Fishing for Aquaculture: Non-Food Use of Small Pelagic Forage Fish—A Global Perspective

ALBERT G. J. TACON1 and MARC METIAN2

1The University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Spain
2Hawaii Institute of Marine Biology, University of Hawaii, Kaneohe, Hawaii, USA

About 33.29 million tonnes or 36.2% of the total world fisheries catch was destined for non-food uses in 2006, either targeted for reduction into dry meal (fish meal) and oil (fish oil) for use within industrially compounded animal feeds, or used directly as animal feed in fresh, frozen, or wet processed form. However, whereas the proportion of non-food landings destined for reduction has been relatively constant since 1970 (mean ± SD: 23.17 ± 3.74 million tonnes), “other” non-food use landings have risen markedly from 0.90 million tonnes in 1970 (3.7% total non-food use landings) to 13.14 million tonnes in 2006 or 39.5% total non-food use landings. At present, small pelagic forage fish species, including “low-value/trash fish,” form the bulk of the fisheries catch destined for non-food uses, with the aquaculture sector currently being the largest consumer. In 2006, it is estimated that the aquaculture sector consumed an estimated 23.8 million tonnes of small pelagic forage fish in the form of feed inputs, including 3.72 million tonnes used to make fish meal, 0.83 million tonnes to make fish oil used in compounded aquafeeds, and an additional 7.2 million tonnes of low value/trash fish as a direct feed or within farm-made aquafeeds.

Keywords   fisheries, aquaculture, fishmeal, fish oil, trash fish, aquafeeds

OVER-FISHING AND DISPOSITION OF THE FISHERIES CATCH

Fishing has been practiced since mankind first started hunting and searching for food. From its humble beginnings as a subsistence-based food fish hunting and gathering activity, fishing has grown into a multibillion dollar industry, with total capture fisheries’ landings of fish and shellfish in 2006 reported at 92.0 million tonnes (FAO, 2008a) and valued at over US $91.24 billion in 2006 (FAO, 2008b). However, rising global population and increasing market demand for fish has resulted in increasing fishing pressure and consequent over-fishing in many parts of the world. According to the latest FAO assessments concerning the health and exploitation of known capture fishery resources, more than 75% of the world fish stocks for which assessment information is available are reported as already fully exploited or overexploited (or depleted and recovering from depletion; Figure 1), reinforcing earlier observations that the maximum wild capture fisheries potential from the world’s oceans has probably been reached and calls for a more cautious and closely controlled development and management of world fisheries (FAO, 2007).

Global trends in over-fishing have been fueled to a large extent by market demands within economically developed countries for the consumption and importation of high market value carnivorous finfish and crustacean species (Alder and Sumaila, 2005; Montaigne, 2007; Rosenthal, 2008), with developed countries importing 80% of total internationally traded fisheries products in 2006 valued at US $72.6 billion (FAO, 2008a). At present, over 76.9% of total finfish landings from capture fisheries are species positioned high in the aquatic food chain, with a mean trophic level of 3 and above (Figure 2). In fact, it has been reported by several authors that over-fishing of large-sized high-value carnivorous finfish species has resulted in fish species being targeted lower on the aquatic food chain by fisheries (Caddy and Garibaldi, 2000; Hannesson, 2002; Pauly et al., 1998).
Notwithstanding the above, about 33.29 million tonnes or 36.2% of the total landed fisheries catch was destined for non-food uses in 2006, either targeted for reduction into dry meal (fish meal) and oil (fish oil), or used directly for animal feeding (Figure 3). Although the proportion of the total fisheries catch destined for non-food uses has remained relatively constant over the past 35 years (fluctuating from 39.0% of the total catch in 1970 to 36.2% of the total catch in 2006), total reported non-food fish landings have increased in real terms by 8.79 million tonnes or 35.9%, from 24.5 million tonnes in 1970 to 33.29 million tonnes in 2006 (FAO, 2008a, 2008b). Moreover, although the proportion of non-food landings destined for reduction has been relatively constant in global terms over this period (mean ± SD: 23.17 ± 3.74 million tonnes), “other” non-food use landings have risen markedly over this period, from 0.90 million tonnes in 1970 (3.7% total non-food use landings) to 13.14 million tonnes in 2006 or 39.5% total non-food use landings for that year (FAO, 2008a). For the purposes of this article, “other” non-food use landings include fresh, frozen, or wet-processed fish used for direct animal feeding (including farmed fish and crustaceans), for use within canned semi-moist pet foods or used as fish bait.

