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Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects

Albert G.J. Tacon [a,*], Marc Metian [b]

[a] Aquatic Farms Ltd, 49-139 Kamehameha Hwy, Kaneohe, HI 96744, USA
[b] Hawaii Institute of Marine Biology, University of Hawaii, Kaneohe, P.O. Box 1346, Kaneohe, HI 96744, USA

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ABSTRACT

The finfish and crustacean aquaculture sector is still highly dependent upon marine capture fisheries for sourcing key dietary nutrient inputs, including fish meal and fish oil. This dependency is particularly strong within compound aquafeeds for farmed carnivorous finfish species and marine shrimp.

Results are presented concerning the responses received from a global survey conducted between December 2006 and October 2007 concerning the use of fish meal and fish oil within compound aquafeeds using a questionnaire sent to over 800 feed manufacturers, farmers, researchers, fishery specialists, and other stakeholders in over 50 countries. On the basis of the responses received, it is estimated that in 2006 the aquaculture sector consumed 3724 thousand tonnes of fish meal (68.2% total global fish meal production in 2006) and 835 thousand tonnes of fish oil (88.5% total reported fish oil production in 2006), or the equivalent of 16.6 million tonnes of small pelagic forage fish (using a wet fish to fish meal processing yield of 22.5% and wet fish to fish oil processing yield of 5%) with an overall fish-in fish-out ratio of 0.70. At a species-group level, calculation of small pelagic forage fish input per unit of farmed fish or crustacean output showed steadily decreasing fish-in fish-out ratios for all cultivated species from 1995 to 2006, with decreases being most dramatic for carnivorous fish species such as salmon (decreasing from 7.5 to 4.9 from 1995 to 2006), trout (decreasing from 6.0 to 3.4), eel (decreasing from 5.2 to 3.5), marine fish (decreasing from 3.0 to 2.2) and to a lesser extent shrimp (decreasing by 1.9 to 1.4 from 1995 to 2006. Net fish producing species in 2006 (with fish-in fish-out ratios below 1), included herbivorous and omnivorous finfish and crustacean species, including non-filter feeding Chinese carp (0.2), milkfish (0.2), tilapia (0.4), catfish (0.5), and freshwater crustaceans (0.6).

On the basis of increasing global fish meal and fish oil costs, it is predicted that dietary fish meal and fish oil inclusion levels within compound aquafeeds will decrease in the long term, with fish meal and fish oil usage increasingly being targeted for use as a high value specialty feed ingredient for use within higher value starter, finisher and broodstock feeds, and by so doing extending supply of these much sought after and limited feed ingredient commodities.

1. Dependency of aquaculture on external feed inputs, including fishery resources

Aquaculture, the farming of aquatic plants and animals, is no different from any other terrestrial farming activity in that production is totally dependent upon the provision and supply of nutrient inputs. In the case of farmed aquatic plants and bivalve mollusks (29.2 million tonnes or 43.7% of total global aquaculture production in 2006: FAO, 2008a), these nutrient inputs are usually supplied in the form of dissolved mineral salts or wild planktonic food organisms, respectively. However, in the case of the other 37.5 million tonnes or 56.3% of aquaculture production in 2006 (mainly fish and crustaceans; FAO, 2008a), these nutrients are either supplied through the consumption of natural food organisms produced within the culture system for the target species or through the direct external application of feed inputs. Feed inputs may include the use of industrially compounded aquafeeds, farm-made aquafeeds, or the use of natural food organisms of high nutrient value such as forage/trash fish and natural/cultivated invertebrate food organisms; feeds and feeding usually representing the largest operating cost item of most fish and crustacean farming operations (FAO, 2006). Clearly, if the finfish and crustacean aquaculture sector is to sustain its current growth rate of 8.5% per year (the sector growing over 115-fold from 322,765 tonnes in 1950 to 37,109,751 tonnes in 2006: FAO, 2008a), then it follows that the supply of feed inputs will also have to grow at similar rates so as to meet demand. Nowhere is this supply more critical than with the current dependency of the export oriented fish and crustacean aquaculture sector upon capture fisheries for sourcing feed inputs, including fish

* Corresponding author. Tel.: +1 808 239 2929; fax: +1 808 239 8426.
E-mail address: agjtacon@aol.com (A.G.J. Tacon).

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Table 1
Countries who responded to the Lenfest aquafeed questionnaire and the contribution of these countries toward total reported aquaculture production in 2006 within their respective regions (FAO, 2008)

Asia Pacific	Europe	Americas	Africa
Australia	Denmark	Brazil	Egypt
China	France	Canada	Madagascar
India	Germany	Chile	Namibia
Indonesia	Greece	Colombia	Nigeria
Japan	Ireland	Costa Rica	South Africa
Korea Rep	Israel	Ecuador	
New Caledonia	Italy	Honduras	
Philippines	Norway	Mexico	
Taiwan	Spain	Peru	
Thailand	Turkey	USA	
Vietnam	UK		
Total aquaculture production in 2006 61,591,670 tonnes	Total aquaculture production in 2006 2,167,084 tonnes	Total aquaculture production in 2006 2,227,923 tonnes	Total aquaculture production in 2006 760,036 tonnes
11 country responses 58,680,582 tonnes or 95.3% region total	11 country responses 1,976,266 tonnes or 91.2% region total	10 country responses 2,118,488 tonnes or 95.1% region total	5 country responses 697,293 tonnes or 91.7% region total

meal and fish oil (Naylor et al., 1998, 2000; Tidwell and Allan, 2001; FAO, 2006; Kristofersson and Anderson, 2006; Tacon et al., 2006; Deutsch et al., 2007).

The present paper attempts to review the use of fish meal and fish oil within industrially compounded aquafeeds, including constraints and future prospects. The information contained in this review was obtained from the responses received from a global survey conducted between December 2006 and October 2007 using an electronic questionnaire concerning the use of fish meal and fish oil within compound aquafeeds sent to over 800 feed manufacturers, farmers, researchers, fishery specialists, and other stakeholders in over 50 countries. Information had been received from over 200 respondents from over 37 countries; the combined aquaculture production from these countries in 2005 representing over 95% of total global aquaculture production (Table 1). Although a response rate of 25% may appear to be low, it is not when one considers that the majority of the information requested is not generally reported in official government statistical reports and is usually considered as being sensitive and proprietary in nature by the aquaculture sector and feed industry.

2. Compound aquafeed production and major fed species

The result of the survey concerning estimated compound aquafeed production and fish meal and fish use, including reported feed conversion ratio of the major cultivated species groups within the major aquaculture producing countries is shown in Tables 2 and 3, respectively. When information was lacking, relevant published information was used whenever possible. The data requested and collected were for 2006, unless otherwise stated, and represented observed ranges and means (in parenthesis; for Table 3 only) for each of the above named parameters.

