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# Most fish destined for fishmeal production are food-grade fish

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## Abstract

Marine fisheries target and catch fish both for direct human consumption (DHC) as well as for fishmeal and fish oil, and other products. We derived the fractions used for each for 1950–2010 by fishing country, and thus provide a factual foundation for discussions of the optimal use of fisheries resources. From 1950 to 2010, 27% (~20 million tonnes annually) of globally reconstructed marine fisheries landings were destined for uses other than DHC. Importantly, 90% of fish destined for uses other than DHC are food-grade or prime food-grade fish, while fish without a ready market for DHC make up a much smaller proportion. These findings have implications for how we are using fish to feed ourselves or, more appropriately, how we are not using fish to feed ourselves.

KEYWORDS
catch reconstruction, direct human consumption, feed, food security, reduction fisheries, trash fish

## 1 | INTRODUCTION

There is a widely held perception that the catch of marine fisheries that is landed (i.e. "landings" excluding discarded catches) is basically used for direct human consumption (DHC); that is, most of it ends on consumers' tables. However, there is a fraction of global landings that is taken for other uses. This occurs mainly through directed fisheries (also called "reduction fisheries") for the production of fishmeal and fish oil (i.e. FMFO), as well as finfish and marine invertebrates (here "fish") fed directly for livestock production (i.e. "feed"), especially in aquaculture.

Aquaculture produces an increasing proportion of fish for DHC (FAO, 2016). However, aquaculture itself is also a major consumer of fish protein, as almost 70% of the animals raised in aquaculture operations are now provided with feeds (FAO, 2014), as opposed to relying on food organisms growing naturally in the farmed area. Much of the growth of aquaculture seems driven by a growing demand for fish of a specific type that is preferred by consumers in developed countries (e.g. salmon; Golden et al., 2016a, 2016b) in the context of an ocean where top predators and many other fish stocks are severely depleted (Kleisner, Zeller, Froese, & Pauly, 2013; Naylor & Burke, 2005). Aquaculture is thus trying to meet the market demand for these species by relying on inputs of fish from wild capture fisheries.

Currently, the amount of wild fish used in aquaculture feeds for carnivorous species is being reduced and substituted by agricultural products (Tacon & Metian, 2008). On the other hand, many aquaculture species that were formerly not artificially fed or had no fish inputs in their feed are increasingly being supplemented with wild fish (either via fishmeal or direct feed) to speed up growth (Tacon & Metian, 2008). As aquaculture continues to expand, these competing trends have led to a steady requirement for fishmeal, with demand potentially growing in the future (World Bank, 2013). In parallel, the use of wild capture fish directly as feed (often mislabelled as "trash fish"; Pauly, 1996, 2007) has grown, but estimates of the scale of this practice vary widely (Cao et al., 2015; Funge-Smith, Lindebo, & Staples, 2005). While FMFO is generally sourced from directed reduction fisheries, fish used directly for feed are mainly from the by-catch of non-selective fisheries such as shrimp trawls (Funge-Smith et al., 2005). Therefore, which species of fish and the amount of fish that are used for non-DHC purposes is currently unknown on a global basis.

Furthermore, the use of these fish resources to artificially feed fish and livestock means these fish are not destined directly for human consumption. As fish are an important provider of nutrients and animal protein to 2.9 billion people (Belton & Thilsted, 2014, FAO, 2014; Golden et al., 2016b), the current and potentially increasing use for non-DHC may represent a challenge to global food security (Béné et al., 2016; Naylor et al., 2000), especially with regards to animal protein and micronutrients (Béné et al., 2015; Golden et al., 2016b). However, the ability to redirect much of this non-DHC catch to human consumption has been contested by some based on the quality of the fish, and the market options (Wijkström, 2009).