For comparative purposes, the growth of the aquaculture sector (an important user of non-food landed fish products as feed inputs) and reported landings of small pelagic forage fish, which constitute the bulk of fish usually targeted for non-food uses (Alder and Pauly, 2006) are also shown in Figure 3. Of particular note is the strong correlation between the reported non-food use trend lines with that of the estimated small pelagic forage fish landings over the same period (total landings estimated at 27.26 million tonnes in 2006; FAO, 2008a).

For the purposes of this article, small pelagic forage fish includes those usually lower trophic level finfish species, which, because of their size and position in the upper layers of the water...
column, usually serve as prey for higher trophic level animals to forage on, including larger piscivorous finfish, seabirds, and marine mammals. Also included within the forage fish grouping are sandeels (= sandlances: Ammodytes sp.), which, although demersal in habit, aggregate in large schools and are targeted for reduction in Europe (Masuda et al., 1984). As mentioned previously, in contrast to targeted food-fish species landings, small pelagic forage fish species are usually (with a few exceptions) positioned lower on the aquatic food chain, with a weighted mean annual trophic level ranging between 2.80 and 3.0 (Figure 4). Gadiformes (cods) and, specifically, blue whiting, hakes, and grenadiers have been excluded from the listing of small pelagic forage fish species, as they are primarily fished for human consumption (Cohen et al., 1990). Notwithstanding the above, it is often claimed that it is because of the poor flesh-keeping qualities of small “oily” pelagic forage fish and certain demersal species such as blue whiting that they have to be processed industrially for reduction into fish meal and fish oil (http://www.fao.org/fishery/species/3021).

The order Clupeiformes represents the bulk of total small pelagic forage fish landings (19.76 million tonnes or 72.5% of total small pelagic forage fish landings in 2006) and includes anchovies, herring, pilchards, sardinellas, sprat, sardines, menhaden, shad, ilisha, and dagaas (FAO, 2008a). Other major forage fish include species from the order Scombroidei (3.83 million tonnes or 14.0% total forage fish landings in 2006, including chub mackerel, Atlantic mackerel, Indian mackerels neil, short mackerel, Indian mackerel, narrow-barred Spanish mackerel), Percoidae (2.39 million tonnes or 8.8%, including Chilean jack mackerel, Japanese jack mackerel, Atlantic horse mackerel), Trachinoidei (605,612 tonnes or 2.2%, including Pacific sandlance and sandeels neil), Beloniformes (396,175 tonnes or 1.5%, including Pacific saury and Atlantic saury) and Salmoniformes (278,289 tonnes or 1.0%, including capelin).
As mentioned previously, over 75% of the world fish stocks are currently considered as being fully exploited or overexploited and, as such, are not expected to yield further increases. Thus, in the specific case of the key small pelagic forage fish species, according to FAO (2007), the two main stocks of anchoveta (Engraulis rigens) in the Southeast Pacific are considered fully exploited and overexploited; Atlantic herring (Clupea harengus) stocks are fully exploited or recovering from depletion in the North Atlantic; and Japanese anchovy (Engraulis japonicus) stocks are fully exploited in the Northeast Pacific. The major fishing areas with the highest proportions of fully exploited stocks (69–77%) are the Western Central Atlantic, the Eastern Central Atlantic, the Northwest Atlantic, the Western Indian Ocean, and the Northwest Pacific, while the areas with the highest proportions (46–60%) of overexploited, depleted, and recovering stocks are the Southeast Atlantic, the Southeast Pacific, the Northeast Atlantic (FAO, 2007).