Reported total compound aquafeed production in 2006 within the 36 reporting countries was between 20.2 and 22.7 million tonnes, with the top ten country producers including China (11.0–12.0 million tonnes), Thailand (1.1–1.3 million tonnes), Chile (1.1–1.2 million tonnes), Norway (940,000–960,000 tonnes), Indonesia (750,000–900,000 tonnes), USA (750,000–850,000 tonnes), Vietnam (650,000–850,000 tonnes), Japan (650,000–800,000 tonnes), Philippines (350,000–400,000 tonnes), and Taiwan (ROC: 340,000–350,000 tonnes). The above value for total reported compound aquafeed production is in line with the estimate of Gill (2007) for 2006; total aquafeed production estimated at 4% of total global animal feed production in 2006 at 25.4 million tonnes.

The major reported cultivated species groups fed compound aquafeeds in 2006 were (in order of total feed production of 20.2 to 22.7 million tonnes), non-filter feeding Chinese carp species (31.1 to 41.6%), marine shrimp (12.5 to 16.6%), salmon (8.5 to 8.8%), tilapia (8.2 to 10.7%), catfish (6.4 to 6.6%), marine finfish (6.0 to 7.1%), trout (2.6 to 2.7%), eel (1.5 to 1.7%), milkfish (1.6%), and freshwater crustaceans (0.4 to 0.5%: Table 3).

3. Fish meal and fish oil use in compound aquafeeds

The results of the global survey concerning the current estimated use of fish meal (FM) and fish oil (FO) within compound aquafeeds for the major cultivated species groups, including reported feed conversion ratio (FCR), are shown in Table 3. Of particular note was the wide variation observed concerning dietary fish meal and fish oil use within and between countries for the same species, including: shrimp (FM use range 5 to 40%, FO use range 0.5 to 10%), salmon (FM 20 to 50%, FO 9 to 35%), trout (FM 15 to 55%, FO 3 to 40%), eel (FM 40 to 80%, FO 0 to 24%), marine fish (FM 7 to 70%, FO 1 to 15%), tilapia (FM 0 to 20%, 0 to 10%), milkfish (FM 1 to 5%, FO 0 to 2), freshwater prawns (FM 5 to 25%, FO 0 to 3%), Chinese carps (FM 0 to 20%, FO 0 to 2%), and catfish (FM 3 to 40%, FO 0 to 15%; Table 3).

To a large extent these variations reflect the differences within and between countries regarding the production systems employed

Table 2
National responses regarding total estimated compound aquafeed production within the reporting countries (values given tonnes, as fed basis)

Country	Year	Compound feed production estimate (tonnes)
Australia	2006–2007	40,000–60,000
Brazil	2006–2007	200,000–250,000
Canada	2006–2007	150,000–200,000
Chile	2006–2007	1,000,000–1,200,000
China	2005–2006	11,000,000–12,000,000
Colombia	2006	80,000–120,000
Costa Rica	2006–2007	15,000–20,000
Denmark	2006	40,000–45,000
Ecuador	2006	225,000–250,000
Egypt	2005–2006	200,000–300,000[1/]
France	2006	50,000–70,000
Germany	2005–2006	30,000–50,000
Greece	2006	225,000–250,000
Honduras	2006–2007	100,000–120,000
India	2006	200,000–250,000[2/]
Indonesia	2006	750,000–900,000[3/]
Ireland	2005–2006	15,000–20,000
Israel	2006	25,000–30,000
Italy	2006–2007	75,000–85,000
Japan	2006	650,000–800,000[4/]
Korea Rep.	2006	150,000–160,000
Madagascar	2006	18,000–20,000
Mexico	2006–2007	200,000–250,000
New Caledonia	2006	3,600–5,000
Nigeria	2006	10,000–12,000
Norway	2006	940,000–960,000
Peru	2006	20,000–25,000
Philippines	2006	350,000–400,000[5/]
South Africa	2006	1,500–2,000
Spain	2006	100,000–105,000
Taiwan	2006	340,000–350,000
Thailand	2006	1,100,000–1,300,000[6/]
Turkey	2006	190,000–200,000
UK	2006–2007	200,000–250,000
USA	2006	750,000–850,000
Vietnam	2006	650,000–850,000
Total	2006	20,068,100–22,734,000

[1/]Total compound aquafeed production in Egypt estimated at 250,000 tonnes (El-Sayed, 2007); [2/]Suresh (2007); [3/]Total aquafeed requirement in 2005 estimated at 590,100 tonnes (Nur, 2007); [4/]Includes both dry compound and semi-moist compound feeds; [5/]Total compound aquafeed production in 2003 reported as 204,395 tonnes (Sumagaysay-Chavoso, 2007); [6/]Estimated total compound aquafeed production in 2005 reported as 1.07 million tonnes (Thongrod, 2007).

Table 3
Country responses regarding compound feed production, reported feed conversion ratio, and estimated fish meal and fish oil use for major cultivated species groups (values represent country ranges and means in parentheses for 2006, unless otherwise stated)