Finally, fishmeal production is mainly sourced from forage fish species (Alder, Campbell, Karpouzi, Kaschner, & Pauly, 2008), that is species that play a vital role in ecosystems in transferring energy from primary producers to higher trophic-level species including large fish, marine mammals and seabirds. Based on the cultural importance of marine mammals and seabirds, and the economic value of fisheries for high-trophic-level species (such as various salmons, cods and tunas), the sustainability of forage fish populations is important for these ecosystem functions (Pikitch et al., 2012). Thus, the fish caught for fishmeal production potentially represent a loss in production of higher trophic-level species in the ecosystem, and a less valuable ecosystem service as the predators of forage fish are worth more than the fish themselves (Pikitch et al., 2014).

There is a dearth of research on the extent and differences in the use of fish for non-DHC purposes among fishing countries and taxa used globally and over time since 1950. By analysing global commercial fisheries landings for their end use, we uncovered trends in DHC and non-DHC use of different species and by different fishing countries, and quantified the extent of non-DHC landings. This is necessary to understand the food security implications of using inherently limited but renewable fisheries resources for non-DHC purposes (Belton & Thilsted, 2014; Béné et al., 2016). Importantly, by considering all taxa and all fishing countries over time, our study unveils trends in the use of these resources that have been largely obfuscated until now.

## 2 | METHODS

We based our analysis on the reconstructed landings data (i.e. excluding discarded catch) by taxon for each fishing country for each year from 1950 to 2010 as documented in the *Sea Around Us* database (currently, 1950–2010; Pauly & Zeller, 2016; Zeller et al., 2016). We used commercial landings data only (i.e. industrial and artisanal), and excluded all subsistence and recreational catches. Thus, we assumed all subsistence and recreational catches are consumed directly (recreational catch-and-release fisheries catches are not generally included in the *Sea Around Us* catch data). Separately, we reviewed the global literature to assemble a wide range of information and data on the relative proportions of landings that were destined for DHC, reduction to FMFO and "other uses," by taxon, fishing country and year. Thus, we broadly followed the general catch reconstruction methodology of assembling alternative information sources to add value to the global reconstructed catch data of the *Sea Around Us* (Zeller, Harper, Zylich, & Pauly, 2015; Zeller et al., 2016).

We focused our FMFO and animal feed study at the level of the fisheries rather than on the final products (e.g. FMFO and feeds) or use of these products (e.g. aquaculture or livestock production), as quantifying fish inputs to these products introduces additional uncertainties. Therefore, we allocated all fisheries landings (measured in tonnes of wet weight) to their end uses, that is (i) DHC; (ii) FMFO production; or (iii) "other uses" including direct feed, bait, direct fertilizer application, and industrial uses. The by-products of DHC landings (e.g. the by-products of fish processing) that can also be used for FMFO production were not accounted for in this analysis, as these are separate from dedicated reduction fisheries, and because the global landings data of the *Sea Around Us* (in line with FAO data) are reported as whole fish wet weights. As far as possible, we assembled data that were specific to the taxon, fishing country, and time period under consideration. However, when this was not possible (e.g. due to lack of country-, taxon- or time period-specific information), proxies were used based on taxonomic affinities, 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. Furthermore, the use of various taxa for DHC or non-DHC purposes often changes within or between years based on market situations and condition of the landings (e.g. high-value species when landed in poor condition are redirected to fishmeal production). Thus our values of species generally used for DHC should be viewed as "average" use values.

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. 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 for fishmeal production). Thus, major reports on fishmeal production (Alder & Pauly, 2006, Bureau of Commercial Fisheries, 1961; Hasan & Halwart, 2009; Jackson & Shephard, 2012; Macer, 1974; National Marine Fisheries Service, 1968), as well as country FAO Fishery Profiles (see http://www.fao.org/fishery/countryprofiles/search/en), were used to inform the analysis of the major fishmeal producing countries, as well as the lack of fishmeal production from other countries.

Determining that a fishing country had 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 countries was used as supporting evidence of likely absence of reduction fisheries in the given fishing country.