Moreover, within many Asian countries, overfishing of “low value/trash fish” species for use as feed for the local finfish and shellfish aquaculture sector has fueled increased fishing pressure on already degraded local fishery resources (FAO, 2007). “Low value/trash fish” is generally defined as fish that have a low commercial value by virtue of their low quality, small size, or lack of consumer preference. They are either used for human consumption (often processed or preserved) or used for livestock/fish, either directly or through reduction to fish meal/oil (FAO/RAP, 2005; Funge-Smith et al., 2005). Apart from small pelagic forage fish species, “low value/trash fish” may also contain (depending upon the fishery) discarded fish (bycatch) and juveniles of other commercially important coastal and demersal fish species. For example, it has been estimated that “low value/trash fish” represents about 60% of the trawl catch in the Gulf of Thailand, and that between 18 and 32% of trash-fish were juveniles of commercially important species (FAO/RAP, 2005; Funge-Smith et al., 2005).

REDUCTION OF SMALL PELAGIC FORAGE FISH AND USE OF FISH MEAL AND FISH OIL

The estimated total production of fish meal and fish oil from small pelagic forage fish by a major producing country is shown in Figure 5; total fishmeal and fish oil production in 2006 reported as 5.46 million tonnes and 943,167 tonnes, respectively (FAO, 2008a). Fish meal production has fluctuated from a minimum of 4.57 million tonnes to a maximum of 7.48 million tonnes over the past 30 years (mean ± SD = 6.10 ± 0.77 million tonnes), whereas fish oil production has fluctuated from a...
minimum of 0.85 million tonnes to a maximum of 1.67 million tonnes (mean ± SD = 1.24 ± 0.23 million tonnes). Moreover, production is currently dominated by Peru and Chile, with these two countries alone producing 38% and 49% of total global fish meal and fish oil production in 2006, respectively (Figure 5; FAO, 2008a).

Despite the fact that fish meal and fish oil are usually produced from landings of single fish species (especially within the Americas and Europe), over 85% of the total fish meal production and 58% of the total fish oil production reported by FAO is non-species specific (FAO, 2008a), with only a few countries being species specific in their reporting, including Chile (for meals and oils), Canada, Iceland, Peru (for oils), and the USA. It is not known why many major producing countries do not always report their fish meal and fish production statistics to FAO down to the species level. A case in point is Peru, where fish meal is not reported down to the species level, whereas fish oil, which is a byproduct of the fish meal manufacturing process, is reported as Anchoveta oil (FAO, 2008a). Clearly, this discrepancy requires more attention by major fish meal and fish oil reporting countries for better transparency and credibility. Moreover, in some Asian countries, fish meal is manufactured from "low value/trash fish," including Thailand (Kaewnern and Wangvoralak, 2005) and Vietnam (Edwards et al., 2004). Moreover, the above global figures usually only refer to whole fish destined for reduction, and so generally exclude fish processing wastes and other fish scraps. For example, within the European Union (EU), it was estimated that about 33% of the fish meal produced in the EU-15 in 2002 was manufactured from trimmings from food fish processing, including Spain 100% trimmings, France 100%, Germany 100%, Italy 100%, UK 84%, Ireland 60%, Sweden 25%, and Denmark 10% (Huntington et al., 2004). Similarly, Hardy and Shepherd (2007) report that 84,579 tonnes of fish meal and 21,916 tonnes of fish oil were produced in Alaska from Alaskan pollock and cod processing wastes, although this information is not usually evident within annual fishery statistical reviews (NMFS, 2007a, 2007b).

Notwithstanding the above reporting difficulties, the use of fish meal and fish oil has varied considerably since the beginning of the 20th century, when industrial fish meal production first emerged in the market place (Kreuzer, 1974). Thus, in the 1800s in the United States, menhaden were fished primarily for oil production, and the cooked press-cake residue after oil extraction then usually used as fertilizer. At the time, fish oil was a major industrial commodity used in paints, lubricants, soaps, printing ink, and in the tanning of hides (Hardy and Tacon, 2002). By 1920, hydrogenated or hardened fish oils were heavily used in margarine and shortenings in Europe (Gauglitz et al., 1974). During the early mid to late 1950s, the global production and use of fish oil had increased considerably (especially within countries such as Peru, Norway, and Japan), and a substantial part of the oil was converted into edible food products such as margarine, shortening, and cooking fats (with the exception of the United States; Gauglitz et al., 1974).