Country	Feed produced (tonnes)	Reported FCR[1/]	Fish meal use %	Fish oil use %
Shrimp (includes *Penaeus vannamei, P. monodon, P. merguiensis, P. japonicus, P. chinensis, P. indicus, P. stylirostris, Metapenaeus ensis*: FAO, 2008a)				
Australia	6000–8000	1.6–2.4 (2.0)	20–40 (30)	4–10 (8)
Brazil	65,000–74,000	1.2–2.0 (1.8)	5–25 (15)	2–4 (3)
China[2/]	650,000–1,440,000	–	20–30 (25)	1–2 (2)
Colombia	24,000–43,000	1.6–1.7 (1.6)	15–30 (22)	4.8
Costa Rica	3000–4000	1.3–1.8 (1.6)	12–15 (13)	3–4 (3.5)
Ecuador	130,000–190,000	1.0–1.4 (1.2)	15–25 (20)	2–5 (3)
Honduras	30,000–40,000	1.6–2.0 (1.8)	5–12 (10)	1–5 (3)
India	165,000–200,000	1.2–3.0 (1.7)	20–30 (25)	1–3 (1.5)
Indonesia[3/]	312,000–400,000	1.4–1.8 (1.6)	8–20 (15)	1–3 (2)
Korea Rep.	5000–7000	1.5–2.0 (1.7)	20–30 (25)	3
Madagascar	19,000	2.35	38	–
Mexico	170,000–210,000	1.2–2.3 (1.9)	8–40 (16)	1–4 (3)
New Caledonia	5000	1.8–2.5 (2.1)	20–30 (25)	1–2 (1)
Peru	13,000–18,000	1.3–1.8 (1.6)	15–35 (20)	1–3 (2)
Philippines (06/07)[4/]	15,000–30,000	1.2–1.8 (1.5)	10–30 (20)	4–6 (5)
Taiwan	4160	1.2–1.8 (1.6)	25–35 (30)	2–3 (2.5)
Thailand[5/]	650,000–750,000	1.2–2.0 (1.5)	5–35 (25)	0.5–3 (2)
USA	6,000–7,000	1.5–2.2 (2)	5–20 (15)	1–8 (4)
Vietnam	260,000–310,000	1.2–1.8 (1.6)	10–30 (20)	1–3 (2)
Global average	2,532,160–3,759,160	1.1–3.0 (1.7)	5–40 (20)	0.5–10 (2)
Salmon (includes *Salmo salar, Oncorhynchus kisutch, O. tshawytscha*: FAO, 2008a)				
Australia (2007)	36,450	1.4–1.6 (1.5)	20–35 (25)	9–20 (12)
Canada	125,000–150,000	1.2–1.4 (1.3)	25–50 (30)	14–30 (18)
Chile	600,000–700,000	1.2–1.4 (1.3)	20–45 (28)	14–24 (17)
Japan (2005)	15,477–16,403	1.2–1.3 (1.25)	–	–
Norway	834,253–844,400	1.0–1.4 (1.2)	25–40 (31)	15–30 (21)
UK	160,000–190,000	1.2–1.5 (1.3)	25–46 (36)	20–35 (28)
Global average	1,771,180–1,937,253	1.0–1.6 (1.25)	20–50 (30)	9–35 (20)
Trout (includes *Oncorhynchus mykiss, Salvelinus fontinalis, Salmo trutta*, FAO, 2008a)				
Australia (2007)	5630	1.4–1.7 (1.6)	15–35 (23)	9–13 (10)
Canada (2005)	6000–7000	1.2–1.3 (1.25)	30–50 (40)	15–30 (22)
Chile (2007)	150,000	1.4	23–45 (29)	15
Colombia	6750	1.35	15–30 (25)	8–10 (9)
Costa Rica	4000	2.0	20–25 (22)	3–5 (4)
Denmark	34,000–41,000	0.8–1.2 (1.0)	25–50 (35)	5–20 (15)
France	34,000–55,000	0.8–1.4 (1.1)	15–45 (30)	5–25 (15)
Germany (2005/06)	28,800	1.2	45	24
Greece	5500	1.5–2.0 (1.8)	25–40 (30)	10–12 (11)
Ireland (2005)	1900	1.2	30–45 (38)	30–40 (35)
Italy (2007)	43,000	1.0–1.2 (1.1)	45–55 (50)	12–20 (16)
Korea Rep	4820	1.1–1.5 (1.3)	25–50 (35)	13
Mexico (2006/07)	4200	1.5	25	9
Norway	89,100–92,695	1.1–1.3 (1.2)	20–35 (31)	15–30 (18)
Peru	6460	1.1–1.4 (1.25)	30–40 (35)	4–7 (5)
Spain	30,000	1.0	20	15
Turkey	40,500	0.7–1.2	30–55 (35)	8–15 (13)
UK (2007)	20,000	1.1	25–45 (30)	25–35 (30)
USA	39,000	1.3	20–30 (24)	4–10 (8)
Global average	553,660–586,255	0.7–2.0 (1.25)	15–55 (30)	3–40 (15)
Eel (includes *Anguilla japonica, A. Anguilla, A. australis*: FAO, 2008a)				
China[2/]	233,000–316,000	–	50–60 (55)	0[6/]
Denmark	2500–3000	1.0–2.5 (1.4)	40–60 (48)	10–24 (18)
Korea Rep.	15,320	1.2–1.7 (1.4)	50–80 (60)	5
Taiwan	47,600	1.3–2.0 (1.7)	55–65 (60)	3–4 (3.5)
Global average	298,420–381,920	1.0–2.5 (1.5)	40–80 (55)	0–24 (5)
Marine finfish (includes *Seriola quinqueradiata, Lateolabrax japonicus, Sparus aurata, Pagrus auratus, Larimichthys croceus, Bothidae, Dicentrarchus labrax, Sciaenops ocellatus, Paralichthys olivaceus, Sebastes schlegeli, Tetraodontidae, Rachycentron canadum, Schuettea scalaripinnis, Gadus morhua, Psetta maxima*; FAO, 2008a)				
Australia (2007)				
– Barramundi	3840	1.0–1.5 (1.3)	20–30 (25)	5–12 (9)
– Yellowtail kingfish	4000	1.8–2.3 (2.1)	22–40 (25)	6–12 (9)
China[2/]				
– Marine fish (all species)	210,000–600,000	–	20–30 (25)	1–5
Egypt (2005)				
– E. seabass/ G. seabream	15,000	1.6–2.4	10–25 (20)	3–6 (4)
France				
– European seabass	9000–12,000	1.6–2.2 (1.9)	20–35 (25)	5–15 (12)
– Gilthead seabream	3,300–4,400	1.5–2.0 (1.7)	20–35 (22)	5–12 (8)
Greece				
– E. seabass/ G. seabream	220,000	1.8–2.5 (2.2)	25–50 (35)	10–12 (11)
Israel				
– European seabass	4000	1.6–2.0 (1.8)	7–17 (12)	1–2 (1.5)
Italy (2007)				
– E. seabass/ G. seabream	30,000–36,000	1.8–2.6 (2.2)	–	–
Japan (2005)				
– Yellowtail	194,614	1.2	–	–
– Red seabream	139,972	1.8	–	–
– Jack mackerel	9662	1.9	–	–
Korea Rep.				
– Olive flounder	27,865	1.5	50–70 (60)	8
– Korean rockfish	36,622	2–3 (2.5)	10–40 (25)	5
– Seabream (silver/black)	22,365	2–3 (2.5)	20–40 (30)	5
– Japanese seabass	3510	2	20–40 (30)	5
– Mullet	17,336	2–3	2–10 (6)	2
Norway				
– Atlantic cod	20,398	0.9–1.4 (1.3)	30–60 (40)	5–15 (10)
Spain				
– Turbot	6270	1.0	40–60 (50)	9–12 (10)
– Gilthead seabream	48,400	2.2	20	13
– European seabass	18,400	2.3	30	16
Taiwan				
– Cobia	5700	1.4–1.6 (1.5)	40–50 (45)	5–6 (5.5)
– Grouper	8400	1.1–1.6 (1.4)	40–50 (45)	6–7 (6.5)
Thailand				
– Barramundi	1173	1.4–3.0 (1.8)	20–50 (35)	2.5–6 (4)
Turkey				
– Gilthead seabream	63,000	1.6–2.2 (1.9)	30–65 (40)	8–13 (12)
– European seabass	88,000	1.8–2.4 (2.1)	30–65 (40)	8–14 (13)
USA				
– Hawaiian yellowtail	280–360	1.4–1.8 (1.6)	35	15
Global average	1,211,107–1,611,287	0.9–3.0 (1.9)	7–70 (32)	1–15 (8)
Tilapia (includes *Oreochromis niloticus, O. mossambicus, O. aureus, O. andersonii, O. spilurus*,: FAO, 2008a)				
Brazil (2007)	40,000	1.4–2.5 (1.7)	2–5 (2.5)	0.1–1 (0.5)
China[2/]	750,000–1,500,000	–	2–5	0–1 (0.5)
Colombia	45,000	1.6	5–15 (10)	2
Costa Rica	10,000	1.85	8–12 (10)	0–3 (1.5)
Ecuador (2005/06)	62,400	2.36	8–12 (10)	3
Egypt (2005)	96,578	1.3–2.6 (1.8)	4–10 (6)	0.5–1 (0.6)
Honduras (2007)	70,000–80,000	1.9–2.1 (2.0)	3–10 (6)	0
Indonesia (2007)	84,000	1.8	3–8 (5)	1–2.5 (1.5)
Israel	12,500	1.4–2.0 (1.7)	3–7 (5)	0
Mexico	12,000	1.8	3	3
Nigeria	6554	1.0–1.8 (1.4)	15	6–10 (8)
Philippines (2007)	175,000	1.4–1.8 (1.6)	7	–
Taiwan	149,400	1.5–2.0 (1.8)	1–2 (1.5)	0
Thailand	151,200	1.3–1.7 (1.5)	0–20 (10)	1–3 (1.5)
Global average	1,664,632–2,424,632	1.3–2.6 (1.7)	0–20 (6)	0–10 (0.5)
Milkfish (*Chanos chanos*: FAO, 2008a)				