As required, whole fish wet weights (being the default weight unit for reporting of global landings) were back-calculated based on requirements for fishmeal production, as well as bait and direct feed uses.

When estimating fish destined for fishmeal, we estimated the amount of fish used for fishmeal production from 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 country, as well as the FMFO yields of fish into fishmeal which varies temporally, based on technology, and species composition used (Cashion, Hornborg, Ziegler, Hognes, & Tyedmers, 2016). When this method was used to calculate fish destined for reduction from fishmeal, the average fishmeal yield of 22.5% was employed (Tacon & Metian, 2008). When estimating fish destined for direct feed or bait, this alternative method introduces 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 with amount of bait used per fish caught (e.g. for trap fisheries, or for tuna pole-and-line fisheries). Complete details on how this method was applied to each fishing country or region can be found in the supplementary methods and results.

As this method allowed for an analysis of the end use of all commercial landings from 1950 to 2010, we also analysed the end use by fish “quality” as determined by the taxa. We adapted the (forage) fish classification of Wijkström (2012) that assigns forage fish taxa into industrial-grade fish, food-grade fish and prime food-grade fish, and applied this classification to all fisheries landings. Food-grade forage fish include fish that are of varying consumer acceptability depending on the geographic region. Prime food-grade fish are acceptable fish for eating, and are almost all fish that are not forage fish. While these categories are broad and somewhat Eurocentric, they provide a starting point to the debate on whether fish used for reduction are acceptable as food and vice versa. See Table S1 for classification of some taxa.

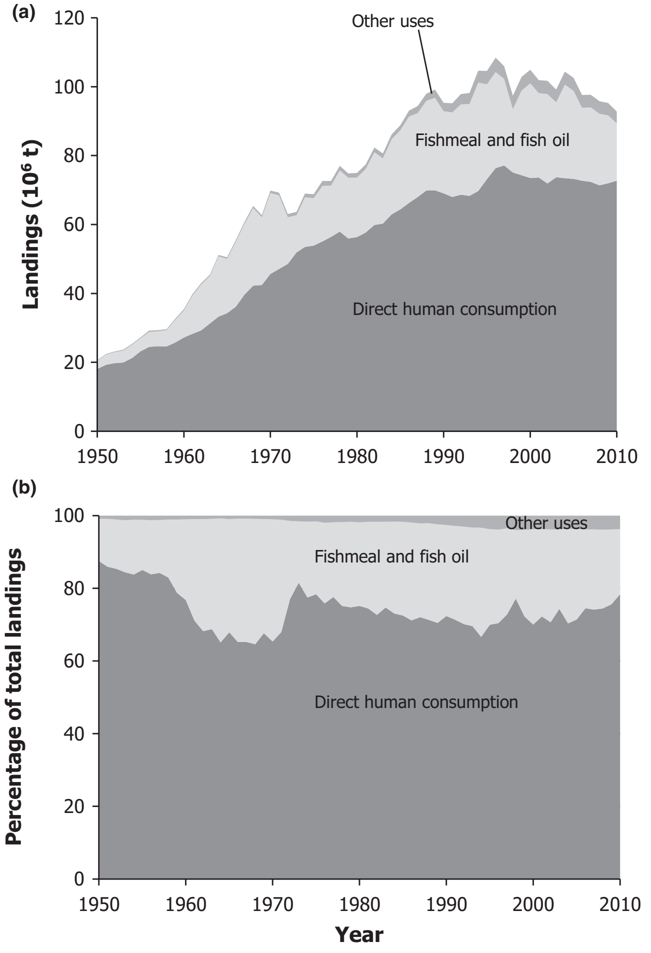


**FIGURE 1** End use of global industrial and artisanal marine landings (i.e. excluding discarded catch) as (a) nominal tonnages and (b) percentages