Prior to mid 1950s, the global production of fish meal was only about 1 million tonnes per year, reaching 2 million tonnes by 1960, and then production rapidly expanded over the next 20 years (within countries such as Peru, Chile, Norway, Iceland, and Denmark), up to 6–7 million tonnes per year. With the increase in global fish meal production and quality, through technological improvements in production methods, fish meal emerged as the premier protein source in animal feeds, initially almost exclusively for use within terrestrial livestock feeds (poultry, swine, cattle), and from the 1990s increasingly within aquaculture feeds (Hardy and Tacon, 2002).

Table 1 shows the reported use of fish meal and fish oil from published data derived from industry sources within the fish meal and fish oil manufacturing sector. From the data presented, it can be seen that, in the case of fishmeal, the largest consumer in 1988 was within poultry feeds (60%), followed by pig feeds (20%), aquaculture feeds (10%), ruminant feeds (3%), and others (7%). However, by 2006, the situation changed markedly, with aquaculture being the largest consumer (57%), followed by pig feeds (21%), poultry (13%) and others (6%). Similarly, in the case of fish oil, in 1994 (the earliest year for which complete data is available), the largest consumer was for edible food purposes (hydrogenation and use in margarines and shortenings, 68.5%), followed by feed (primarily aquaculture, 24.7%), and pharmaceutical/industrial uses (6.8%). However, by 2002 (the latest year for which complete information exists), the major use of fish oil had changed to aquaculture (81%), followed by edible food purposes (14%), and industrial (5%). The main reason for the above shifts in fish meal and fish oil use has been mainly economic, namely the market price and availability of fish meal and fish oil (depending upon quality), and the generally higher market prices paid for these much sought after nutrient-rich commodities by the aquaculture feed manufacturing sector. However, the future use of these finite and valuable commodities is likely to change yet again in view of the dramatic price increases observed in the case of fish meal between 2005 and 2006 and, more recently, for fish oil between 2007 and 2008 (Figure 6).

In the case of fish meal, prices more than doubled from US $694 per tonne to US $1379 per tonne between July 2005 and July 2006 (Figure 6). The reason for this price increase was due to numerous interconnected factors, including:

1. Reduced landings of pelagics within the major fish meal-producing countries and consequent reduced fish meal production and availability (Peruvian anchoveta landings destined for reduction decreasing by 31.7% from 8.6 to 5.9 million tonnes between 1995 and 2006; PRODUCE, 2007).
2. Increasing price paid for pelagics for fish meal production (prices paid by fish meal factories for anchoveta from fishermen in Peru reportedly increasing from an average of US $80 per tonne to as high as US $220 per tonne).
3. The strong market demand for fish meal by the resident aquaculture and livestock sector within the major importing

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Table 1  Reported global usage of fish meal and fish oil by major user (values given in %)

<table>
<thead>
<tr>
<th>Year</th>
<th>Use</th>
<th>Aquaculture</th>
<th>Poultry feed</th>
<th>Pig feed</th>
<th>Other feeds</th>
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<td>24</td>
<td>29</td>
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<td>22</td>
<td>24</td>
<td>8</td>
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<td>Fishmeal</td>
<td>57</td>
<td>13</td>
<td>21</td>
<td>6</td>
<td>Jackson (2007a)</td>
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<th>Year</th>
<th>Use</th>
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<td>70</td>
<td>711</td>
<td>5</td>
<td>Kilpatrick (2003)</td>
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<td>Fish oil</td>
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<td>34</td>
<td>2612</td>
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<td>19</td>
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<td>Fish oil</td>
<td>8714</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Jackson (2007a)</td>
</tr>
</tbody>
</table>

1Includes 3.0% ruminants; 2Includes 3.0% ruminants, 1% fur; 3Includes 2.5% ruminants, 1.5% fur; 4Includes 5.0% ruminants; 5Includes 3.0% ruminants; 6Includes 2.0% ruminants; 7Includes 1.0% ruminants; 8Includes refined and hydrogenated or hardened fish oil used in margarines and shortenings; 9Includes industrial and pharmaceutical uses; 10Small amounts of hydrogenated fish oils reportedly used in calf milk replacer feeds (Pike, 1998); 11Includes 1.0% refining/pharmaceutical; 12Includes 2.0% refining/pharmaceutical; 13Includes 5.0% industrial, 1.0% refining, 2.0% nutraceutical; 14Total use of fish oil in aquafeeds in 2006 reported as 783,000 tonnes, and 117,000 tonnes or 13% used direct human consumption, land animal feeds and industrial purposes: Jackson, 2007a).
(IFFO, 2007b, 2008a, 2008b), with fish oil currently being a more valuable commodity than the protein meal. Clearly, with fish oil prices now being double what they were a year ago, the continued use of fish oil as a relatively inexpensive source of dietary energy within compound aquafeeds (as in the case of salmonid diets which consumed over 55% of the fish oil used by the aquaculture sector in 2006; Jackson, 2007) will no longer be economically sustainable in the long run.