Table 3 (*continued*)

Country	Feed produced (tonnes)	Reported FCR[1/]	Fish meal use %	Fish oil use %
Indonesia	30,000–50,000[7/]	1.8	2–5 (3)	0.5–2 (1)
Philippines (2007)	200,000[8/]	1.8–2.7 (2.2)	5	–
Taiwan	102,000	1.6–2.3 (2.0)	1–2 (1.5)	0
Global average	332,000–352,000	1.6–2.7 (2.0)	1–5 (3)	0–2 (1)
Freshwater crustacean (includes *Eriocheir sinensis*, *Macrobrachium nipponense*, *M. rosenbergii*, *Procambarus clarkia, M. malcolmsonii*; FAO, 2008a)				
China	–	–	15–28[9/]	–
India	45,000	1.3–3.0 (1.5)	5–20 (10)	0.5–2 (0.75)
Taiwan	27,720	1.2–1.8 (1.4)	15–25 (20)	0–1 (0.5)
Thailand	21,420	1.5–2.5 (1.7)	5–20 (15)	1–3 (1.0)
Global average	94,140	1.2–3.0 (1.5)	5–25 (15)	0–3 (0.75)
Chinese carps (non-filter feeding Chinese carp species: *Ctenopharyngodon idellus*, *Cyprinus carpio*, *Carassius carassius*, *Parabramis pekinensis*, *Mylopharyngodon piceus;* FAO, 2008a)				
China[2/] total carps	6,000,000–9,000,000			
– Grass carp	–	–	0–3 (1.5)	0[9/]
– Common carp	–	–	3–8 (5)	0[9/]
– Crucian carp	–	–	8–12 (10)	0[9/]
Egypt (2005)				
– Cyprinids nei	69,578	1.3–1.7 (1.5)	4–10 (6)	0.5–1 (0.6)
France				
– Common carp	15,000	1.5–2.5 (2.0)	5–20 (10)	–
Indonesia				
– Common carp	185,000–360,000[10/]	1.4–2.0 (1.7)	2–7 (5)	0.5–2 (1)
Israel				
– Common carp	11,000	1.3–2.1 (1.7)	5–11 (8)	0
Global average	6,280,578–9,455,578	1.3–2.5 (1.8)	0–20 (5)	0–2 (0)
Catfish (includes *Pangasius* spp, *Ictalurus punctatus*, *Silurus asotus*, *C. gariepinus*×*C. macrocephalus*, *Pelteobagrus fulvidraco*, *Clarias gariepinus*, *P.hypophthalmus, Leiocassis longirostris, C. anguillaris, P. pangasius*: FAO, 2008a)				
Indonesia	60,000–70,000[11/]	1.0–1.3 (1.2)	5–10 (7)	1–3 (2)
Korea Rep.	8580	1.2–1.7 (1.5)	10–30 (20)	2
Nigeria	4206	0.9–1.5 (1.2)	30–40 (35)	8–15 (12)
Thailand	113,400	1.2–1.5 (1.4)	5–20 (10)	1–3 (1.5)
USA	750,000	1.8–2.6 (2.2)	3–6 (4)	0–1 (0.5)
Vietnam	400,000–500,000[12/]	1.4–1.8 (1.6)	5–15 (10)	1–2 (1.5)
Global average	1,336,186–1,446,186	0.9–2.9 (1.5)	3–40 (10)	0–15 (1.7)

[1/]Estimated species-group feed conversion ratio (total compound feed fed/species-group production; [2/]Fish meal and aquafeed estimates calculated from the papers of Jin (2006) and Huang (2007), and fish oil estimates from Weimin and Mengqing (2007). However, the paper of Weimin and Mengqing (2007) report fish meal levels ranging from 30% (red sea bream) to 45% (turbot, flounder) for practical marine finfish feeds; [3/]Estimated shrimp requirement in 2005 reported as 342,000 tonnes (Nur, 2007); [4/]Estimated shrimp feed production in 2003 reported as 11,472 tonnes with the shrimp feed sector growing at an average rate of 10% per year since 1996 (Sumagaysay-Chavoso, 2007); [5/]Estimated shrimp feed consumption in 2005 reported as 672,000 tonnes (Thongrod, 2007); [6/]Fish oil estimate from Weimin and Mengqing (2007); [7/]Reported milkfish compound aquafeed requirement in 2005 reported as 42,750 tonnes (Nur, 2007); [8/]Milkfish aquafeed production estimated at 95,173 tonnes in 2003 (Sumagaysay-Chavoso, 2007); [9/]Weimin and Mengqing (2007); [10/]Carp aquafeed requirement in 2005 given as 111,250 tonnes (based on an estimated 30% of total carp production on aquafeeds and an FCR of 1.5: Nur, 2007); [11/]Catfish aquafeed requirement in 2005 given as 40,000 tonnes (based on an estimated 50% of total catfish production on aquafeeds and an FCR of 1.0: Nur, 2007); [12/]Catfish aquafeed production estimated at 300,000–400,000 tonnes in 2004 (Hung and Huy, 2007).

(including stocking density, water management, feed management, natural food availability, etc), specific differences among different species of salmon, trout, shrimp, catfish, carp, marine fish, tilapia, etc, and differences regarding the feeds used (depending upon local fish meal, fish oil and feed ingredient availability, quality and cost, the existence of different national legislative controls regarding imports and/or ingredient use (including subsidies and incentives), and the intended market and market value of the culture species. For example, the United Kingdom reported the highest usage of fish meal and fish oil within salmon feeds in 2006 (36 and 28%, respectively), primarily due to the restrictive demands of the resident national salmon farming associations and major salmon retailers/supermarket chain retailers within the UK concerning the use or not of dietary fish meal and fish oil replacers, including the prohibition of the use of terrestrial animal by-products (including poultry) and genetically modified feed ingredient sources within compound aquafeeds (Strategic Framework for Scottish Aquaculture, Code of Good Practice for Scottish Finfish Aquaculture, 114p. January 2006; http://www.scottishsalmon.co.uk/dlDocs/CoGp.pdf; Tacon, 2005).