## 3 | RESULTS

Over the six decades from 1950 to 2010, 27% or ~20 million t per year, on average, of global commercial marine landings were directed to uses other than DHC (Figure 1; Table S2). Fish for FMFO production represent the greatest proportion of this with 25% (~18 million t per year) of average annual global landings. However, the proportion of landings destined for FMFO has declined in recent years from a recent high of 30% of global landings in the mid-1990s to 18% by 2010 (Figure 1). In contrast, fish destined for “other uses,” notably direct feed for animals and aquaculture, has risen slightly over the last two decades (Figure 1; Table S2). The decline in use of fish for FMFO in recent years is driven mainly by European and North American fishing countries, where landings formerly destined for FMFO are increasingly being redirected to DHC (Figure 2a,b). However, this trend is being countered by the increasing retention and even targeting of ill-labelled “trash fish” catch mainly by Asian trawl fisheries for fishmeal production and direct feed (Figure 2c). On a positive note, the increased utilization of this formerly discarded by-catch has resulted in declining rates of discarding by these (mainly Asian) industrial fleets (Pauly & Zeller, 2016).

Unsurprisingly, the two countries (Peru and Chile) that have the world’s largest single-species reduction fishery utilizing Peruvian anchoveta (*Engraulis ringens*, Engraulidae) are also the largest producers of fish for fishmeal (Table 1; Fig. S1), making South America the world’s leading fishmeal producing region (Figure 2d). Africa has a few countries that were large producers of fishmeal in the past, but the region generally uses much less fish for FMFO presently (Figure 2e). Oceania has been marked by low use of fish for non-DHC uses from 1950 to 2010 except for small amounts used for bait for tuna fisheries, and Australia’s fishmeal production and direct feeding in tuna ranching (Figure 2f; Ottolenghi, 2008).

The top ten species used for reduction accounted for ~77% of fish landings destined for fishmeal from 1950 to 2010, although this decreased to around 53% by 2010 (Table 1). Thus, there is a growing diversity of taxa used for fishmeal production. China is the largest producer of fish for “other uses” (Table 2; Fig. S2), notably as direct feed for its massively expanding aquaculture sector. When the 10 taxa with the highest reduction landings (Table 1; Fig. S3) are excluded, there is a trend of a greater proportion of landings to be directed towards non-DHC purposes (from 5% in 1950 to 14% in 2010; Figure 3).

