for FMFO from 1950-2010.

Taxon	**%**	**Fishing Country**	**%**
Peruvian anchoveta (*Engraulis ringens*)	33.7	Peru	33.8
Pacific sardine (*Sardinops sagax*)	16.6	Chile	14.9
Chilean jack mackerel (*Trachurus murphyi*)	5.5	Norway	6.6
Capelin (*Mallotus villosus*)	5.5	Japan	6.1
Atlantic herring (*Clupea harengus*)	4.2	USA	5.0
Gulf menhaden (*Brevoortia patronus*)	2.9	South Africa	4.7
Sand lances (*Ammodytes* spp.)	2.6	China	4.2
Blue whiting (*Micromesistius poutassou*)	2.3	Denmark	3.7
Japanese anchovy (*Engraulis japonicus*)	2.2	Iceland	3.3
Atlantic menhaden (*Brevoortia tyrannus*)	1.9	Thailand	3.2
Other Taxa	22.5	Other Countries	14.4

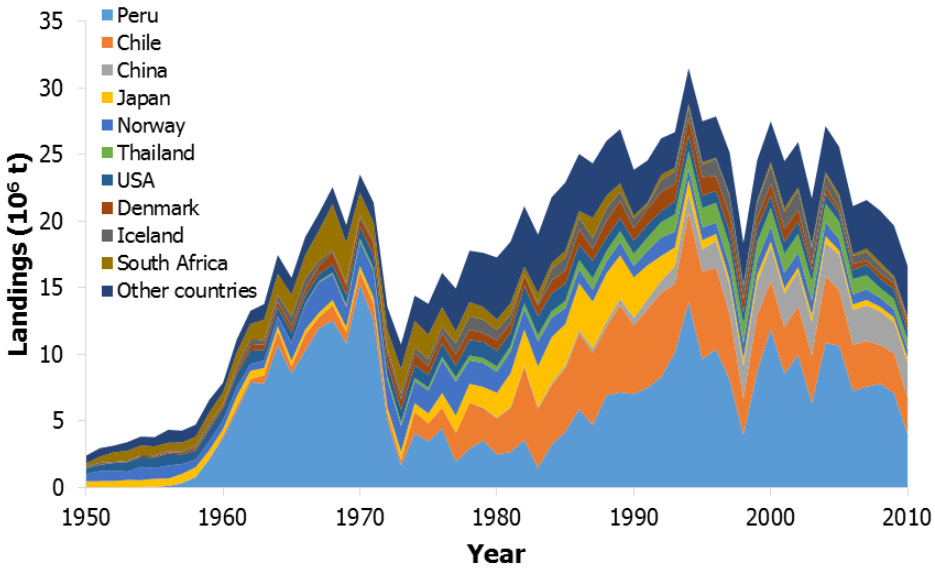

Figure 3. Fish destined for FMFO by fishing country.

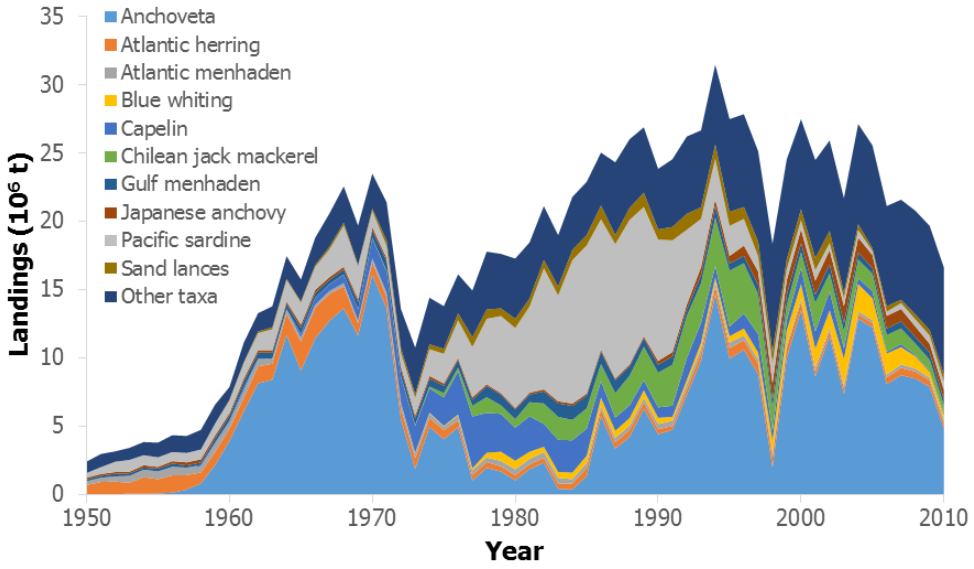

Figure 4. Fish destined for FMFO by taxa.

The Peruvian anchoveta (*Engraulis ringens*) fishery being the largest single-species fishery in the world, is also the largest reduction fishery (Figure 4, Table 3). The two main fishing countries for this species, Peru and Chile, are also the largest producers of fish destined for FMFO (Figure 3, Table 3). China, with the world's largest aquaculture sector and a growing proportion of it being direct-feed aquaculture (Tacon and Metian 2008; FAO 2014b), catches the most fish destined for 'other uses' (Table 4).

Table 4. Top taxon and fishing entities for other uses from 1950-2010.

Taxon	%	Fishing Country	%
Miscellaneous marine fishes	15.5	China	52.2
Largehead hairtail (*Trichiurus lepturus*)	12.2	Thailand	18.4
Jacks, pompanos (Carangidae)	9.0	Japan	5.6
Miscellaneous marine crustaceans	7.0	USA	4.8
Threadfins, whiptail breams (Nemipteridae)	6.4	Indonesia	3.3
Lizardfishes, sauries (Synodontidae)	4.7	Vietnam	3.2
Drums, croakers (Sciaenidae)	4.2	Myanmar	2.9
Chub mackerel (*Scomber japonicus*)	4.1	Malaysia	2.3
Pacific sandlance (*Ammodytes personatus*)	3.4	Finland	1.1
Atlantic herring (*Clupea harengus*)	3.2	Norway	0.8
Other Taxa	30.5	Other Countries	5.4

The data and analysis presented here encompasses the end use of commercial marine fisheries landings from 1950 to 2010, based on the best information available. Subsequent research will aim to keep these data updated and presented by the *Sea Around Us* at www.seaaroundus.org where the data processed in this report can be accessed.

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