Given the above possible variables and observed ranges, the reported mean dietary fish meal and fish oil inclusion levels for the different major species groups are in close agreement (although not always) with those predicted by Tacon et al. (2006) for 2005 and the International Fishmeal and Fish Oil Organization (IFFO) for 2006 (Jackson, 2006, 2007). Thus, the major differences between this study and previous estimates were for 1) marine fish (lower dietary fish meal levels reported in the current study: 32 vs 38%), 2) salmon (higher fish oil levels reported: 20 vs 10%), 3) trout (higher fish meal: 30 vs 18%, higher fish oil: 15 vs 10%), 4) eel ((higher fish meal: 55 vs 40%, higher fish oil: 5 vs 3%), 5) Chinese carp (lower fish oil: 0 vs 1%), 6) tilapia (higher fish meal: 6 vs 3%), and 7) catfish (higher fish meal: 10 vs 2%; Tacon et al., 2006).

On the basis of the above survey and previous estimates by Tacon et al. (2006) and IFFO (Jackson, 2006, 2007), and the anticipated limited future availability and increasing cost of fish meal and fish oil, a table was constructed concerning the current global use and estimated demand for fish meal and fish oil within compound aquafeeds from 1995 to 2020 (Table 4). The new reported data show a significant increase in current fish meal and fish oil use (compared with previous estimates by the author and IFFO) due to increased global trends in aquaculture production, including markedly increased shrimp production in China, Vietnam and Ecuador (and increased fish meal inclusion levels as mentioned above), increased marine finfish production in China (although the percent of compound aquafeeds was reduced due to higher use of trash fish as feed in China), markedly increased catfish production in China and Vietnam, increased freshwater crustacean and carnivorous miscellaneous freshwater fish production in China, and increased proportion of the estimated total tilapia production based on the use of formulated feeds (FAO, 2008a).

From the new data presented in Table 4 it can be seen that the estimated fish meal use within compound aquafeeds increased over two-fold from 1882 thousand tonnes in 1995 (27.5% total reported fish meal production of 6852 thousand tonnes) to a high of 4300 thousand tonnes in 2005 (68.9% total reported fish meal production of 6242 thousand tonnes; FAO, 2008a), thereafter decreasing by 13.4% to 3724 thousand tonnes in 2006 (68.2% total reported fish meal production of 5460 thousand tonnes: FAO, 2008a). This differs significantly with previous estimates of 2666 and 3041 thousand tonnes in 2005 (42.7 and 48.7% total fish meal production in 2005: Tacon et al., 2006 and Jackson, 2006, respectively) and 3055 thousand tonnes in 2006 (55.9% total fish meal production in 2006: Jackson, 2007).

In the case of fish oil, estimated use within compound aquafeeds increased from 474 thousand tonnes in 1995 (34.3% total reported fish oil production of 1382 thousand tonnes) to a high of 843 thousand tonnes in 2005 (93.7% total reported fish oil production of 900 thousand tonnes; FAO, 2008a), thereafter decreasing by 0.6% to 835 thousand tonnes in 2006 (88.5% total reported fish oil production of 943 thousand tonnes in 2006; FAO, 2008a). This differs from previous

Table 4
Estimated global use and demand (thousand tonnes) for fish meal and fish oil within compound aquafeeds 1995–2020