OTHER NON-FOOD USES OF SMALL PELAGIC FORAGE FISH

In contrast to capture fisheries landings destined for reduction, which have not increased since the mid 1980s, the proportion of the catch destined for other non-food uses in fresh and/or wet processed form as animal feed (and to a lesser extent fishing bait) has increased significantly (Figure 3); “other” non-food use landings increased from almost zero in 1985 to 13.14 million tonnes in 2006 or 39.5% of total reported non-food use landings for that year (FAO, 2008b). As mentioned previously, the bulk of these landings are small pelagic forage fish species and, in particular, “low value/trash fish species” from Asia (Funge-Smith et al., 2005).

Moreover, the rapid growth of “other” non-food fish landings since 1985 mimics very closely the rise in production of those higher value (in marketing terms) aquaculture species currently dependent upon the use of “low value/trash fish” and other small pelagic forage fish as direct feed inputs (Figure 8; Funge-Smith et al., 2005; Edwards et al., 2004; Tacon et al., 2006). For example, finfish species whose production is currently largely based upon the direct use of small pelagic forage fish, either fed alone as a complete natural diet or fed in minced/processed form within farm-made aquafeeds, include most wild-caught marine carnivorous aquaculture species, including tuna (Australia, Croatia, Cyprus, Italy, Lybia, Mexico, Spain, Tunisia; Allan, 2004; Ottolenghi et al., 2004; Van Barneveld and Vandeper, 2007; Zertuche-Gonzalez et al., 2008), yellowtail (Japan: Seriola sp.; Kolkovski and Sakakura, 2007; Nakada, 2000), grouper (China and most Southeast Asian countries: Epinephelus sp.; Ottolenghi et al., 2004; Sim et al., 2005), barramundi (Thailand: Lates calcarifer; Thongrod, 2007; Sim,
2008), seabream (Pagrus sp.), snapper (Lutjanus sp.), flounder (Paralichthys sp.), croaker (Larimichthys sp.), pompano (Trachinotus sp.), and cobia (Rachycentron canadum, China and most Southeast Asian countries; De Silva et al., 2008; Hung and Huy, 2007; Kim et al., 2007; Mao et al., 2007; Sim, 2008).

In the case of Pangasius catfish farming in Vietnam (with production at 825,000 tonnes in 2006, and expected to reach over 1.0 million tonnes in 2007), it is estimated that 30% to 50% of farmers use farm-made aquafeeds, of which 80% use “low value/trash fish” as the main ingredient (Nguyen, 2007). Similarly, the production of cultured ornate spiny lobster (Panulirus ornatus) in Vietnam is expected to have exceeded 1500 tonnes in 2005/2006 and was fed exclusively on forage feed fish from 0.3 g (wild-caught seed) to market size (950 g) over a 18–22 culture period, with a reported feed conversion ratio (FCR) of 40–45:1 (Thuy et al., 2007). On the basis of this reported FCR, the lobster industry in Vietnam consume approximately 60,000 to 67,500 tonnes of forage feed fish. De Silva and Phillips (2007) estimated that over 90% of the marine fish farms in Vietnam use forage feed fish as the main direct feed (with less than 10% using farm-made feeds), and calculate that nearly one million tonnes of trash fish is currently being used as direct feed in aquaculture in Vietnam.

Other aquaculture species that are also currently routinely being fed on forage feed fish include wild-caught spiny lobster (China, Vietnam: Panulirus sp. Stimsoni; Chen et al., 2000; Hung and Huy, 2007; Mao and Tuan, 2007; Thuy et al., 2007), mangrove crab (most Southeast Asian countries, Kenya: Scylla serrata; De Silva et al., 2008; Marichamy and Rajapackiam, 1999; Mwaluma, 2002), spotted babylon (China, Thailand, Vietnam: Babylonia areolata; De Silva et al., 2008), snakehead (Chana sp.; De Silva et al., 2008), and catfish (Vietnam: Pangasius sp.; Hung and Merican, 2006; Nguyen, 2007; Phu et al., 2007).