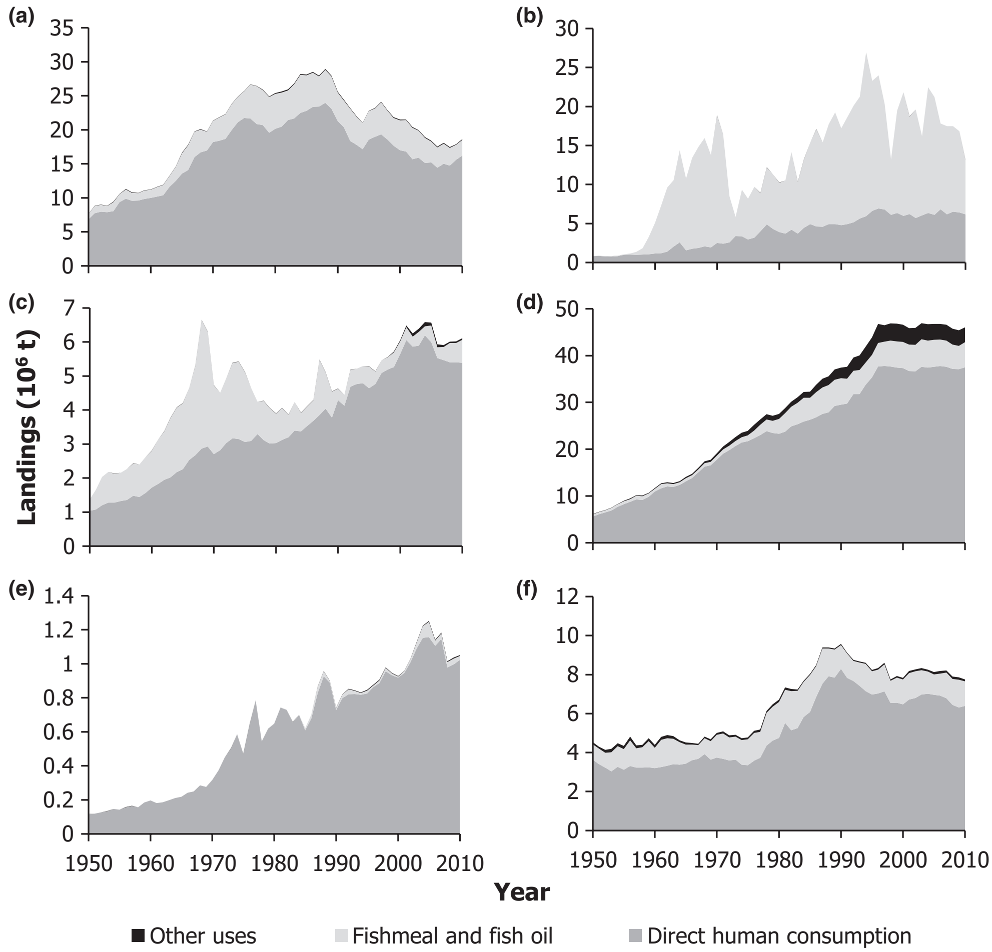


**FIGURE 2** End use of marine fisheries landings by region, (a) Europe, (b) South America and the Caribbean, (c) Africa, (d) Asia, (e) Oceania and (f) North America

Finally, and importantly, we demonstrate clearly that over 90% of fish landings destined for fishmeal, fish oil, or other non-direct human consumption uses are food-grade or prime food-grade fish (Figure 4). Conversely, very little catch destined for FMFO or other non-DHC uses are industrial-grade fish that have no DHC markets.

## 4 | DISCUSSION

The implication of directing ~20 million tonnes of fish every year towards feeding farmed fish, pigs and chickens instead of humans is cause for concern (Belton & Thilsted, 2014). A recent review of the evidence points to the important benefits fisheries and fish protein have on food security (Béné et al., 2016). The 20 million tonnes identified here represent a substantial portion of global commercial marine fisheries landings. This must also be considered in the context of the spatial expansion of global fisheries (Swartz, Sala, Tracey, Watson, & Pauly, 2010), the declining trend of global marine catches since the mid-1990s (Pauly & Zeller, 2016), and China's massive distant water fleet development (Pauly et al., 2014). Thus, the global depletion of ecosystems relied upon by many for essential calories and micronutrients (Béné et al., 2015; Golden et al., 2016b) to feed aquaculture and livestock species appears to be harmful to humanity's global food security.

There are two major trends in the use of fish for uses other than DHC: the increased diversity of species used, and the diminishing role of the formerly top 10 taxa used for reduction. The increased diversity is observed by the diminishing role of the top 10 taxa used for reduction (Table 1), as well as the growing proportion of fish outside of these taxa not being used for DHC (Figure 3). The increased diversity of species used for non-DHC uses is driven by the growth of non-selective fisheries being used for these purposes. This is created and fuelled by the growth of fed aquaculture in Southeast Asia and China and its reliance on domestic and imported fish inputs (Cao et al., 2015), and because of the overfishing of the former target species such as shrimp, and associated depletion of existing local ecosystems (Funge-Smith et al., 2005; Gillett, 2008). While these fisheries may be reducing the amount of fish discarded, they are doing so at the expense of the ecosystem health as all taxa are taken indiscriminately and without regard for population status nor ecosystem function (Pauly et al., 2002). Finally, as these fish are mostly sourced from by-catch in shrimp trawl fisheries, or targeted by non-selective general trawl fisheries for low-value fish (Cao et al., 2015), they are often not identified to the species level (Table 2). In addition, this practice may