Species-group	Total production[a]	Growth (%/year)[b]	Percent on feeds[c]	Species EFCR[d]	Total feeds used[e]	Mean % fish meal	IFFO % fish meal estimate[f]	Mean % fish oil	IFFO % fish oil estimate	Total fish meal used	IFFO fish meal estimate	Total fish oil used	IFFO fish oil estimate
Shrimp — includes *Penaeus vannamei*, *P. monodon*, *P. merguiensis*, *P. japonicus*, *P. chinensis*, *P. indicus*, *P. stylirostris*, *Metapenaeus ensis*, etc…													
1995	928	5.2	75	2.0	1392	28	–	2.0	–	389.8	–	27.8	–
1996	917	−1.2	75	2.0	1376	27	–	2.0	–	371.4	–	27.5	–
1997	933	1.7	76	2.0	1418	26	–	2.0	–	368.7	–	28.4	–
1998	999	7.1	78	2.0	1558	26	–	2.0	–	405.2	–	31.2	–
1999	1068	6.9	80	2.0	1709	25	–	2.0	–	427.2	–	34.2	–
2000	1162	8.8	82	2.0	1906	25	25.0	2.0	2.0	476.4	372.0	38.1	30.0
2001	1347	15.9	83	2.0	2236	25	–	2.0	–	559.0	–	44.7	–
2002	1496	11.1	85	1.9	2416	25	24.0	2.0	2.0	604.0	545.0	48.3	45.4
2003	2129	42.3	85	1.9	3438	24	23.0	2.0	2.0	825.2	671.0	68.8	58.3
2004	2446	14.9	86	1.8	3786	24	23.0	2.0	2.0	908.7	738.0	75.7	64.1
2005	2716	9.4	89	1.8	4351	24	20.0	2.0	2.0	1044.2	722.0	87.0	72.2
2006	3164	16.5	92	1.7	4948	20	19.0	2.0	2.0	989.7	723.0	99.0	76.1
2007	3544	12.0	93	1.7	5603	18	19.0	2.0	2.0	1008.6	805.0	112.1	84.7
2010	4717	10.0	95	1.6	7170	12	16.0	2.0	2.0	860.4	823.0	143.4	102.8
2015	6930	8.0	95	1.5	9875	8	–	1.5	–	790.0	–	148.1	–
2020	9274	6.0	95	1.4	12,334	5	–	1.0	–	616.7	–	123.3	–
Marine fish — includes *Seriola quinqueradiata, Lateolabrax japonicus, Sparus aurata, Pagrus auratus, Larimichthys croceus, Bothidae, Dicentrarchus labrax, Sciaenops ocellatus, Paralichthys olivaceus, Sebastes schlegeli, Tetraodontidae, Rachycentron canadum, Schuettea scalaripinnis, Gadus morhua, Psetta maxima, etc*…excluding mullets													
1995	498	18.0	50	2.0	498	50	–	15.0	–	249.0	–	74.7	0.0
1996	528	6.0	50	2.0	528	50	–	15.0	–	264.0	–	79.2	0.0
1997	646	22.3	53	2.0	685	50	–	15.0	–	342.4	–	102.7	–
1998	731	13.1	56	2.0	819	48	–	14.0	–	393.0	–	114.6	–
1999	787	7.7	58	2.0	913	46	–	12.0	–	419.9	–	109.6	–
2000	902	14.6	60	2.0	1082	44	45–55	10.0	10–20	476.3	635.0	108.2	249.0
2001	969	7.4	62	2.0	1202	42	–	10.0	–	504.7	–	120.2	–
2002	1064	9.8	65	2.0	1383	41	41.0	8.0	8.0	567.1	576.0	110.7	112.3
2003	1227	15.3	67	2.0	1644	40	40.0	8.0	7.5	657.7	590.0	131.5	110.6
2004	1291	5.2	70	1.9	1717	39	40.0	8.0	7.5	669.6	649.0	137.4	121.7
2005	1462	13.2	70	1.9	1944	36	40.0	8.0	6.0	700.0	671.0	155.6	100.7
2006	1536	5.1	71	1.9	2072	32	38.0	8.0	6.0	663.1	698.0	165.8	110.3
2007	1690	10.0	72	1.9	2311	30	36.0	7.0	6.0	693.4	725.0	161.8	120.8
2010	2128	8.0	73	1.8	2797	24	34.0	6.0	6.0	671.2	882.0	167.8	155.7
2015	3127	8.0	75	1.8	4222	16	–	4.0	–	675.5	–	168.9	–
2020	4185	6.0	80	1.7	5692	8	–	3.0	–	455.3	–	170.8	–
Salmon — includes *Salmo salar, Oncorhynchus kisutch, O. tshawytscha*													
1995	537	20.7	100	1.5	806	45	–	25.0	–	362.5	–	201.0	–
1996	643	19.8	100	1.5	965	44	–	25.0	–	424.4	–	241.0	–
1997	741	15.2	100	1.4	1037	43	–	25.0	–	446.1	–	259.0	–
1998	789	6.5	100	1.4	1105	42	–	24.0	–	463.9	–	265.0	–
1999	910	15.3	100	1.4	1274	41	–	24.0	–	522.3	–	306.0	–
2000	1021	12.2	100	1.3	1327	40	40.0	23.0	25.0	530.9	491.0	305.0	307.0
2001	1201	17.6	100	1.3	1561	39	–	23.0	–	608.9	–	359.0	–
2002	1217	1.3	100	1.3	1582	38	35.0	22.0	26.0	601.2	552.0	348.0	410.0
2003	1259	3.4	100	1.3	1637	37	35.0	22.0	25.0	605.6	573.0	360.0	409.2
2004	1374	9.1	100	1.3	1786	36	35.0	21.0	24.0	643.0	602.0	375.0	412.5
2005	1382	0.1	100	1.3	1797	35	35.0	21.0	23.0	628.8	583.0	376.0	383.1
2006	1465	6.0	100	1.3	1831	30	30.0	20.0	20.0	549.4	525.0	361.0	349.8
2007	1538	5.0	100	1.3	1923	24	28.0	16.0	18.0	461.5	514.0	307.7	330.6
2010	1781	5.0	100	1.3	2226	18	25.0	12.0	15.0	400.7	532.0	267.1	318.9
2015	2273	5.0	100	1.3	2841	12	–	8.0	–	340.9	–	227.3	–
2020	2901	5.0	100	1.3	3626	8	–	6.0	–	290.1	–	217.5	–
Trout — includes *Oncorhynchus mykiss, Salvelinus fontinalis, Salmo trutta*													
1995	392	10.4	100	1.5	588	40	–	20.0	–	235.2	–	118.0	–
1996	421	7.4	100	1.5	632	38	–	20.0	–	240.0	–	126.0	–
1997	473	12.3	100	1.4	662	38	–	18.0	–	251.6	–	119.0	–
1998	491	3.8	100	1.4	687	37	–	18.0	–	254.3	–	124.0	–
1999	475	−3.2	100	1.4	665	37	–	17.0	–	246.1	–	113.0	–
2000	512	7.8	100	1.3	666	36	30.0	17.0	15.0	239.6	189.0	113.0	121.0
2001	570	11.3	100	1.3	741	36	–	17.0	–	266.8	–	126.0	–
2002	566	−0.7	100	1.3	736	35	32.0	16.0	20.0	257.5	234.0	118.0	146.1
2003	568	0.3	100	1.3	738	35	30.0	16.0	17.5	258.4	216.0	118.0	126.1
2004	578	1.8	100	1.3	751	34	30.0	16.0	17.5	255.5	223.0	120.0	129.8
2005	573	−0.9	100	1.3	745	34	28.0	16.0	15.0	253.3	198.0	119.0	105.8
2006	632	10.3	100	1.3	790	30	26.0	15.0	12.0	237.0	193.0	109.0	88.9
2007	683	8.0	100	1.3	853	24	18.0	12.0	10.0	204.8	140.0	102.4	77.8
2010	813	6.0	100	1.3	1016	18	17.0	8.0	8.0	182.9	153.0	81.3	72.0
2015	1038	5.0	100	1.3	1297	12	–	6.0	–	155.6	–	77.8	–
2020	1324	5.0	100	1.3	1655	8	–	4.0	–	132.4	0.0	66.2	–

Table 4 (*continued*)