Among the different aquaculture species currently dependent upon the use of forage feed fish, wild-caught tuna (Thunnus sp.) stand out as being particularly dependent, and at the same time one of the most lucrative to farm. For example, Huntington (2008) estimated that the tuna fattening farms in the Mediterranean area consumed 225,000 tonnes of forage feed fish in 2004, with the global usage, including Mexico and Australia, estimated at between 200,000 to 300,000 tonnes in 2006 for the production of about 15,000 tonnes of tuna. According to FAO, total tuna aquaculture production was reported as 14,624 tonnes in 2006 (Mexico 32.4%, Australia 24.7%, Croatia 15.8%, France 8.5%, Spain 6.6%, others 12.0%) and valued at over US $163.3 million, with tuna production being the top aquaculture commodity by value in Croatia in 2006, and the second most valuable aquaculture commodity after shrimp and salmon in Mexico and Australia, respectively (FAO, 2008a).

With the exception of the tuna fattening operations in Mexico, the Mediterranean, and the North African region, the direct use of “low value/trash fish” and other small pelagic fish as aquaculture feed is currently restricted to the Asia and Pacific region, where over 92% of total global aquaculture production is currently realized; the major producers of high-value aquaculture species in 2006 include China (65.5% total), followed by Vietnam (10.1%), Japan (5.5%), Thailand (4.6%), Indonesia (3.2%), India (2.4%) and the republic of Korea (1.9%; FAO, 2008a).

Notwithstanding the lack of official published information concerning the direct use of “low value/trash fish” and other small pelagic forage fish species as aquaculture feed, it is estimated that the total use in aquaculture was between 5.6 and 8.8 million tonnes in 2006 (mean 7.2 million tonnes); China alone reportedly consumed 4 to 5 million tonnes in 2005 (Jin, 2006), which may explain, in part, the reported current lack of raw material for processing currently experienced by fish meal manufacturing plants along the coast of China (IFFO, 2007a). Similarly, between 176,000 to 364,000 tonnes of low “value/trash fish” was estimated to be used in Vietnam as aquaculture feed in 2003 (Edwards et al., 2004), with 131,931 tonnes of trash fish consumed by seabass and grouper culture in Thailand in 2004 (Thongrod, 2007).

Interestingly, the above global estimate is within the total landings reported by FAO for “other” non-food fish landings of 13.14 million tonnes in 2006 (FAO, 2008a). However, the current estimates are significantly higher than those reported by De Silva et al. (2008), who estimated that the total use of “low value/trash fish” within the Asia Pacific region in 2004 was between 1.60 and 2.77 million tonnes. To a large extent, these differences are due to data reported for China; the value estimated for China in the current article estimated at between 4 and 6 million tonnes, and being in line with the 4 to 5 million tonne estimate for 2005 reported by the representative of the International Fish meal and Fish Oil Organization (IFFO) in China (Jin, 2006).

In addition to aquaculture, a significant proportion of the “other” non-food catch is also destined for use as fishing bait and within other animal feeds, including pet foods. However, as with aquaculture, no official statistical information exists concerning the total global usage by these sectors. Notwithstanding, a limited amount of information does exist for certain countries. For example, in South Africa it has been estimated that about 60,000 to 70,000 tonnes of the Southern African pilchard catch is canned for human consumption, and the remainder (130,000 tonnes) is packed and used as bait in the tuna pole fishery (local and foreign), in the recreational fishery, and also exported for use as feed for tuna fattening operations (Hecht and Jones, 2008). Similarly, in the U.S., 99% of the total reported anchovy catch (Anchoa mitchilli; 25,163 tonnes landed in 2006) was reportedly used for bait (NMFS, 2007b), and a total 210,000 tonnes of total U.S. fisheries landings (4.9% of domestic landings) destined in fresh or frozen form for use as bait and animal food. A further 24,000 tonnes of canned products were also produced in 2006 for use as bait and animal feed (presumably pet food). Moreover, although no statistical data is available, Atlantic menhaden (Brevoortia tyrannus) is also reportedly used as bait in commercial blue crab, lobster, crayfish, and eel fisheries. In addition, Elliot (2006) reports that
the Atlantic herring (Clupea harengus) is the major source of lobster bait in the U.S., and 90% of the bait used in Maine, with an estimated 50,000 to 60,000 tonnes used annually for the harvest of approximately 35,000 tonnes of adult lobsters. Other important U.S. commercial fisheries employing bait fish include the Alaska King crab fishery and spiny lobster fishery (O’Malley, 2004).