**TABLE 1** Major taxa and fishing countries for fishmeal and fish oil production from 1950 to 2010

| Taxon | 1950–2010 (%) | 2010 (%) | Fishing country | 1950–2010 (%) | 2010 (%) |
|---|---|---|---|---|---|
| Peruvian Anchoveta (*Engraulis ringens*) | 33.7 | 28.9 | Peru | 33.8 | 24.0 |
| Pacific sardine (*Sardinops sagax*, Clupeidae) | 16.6 | 3.7 | Chile | 14.9 | 16.5 |
| Chilean jack mackerel (*Trachurus murphyi*, Carangidae) | 5.5 | 3.4 | Norway | 6.6 | 3.7 |
| Capelin (*Mallotus villosus*) | 5.5 | 0.9 | Japan | 6.1 | 2.2 |
| Atlantic herring (*Clupea harengus*) | 4.2 | 2.3 | USA | 5.0 | 4.1 |
| Gulf menhaden (*Brevoortia patronus*, Clupeidae) | 2.9 | 2.5 | South Africa | 4.7 | 1.3 |
| Sand lances (*Ammodytes* spp., Ammodytidae) | 2.6 | 3.0 | China | 4.2 | 15.8 |
| Blue whiting (*Micromesistius poutassou*, Gadidae) | 2.3 | 2.0 | Denmark | 3.7 | 3.0 |
| Japanese anchovy (*Engraulis japonicus*, Engraulidae) | 2.2 | 4.2 | Iceland | 3.3 | 1.7 |
| Atlantic menhaden (*Brevoortia tyrannus*, Clupeidae) | 1.9 | 1.6 | Thailand | 3.2 | 4.6 |
| Other taxa | 22.5 | 47.3 | Other countries | 14.4 | 23.0 |

**TABLE 2** Major taxa and fishing countries for “other uses” from 1950 to 2010

| Taxon | 1950–2010 (%) | 2010 (%) | Fishing country | 1950–2010 (%) | 2010 (%) |
|---|---|---|---|---|---|
| Miscellaneous marine fishes | 15.5 | 21.3 | China | 52.2 | 62.8 |
| Largehead hairtail (*Trichiurus lepturus*, Trichiuridae) | 12.2 | 15.1 | Thailand | 18.4 | 12.6 |
| Jacks, pompanos (Carangidae) | 9.0 | 10.1 | Japan | 5.6 | 2.6 |
| Miscellaneous marine crustaceans | 7.0 | 0.1 | USA | 4.8 | 1.7 |
| Threadfins, whiptail breams (Nemipteridae) | 6.4 | 4.3 | Indonesia | 3.3 | 4.4 |
| Lizardfishes, sauries (Synodontidae) | 4.7 | 3.4 | Vietnam | 3.2 | 3.0 |
| Drums, croakers (Sciaenidae) | 4.2 | 6.7 | Myanmar | 2.9 | 3.3 |
| Chub mackerel (*Scomber japonicus*, Scombridae) | 4.1 | 0.0 | Malaysia | 2.3 | 2.2 |
| Pacific sand lance (*Ammodytes personatus*, Ammodytidae) | 3.4 | 3.3 | Finland | 1.1 | 1.4 |
| Atlantic herring (*Clupea harengus*) | 3.2 | 2.5 | Norway | 0.8 | 0.1 |
| Other taxa | 30.5 | 33.3 | Other countries | 5.4 | 6.0 |

lead to an increased demand for general fish biomass as inputs into aquafeeds directly or through FMFO and thus encourage the practice of non-selective fishing.