Species-group	Total production[a]	Growth (%/year)[b]	Percent on feeds[c]	Species EFCR[d]	Total feeds used[e]	Mean % fish meal	IFFO % fish meal estimate[f]	Mean % fish oil	IFFO % fish oil estimate	Total fish meal used	IFFO fish meal estimate	Total fish oil used	IFFO fish oil estimate
Chinese carp species (non-filter feeding) — includes *Ctenopharyngodon idellus*, *Cyprinus carpio*, *Carassius carassius*, *Parabramis pekinensis*, *Mylopharyngodon piceus*													
1995	4924	19.1	20	2.0	1970	10	–	0.0	–	197.0	–	0.0	–
1996	5696	15.7	25	2.0	2848	10	–	0.0	–	284.8	–	0.0	–
1997	6329	11.1	30	2.0	3797	10	–	0.0	–	379.7	–	0.0	–
1998	7010	10.8	35	2.0	4907	10	–	0.0	–	490.7	–	0.0	–
1999	7755	10.6	36	2.0	5584	9	–	0.0	–	502.5	–	0.0	–
2000	8129	4.8	37	2.0	6015	9	5.0	0.0	0.0	541.4	350.0	0.0	0.0
2001	8790	8.1	38	1.9	6346	8	–	0.0	–	507.7	–	0.0	–
2002	9226	5.0	42	1.9	7362	8	5.0	0.0	0.5	589.0	415.0	0.0	41.5
2003	9629	4.4	43	1.9	7867	8	5.0	0.0	0.5	629.4	438.0	0.0	43.8
2004	9423	−2.1	44	1.9	7878	8	5.0	0.0	1.0	630.2	460.0	0.0	91.9
2005	10,026	5.2	45	1.8	8121	8	5.0	0.0	1.0	649.7	480.0	0.0	95.9
2006	10,225	3.1	46	1.8	8466	5	5.0	0.0	1.0	423.3	515.0	0.0	103.0
2007	10,736	5.0	47	1.7	8578	5	4.0	0.0	1.0	428.9	419.0	0.0	104.7
2010	12,429	5.0	50	1.7	10,564	3	4.0	0.0	1.0	316.9	458.0	0.0	114.6
2015	15,862	5.0	55	1.6	13,959	2	–	0.0	–	279.2	–	0.0	–
2020	20,245	5.0	60	1.5	18,220	1	–	0.0	–	182.2	–	0.0	–
Catfish — includes *Pangasius* spp, *Ictalurus punctatus*, *Silurus asotus*, *C. gariepinus*×*C. macrocephalus*, *Pelteobagrus fulvidraco*, *Clarias gariepinus*, *P. hypophthalmus*, *Leiocassis longirostris*, *C. anguillaris*, *P. pangasius* etc (Order Siluriformes)													
1995	345	5.5	85	2.0	587	5	–	1.0	–	29.3	–	5.9	–
1996	396	14.8	85	2.0	673	4	–	1.0	–	26.9	–	6.7	–
1997	488	23.2	83	2.0	810	3	–	1.0	–	24.3	–	8.1	–
1998	462	−5.3	83	1.9	729	5	0.0	1.0	–	36.4	–	7.3	–
1999	540	16.9	81	1.9	831	7	–	1.0	–	58.2	–	8.3	–
2000	527	−2.4	81	1.8	768	8	3.0	1.0	1.0	61.5	15.0	7.7	5.0
2001	557	5.7	79	1.8	792	8	–	1.2	–	63.4	–	9.5	–
2002	663	19.0	77	1.7	868	10	3.0	1.4	1.0	86.8	22.0	12.2	7.3
2003	1076	62.3	75	1.7	1372	10	3.0	1.4	1.0	137.2	24.0	19.2	8.0
2004	1319	22.6	75	1.6	1583	12	2.0	1.5	1.0	189.9	17.0	23.7	8.6
2005	1572	19.2	73	1.6	1836	12	2.0	1.5	1.0	220.3	18.0	27.5	8.8
2006	1809	15.1	71	1.5	1927	10	2.0	1.7	1.0	192.7	18.0	32.8	9.2
2007	2080	15.0	72	1.5	2247	8	2.0	1.7	1.0	179.7	19.0	38.2	9.7
2010	2923	12.0	73	1.5	3200	6	2.0	1.6	1.0	192.0	22.0	51.2	10.9
2015	4707	10.0	75	1.4	4942	3	–	1.4	–	148.3	–	69.2	–
2020	6916	8.0	80	1.3	7193	2	–	1.0	–	107.9	–	71.9	–
Eel — includes *Anguilla japonica*, *A. Anguilla*, *A. australis*													
1995	188	0.0	90	2.0	338	65	–	8.0	–	220.0	–	27.1	–
1996	234	24.5	90	1.9	400	65	–	8.0	–	260.1	–	32.0	–
1997	234	0.0	90	1.9	400	64	–	8.0	–	256.1	–	32.0	–
1998	226	−3.4	91	1.8	370	63	–	6.0	–	233.2	–	22.2	–
1999	219	−3.1	91	1.8	359	63	–	6.0	–	226.0	–	21.5	–
2000	233	6.4	92	1.8	386	62	50.0	6.0	5.0	239.2	173.0	23.2	17.0
2001	231	−0.9	92	1.7	361	62	–	6.0	–	224.0	–	21.7	–
2002	232	0.4	93	1.7	367	61	47.0	5.0	4.0	223.7	179.0	18.3	15.2
2003	232	0.0	93	1.7	367	61	45.0	5.0	3.0	223.7	173.0	18.3	11.6
2004	248	6.9	94	1.6	373	60	45.0	5.0	3.0	223.8	175.0	18.6	11.7
2005	242	−2.4	94	1.6	364	60	40.0	5.0	3.0	218.4	145.0	18.2	10.9
2006	266	9.9	95	1.5	379	55	40.0	5.0	3.0	208.5	148.0	19.0	11.1
2007	279	5.0	95	1.5	398	50	38.0	5.0	3.0	199.0	143.0	19.9	11.3
2010	296	2.0	96	1.4	398	45	37.0	4.0	2.0	179.3	139.0	15.9	7.5
2015	327	2.0	98	1.3	417	35	–	3.0	–	145.9	–	12.5	–
2020	361	2.0	100	1.2	434	25	–	2.0	–	108.4	–	8.7	–
Miscellaneous freshwater carnivorous fish — includes *Channa argus*, *Siniperca chuatsi*, *Monopterus albus*, *C.* spp, *C. striata*, *C. micropeltes*, *Morone chrysops x M. saxatilis*, *Lates niloticus*, *Anabas testudineus*, *Hepsetus odoe*, *Micropterus salmoides*, *Oxyeleotris marmorata*) *Esox lucius*, *Sander lucioperca*, etc…													
1995	107	64.6	5	2.0	11	55	–	8.0	–	5.9	–	0.9	–
1996	131	22.4	6	2.0	16	50	–	8.0	–	7.9	–	1.3	–
1997	145	10.7	7	2.0	20	50	–	8.0	–	10.2	–	1.6	–
1998	234	61.4	8	2.0	37	50	–	6.0	–	18.7	–	2.2	–
1999	247	5.5	9	2.0	44	50	–	6.0	–	22.2	–	2.7	–
2000	192	−22.2	10	2.0	38	50	–	6.0	–	19.2	–	2.3	–
2001	133	−30.7	11	2.0	29	45	–	6.0	–	13.2	–	1.8	–
2002	177	33.1	12	2.0	42	45	–	5.0	–	19.1	–	2.1	–
2003	501	183.0	13	2.0	130	45	–	5.0	–	58.6	–	6.5	–
2004	600	19.8	14	2.0	168	45	–	5.0	–	75.6	–	8.4	–
2005	690	15.0	15	2.0	207	45	–	5.0	–	93.2	–	10.4	–
2006	777	12.6	16	2.0	249	40	–	5.0	–	99.5	–	12.4	–
2007	855	10.0	17	2.0	291	40	–	5.0	–	116.2	–	14.5	–
2010	1138	10.0	20	2.0	455	35	–	4.0	–	159.3	–	18.2	–
2015	1832	10.0	25	2.0	916	25	–	3.0	–	229.0	–	27.5	–
2020	2692	8.0	30	2.0	1615	15	–	2.0	0.0	242.3	0.0	32.3	–

(*continued on next page*)

Table 4 (*continued*)