Finally, another rapidly growing market for small pelagic forage fish and fishery byproducts is the pet food industry; Australia alone in 2003 imported 33,600 tonnes of fish for the production of canned and dry pet foods, primarily for cats. Moreover, De Silva et al. (2008) have estimated, on the basis of a series of generalized assumptions, that the pet food sector globally currently uses the equivalent of 2.43 million tonnes of fish within canned pet foods and 2.9 million tonnes of fish within dry pet foods and for fur animals. However, these estimates appear to be high and remain to be confirmed through direct surveys.

**AQUACULTURE FISH-IN FISH-OUT BALANCE SHEET, AND CONCLUDING REMARKS**

In terms of landed fish supply for direct human consumption, capture fisheries and aquaculture produced 58.71 and 51.67 million tonnes of food fish in 2006, respectively (live weight equivalent; Figure 3). However, aquaculture’s production was achieved through the consumption of about 23.8 million tonnes of small pelagic forage fish in the form of feed inputs in 2006, including 3.72 million tonnes of fish meal and 0.83 million tonnes of fish oil within industrially compounded aquafeeds (equivalent to the consumption of 16.6 million tonnes of small pelagic forage fish; Tacon and Metian, 2008) and a mean value of 7.2 million tonnes of “low value/trash fish” as a direct feed or within farm-made aquafeeds (Figure 9). In this figure, values to the left of the central dotted line refer to non-food uses of captured fish for animal feeding (including use within aquafeeds; shaded in red), whereas values to the right of the dotted line refer to direct food use of captured fish and landed aquaculture products (shaded in yellow).

While there is no doubt of the economic viability of aquaculture production systems based on the use of fishery resources as feed inputs, there is growing concern about the long-term sustainability of aquaculture production systems dependent upon the use of wild fishery resources as feed inputs (Deutsch et al., 2007; FAO, 2008c; Naylor et al., 1998, 2000; Tacon et al., 2006). The segments of the aquaculture sector currently most dependent upon fishery resources as feed inputs are primarily those engaged in the production of higher-value (in marketing terms) crustacean and carnivorous finfish species, either through the use of industrially compounded aquafeeds containing high levels of fish meal and fish oil (including salmonids, marine shrimp, marine finfish, eels; Tacon and Metian, 2008), or through the direct use of “low-value/trash fish” either fed alone or within farm-made aquafeeds (including marine fish and some freshwater fish, primarily within the Asian region; FAO, 2008c; Funge-Smith et al., 2005; Hung and Huy, 2007; Merican, 2005; Sim, 2008).

In the case of fish meal and fish oil, it is generally accepted that future dietary inclusion levels within compound aquafeeds (and animal feeds in general) will decrease in the long run as wild supplies diminish and become tighter and the market price for these commodities increases (Tacon and Metian, 2008), with dietary inclusion levels being reduced to supplying the necessary minimum essential dietary nutrients for the target species as high-value key nutrient additives rather than as major dietary sources of proteins and lipids, respectively. Dietary substitution of fish meal and fish oil with alternative feed ingredient sources will be considerably easier for herbivorous/omnivorous aquaculture and terrestrial species than for the more nutritionally demanding carnivorous aquaculture and terrestrial animal species. Notwithstanding, fish meal and fish

![Figure 9](https://via.placeholder.com/150)

**Figure 9** Flow of fish products through direct and indirect human use in 2006 (values given in million tonnes and calculated from FAO, 2008a). Compound aquafeed-based aquaculture production (with feeds containing fish meal and fish oil) include all marine shrimp and finfish, salmonids, non-filter feeding Chinese carps, eels, tilapia, milkfish, freshwater crustaceans, catfish, and other miscellaneous freshwater fish species. Low value/trash fish-based aquaculture production includes species listed in Figure 8. All other finfish and shellfish aquaculture production includes non-capture fisheries-dependent species, including filter feeding fish (silver carp, bighead carp, catla, rohu), molluscs, and all other production not identified down to the species level.
oil are not essential feed ingredients *per se*, but rather have represented cost-effective providers of high-quality animal protein and marine lipids packaged in near ideal nutritional proportions for most carnivorous and omnivorous high-value aquaculture species.