In contrast to this, new or revived markets for human consumption are being found for many former reduction species, such as capelin (*Mallotus villosus*, Osmeridae), and Atlantic (*Clupea harengus*, Clupeidae) and Pacific herring (*C. pallasii*, Clupeidae). Even the Peruvian anchoveta, which has been used almost exclusively for fishmeal production since 1960, has seen its proportion used for DHC increase in the late 2000s (Christensen, de la Puente, Sueiro, Steenbeek, & Majluf, 2014). This finding is a counterpoint to the trend of a declining overall proportion of fish destined for fishmeal production as noted above (Figure 1) and in official fisheries statistics (FAO, 2014). Thus, while total landings destined for reduction have declined in recent years, it appears that this is driven by a redirection to DHC of former key reduction species (e.g. Atlantic herring and capelin), while other species are being redirected from DHC to non-DHC uses (Figure 3 and Fig. S4). In addition, some FMFO products are destined for directly human consumption, such as fish oil supplements, and this now accounts for 13% of global fish oil use (Ytrestøyl et al., 2011).

The benefits of redirecting fish currently used for reduction or “other uses” to DHC could be enormous. From a purely energetic perspective, using fish as feed is inherently less efficient than feeding fish to people. Furthermore, the high-value aquaculture species such as salmon and trout are net consumers of fish protein and thereby reduce fish availability (Tacon & Metian, 2008). This effect is even more pronounced when factors of price and sourcing of these fish inputs

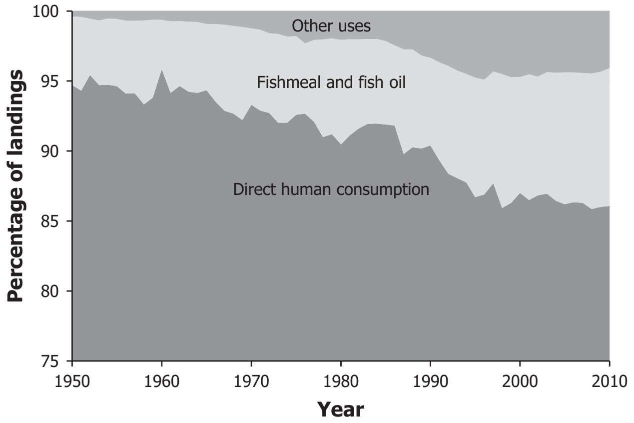


**FIGURE 3** End use of fisheries landings excluding the top 10 reduction taxa. Excluded taxa are Peruvian anchoveta (*Engraulis ringens*), Pacific sardine (*Sardinops sagax*), Chilean jack mackerel (*Trachurus murphyi*), capelin (*Mallotus villosus*), Atlantic herring (*Clupea harengus*), Gulf menhaden (*Brevoortia patronus*), sand lances (*Ammodytes* spp.), blue whiting (*Micromesistius poutassou*), Japanese anchovy (*Engraulis japonicus*) and Atlantic menhaden (*Brevoortia tyrannus*; see Table 1). Note truncated y-axis

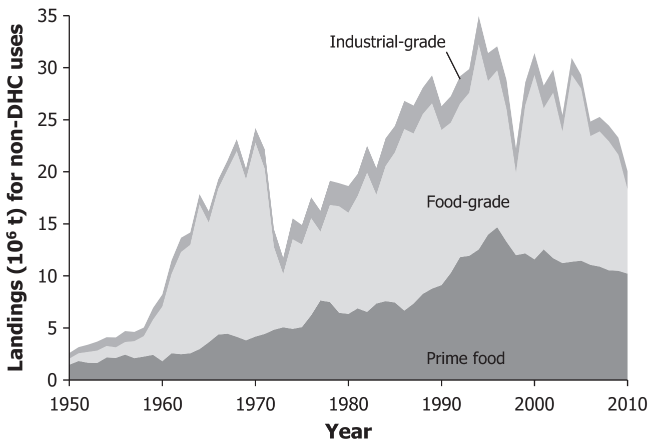


**FIGURE 4** Quality of fish for uses other than DHC (i.e. FMFO and “other use”)

are considered (Swartz, Sumaila, Watson, & Pauly, 2010). These fish inputs are often sourced in the waters of developing countries (Tacon & Metian, 2009), putting pressure on their fish populations as well as reducing access to fresh fish for local human consumption (Pauly et al., 2014). The final aquaculture products are often, but not exclusively, exported to developed countries and are thus an export of animal protein and micronutrients from many food insecure regions (Golden et al., 2016a, 2016b; Kent, 2003). Finally, the economic and social benefits of redirecting reduction fisheries to DHC could be immense as in the case of the Peruvian anchoveta fishery (Christensen et al., 2014).