Concerning the use of “low-value/trash fish,” substitution with alternative feed ingredients and dry diet-based feeding regimes will be more troublesome and will take longer. However, the current widespread use of forage feed fish-based feeding regimes in the Asian region, particularly for the higher value carnivorous marine fish and crustacean species, is very similar to how the salmon farming industry started in Norway in the early 1970s (Talbot and Rosenlund, 2002), the first farmed Atlantic salmon (*Salmo salar*) being fed raw fish in the 1970s, and the industry then progressing to the development of semi-moist and dry pelleted feeds in the 1980s, to the use of high-energy extruded pelleted feeds in the 1990s and 2000s (Figure 10). Of particular importance is the fact that, as a result of these feed technology advancements (see also Kearns, 2005; Larrain et al., 2005), fish growth has increased, and fish production costs and FCRs have reduced for the farmer.

The main reasons why farmers in China and the Asian region reportedly prefer to use forage feed fish as a direct feed is the belief that the cost is lower than that of using pelleted feed; the reported cost of feeding with trash fish (forage feed fish) in China is approximately US $1.5/kg fish produced (Chen et al., 2007). Similarly, according to Hung and Merican (2006), average production costs for catfish in Vietnam are higher if fish are fed pelleted feed (VND 8000–11,000/kg) and lower if fed farm-made feeds (VND 400–1000/kg). In fact, the same authors believe that the increased use of trash fish (forage fish) in farm-made feeds is driven to a large extent by the drive of farmers to reduce production costs so as to remain profitable, especially when catfish farm prices are low and demand from fish processors is low. In fact, the demand for forage feed fish is such that some farmers have resorted to the use of poorer quality forage fish sources (sometimes 7–10 days old) and byproducts from fish processing factories (presumably from the same species).

As with the development of feeds for the salmon industry, it is believed that wet forage feed fish-based feeding regimes will be gradually replaced with dry compound pelleted and/or extruded feed-based feeding regimes, with transfer from wet/moist feeds to dry feeds being most rapid for those species where cost-effective hatchery feeding technologies have already been developed for seed production, and the species can be conditioned to the use of dry feeds at an early age. As observed with fish meal and fish oil, the speed of dietary substitution or transfer over to dry feeds in the case of forage feed fish will be governed in the short term mainly by economic factors, and primarily by increasing fuel and forage fish prices—the latter due to diminishing supplies on the one hand and increasing competition for a shrinking resource on the other, and consequent increasing price volatility.

In the long term, however, other factors could also play a role in dictating the speed of transfer over to dry pellet feeding and to reduced dependence upon forage feed fish, including (1) increased environmental pollution effects due to the use of forage feed fish-based feeding regimes (Chen et al., 2007; Merican, 2005; Ottolenghi et al., 2004; Sim et al., 2005; Xu et al., 2007), (2) increased biosecurity and disease risks of feeding unpasteurized forage fish products back to cultured fish (Anon, 2005; Gill, 2000; Kim et al., 2007; Merican, 2005; Sim et al., 2005), (3) increased competition with other non-food users for available forage fish resources, including the pet food and fishing/bait sector, and (4) increased competition with humans as an affordable food source (Edwards et al., 2004).

Moreover, since the dietary nutrient requirements of many of the cultured marine fish and crustacean species in Southeast Asia are still poorly understood (Boonyaratpalin, 1997), the development and market availability of appropriate cost-effective
compound feeds for many of these species (including crabs and lobsters) is still in its infancy, and, as such, the continued use of forage feed fish as the preferred feed by farmers will continue in the short term until this is resolved.

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**REFERENCES**


Jackson, A. J. Challenges and opportunities for the fishmeal and fish oil industry. **Feed Technol. Update, 2:** 9 (2007a).