Given that most of these 20 million tonnes consist of food-grade or prime food-grade fish species, and that an increasing proportion of non-dominant reduction species are being used for non-DHC uses, the potential benefits of changing this direction are enormous. This will require curtailing the growth of intensive fed aquaculture and reducing fish inputs in animal feeds. The major argument against the use of these species for DHC is the presently often-limited market availability for human consumption, and the inherent quality of the landed fish (Jackson & Shephard, 2012; Wijkström, 2012). However, our results demonstrate that ~90% of fish destined for non-DHC uses is of food-grade quality or better, and that there has been a change in the use of various species including capelin, Atlantic herring, and some former major reduction species like Chilean jack mackerel (Figs. S4–S6). Thus, there has been success in redirecting these fish from animal consumption to human consumption.

Fish used for feed often receives a lower price than fish for human consumption (Fréon et al., 2013), but is also subject to less stringent requirements of quality and freshness. Furthermore, converting fish to fishmeal can address gluts in the markets and turn a lower value fish into an internationally traded commodity. While on average fishers may receive a lower price than fish for direct consumption, fishmeal producers can often pay more than local populations for fish, especially given increasing prices paid for fishmeal (Tacon & Metian, 2009). Fishmeal production also creates a market for species with no market for human consumption, or for by-products of fish with little use for DHC and these two segments together now make up a substantial portion of global fishmeal production (FAO, 2014), although fishmeal from by-products is excluded from this analysis. However, fish oil obtained from by-products is of a lower quality and thus many feeds require fish oil from whole fish for high quality fats such as omega-3s.

Clearly, not all fishing for the production of fishmeal or for direct feed for aquaculture or livestock is necessarily a “waste.” Low-value fish or, increasingly, fish by-products are converted into higher-value fish products that can attain a higher price on domestic and international markets (Tacon & Metian, 2009). Furthermore, fish in the form of FMFO represent high quality fats and protein sources that can substantially improve the growth rate of certain aquaculture and livestock species when fishmeal is supplemented to a diet that formerly relied on other or minimal inputs, such as in pig production or Chinese carp aquaculture, respectively (Alder et al., 2008; Chiu et al., 2013). However, this must be done to optimize the food outputs of these various systems, including capture fisheries and aquaculture and terrestrial livestock. Some progress along these lines is being made through declining fish inputs to carnivorous aquaculture (Tacon & Metian, 2008), and optimizing the levels for other animal culture including pig and carp. Historically, this has largely been driven by the increased economic costs of fish inputs (Alder et al., 2008); however, this same economic cost can reduce access to local fish supplies for the poorest members of society. When using fish as feed instead of as food, efforts should be made to maximize nutritional benefits of these livestock and aquaculture production systems, while minimizing environmental costs.

## 5 | CONCLUSION

Our oceans and their resources are finite, but our appetite for seafood appears to be ever growing. While there is no central actor that can implement a large-scale transition, efforts should be made by governments, intergovernmental organizations and the NGO community in promoting food security through the DHC of fish, and for private actors to reduce their use of fish fit for human consumption for indirect human consumption. In this way, we must use our ocean resources to optimize long-term sustainable benefits, both for food security (especially for the developing world) and livelihood viability. We are witnessing progress on some fronts, but must make greater steps towards the efficient use of our limited ocean resources to feed humans directly, instead of indirectly via fattening farmed fish, chicken and pigs.

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## SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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