Species-group	Total production[a]	Growth (%/year)[b]	Percent on feeds[c]	Species EFCR[d]	Total feeds used[e]	Mean % fish meal	IFFO % fish meal estimate[f]	Mean % fish oil	IFFO % fish oil estimate	Total fish meal used	IFFO fish meal estimate	Total fish oil used	IFFO fish oil estimate
Freshwater crustaceans – includes *Eriocheir sinensis*, *Macrobrachium nipponense*, *M. rosenbergii*, *Procambarus clarkia*, *M. malcolmsonii*, etc…													
1995	104	20.9	35	2.5	91	25	–	2.0	–	22.8	–	1.8	–
1996	146	40.4	36	2.5	131	25	–	2.0	–	32.9	–	2.6	–
1997	193	32.2	37	2.5	179	24	–	2.0	–	42.8	–	3.6	–
1998	229	18.6	38	2.5	218	24	–	2.0	–	52.2	–	4.4	–
1999	303	32.3	39	2.4	284	23	–	2.0	–	65.2	–	5.7	–
2000	484	59.7	40	2.4	465	23	–	2.0	–	106.9	–	9.3	–
2001	589	21.7	41	2.4	580	22	–	2.0	–	127.5	–	11.6	–
2002	652	10.7	42	2.3	630	22	20.0	2.0	2.0	138.6	135.0	12.6	13.5
2003	888	36.2	43	2.3	878	21	20.0	2.0	2.0	184.4	139.0	17.6	13.9
2004	957	7.8	44	2.2	926	21	20.0	2.0	2.0	194.5	151.0	18.5	15.1
2005	1015	6.1	45	2.2	1005	20	18.0	1.5	1.5	201.0	143.0	15.1	11.9
2006	1066	5.0	46	2.1	1030	15	17.0	1.5	1.0	154.5	146.0	15.4	8.6
2007	1119	5.0	47	2.1	1105	14	17.0	1.5	1.0	154.7	159.0	16.6	9.3
2010	1296	5.0	50	2.0	1296	13	16.0	1.5	1.0	168.4	172.0	19.4	10.7
2015	1654	5.0	55	1.9	1728	10	–	1.0	–	172.8	–	17.3	–
2020	2111	5.0	60	1.8	2279	5	–	0.8	–	114.0	–	17.1	–
Tilapia — includes *Oreochromis niloticus*, *O. mossambicus*, *O. aureus*, *O. andersonii*, *O. spilurus*, etc…													
1995	703	18.5	70	2.0	984	14	–	1.0	–	137.8	–	9.8	–
1996	810	15.2	71	2.0	1150	13	–	1.0	–	149.5	–	11.5	–
1997	931	14.9	72	2.0	1341	13	–	1.0	–	174.3	–	13.4	–
1998	951	2.1	73	1.9	1319	12	–	1.0	–	158.3	–	13.2	–
1999	1104	16.1	74	1.9	1552	12	–	1.0	–	186.3	–	15.5	–
2000	1270	15.0	75	1.9	1810	11	7.0	1.0	1.0	199.1	55.0	18.1	8.0
2001	1385	9.1	76	1.9	2000	11	–	1.0	–	220.0	–	20.0	–
2002	1489	7.5	77	1.8	2064	10	5.0	1.0	1.0	206.4	67.0	20.6	13.4
2003	1683	13.0	78	1.8	2363	10	5.0	1.0	1.0	236.3	79.0	23.6	15.8
2004	1899	12.8	79	1.8	2700	9	5.0	1.0	1.0	243.0	87.0	27.0	17.3
2005	2068	8.9	80	1.8	2978	9	3.0	1.0	1.0	268.0	55.0	29.8	18.3
2006	2326	12.5	81	1.7	3203	6	3.0	0.5	1.0	192.2	60.0	16.0	20.1
2007	2575	10.0	82	1.7	3590	5	3.0	0.0	1.0	179.5	66.0	0.0	22.2
2010	3427	10.0	85	1.7	4953	3	3.0	0.0	1.0	148.6	79.0	0.0	26.2
2015	5520	10.0	90	1.6	7949	2	–	0.0	–	159.0	–	0.0	–
2020	8890	10.0	95	1.5	12,668	1	–	0.0	–	126.7	–	0.0	–
Milkfish (*Chanos chanos*)													
1995	366	−3.9	30	2.0	220	15	–	3.0	–	32.9	–	6.6	–
1996	371	1.4	30	2.0	223	14	–	3.0	–	31.2	–	6.7	–
1997	364	−1.9	31	2.0	226	13	–	3.0	–	29.3	–	6.8	–
1998	380	4.4	32	2.0	243	12	–	2.0	–	29.2	–	4.9	–
1999	442	16.3	33	2.0	292	11	–	2.0	–	32.1	–	5.8	–
2000	468	5.9	34	2.0	318	10	12.0	2.0	2.0	31.8	36.0	6.4	6.0
2001	495	5.8	35	2.0	347	9	–	1.0	–	31.2	–	3.5	–
2002	528	6.7	36	2.0	380	8	8.0	1.0	1.0	30.4	46.0	3.8	5.7
2003	552	4.5	37	2.0	408	7	7.0	1.0	1.0	28.6	36.0	4.1	5.2
2004	574	4.0	38	2.0	436	6	7.0	1.0	1.0	26.2	38.0	4.4	5.4
2005	595	3.7	39	2.0	464	5	5.0	1.0	1.0	23.2	27.0	4.6	5.4
2006	585	−1.2	40	2.0	468	3	5.0	1.0	1.0	14.0	28.0	4.7	5.6
2007	608	4.0	41	2.0	499	3	5.0	1.0	1.0	15.0	30.0	5.0	6.0
2010	684	4.0	44	1.9	572	2	4.0	1.0	1.0	11.4	27.0	5.7	6.7
2015	873	5.0	49	1.7	728	2	–	1.0	–	14.6	–	7.3	–
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]		[illegible]	

Conclusion for reported farmed species-group

	Total species production[g]	Total fed production[h]	Total feeds used[i]	Total feeds estimates[j]	IFFO feed estimates[f]	Total fish meal used	Total fish meal estimates	IFFO fish meal estimate	Total fish oil used	Total fish oil estimates	IFFO fish oil estimate
1995	9092	3965	7484	8621	–	1882	1728	–	474	494	–
1996	10,293	4734	8941	9731	–	2093	2016	–	535	576	–
1997	11,477	5645	10,575	–	–	2326	–	–	575	–	–
1998	12,502	6433	11,992	12,321	–	2535	2256	–	589	649	–
1999	13,850	7228	13,506	–	–	2708	–	–	622	–	–
2000	14,900	8000	14,782	15,055	13,630	2922	2413	2316	631	554	716
2001	16,267	8965	16,195	16,018	–	3126	2585	–	718	669	–
2002	17,310	9979	17,830	17,880	17,975	3324	2696	2769	695	758	810
2003	19,744	11,586	20,843	19,474	19,479	3845	2936	2939	768	802	802
2004	20,709	12,551	22,105	–	20,753	4060	–	3137	809	–	878
2005	22,341	13,729	23,812	20,958	21,655	4300	2666	3041	843	552	813
2006	23,851	15,072	25,363	–	23,162	3724	–	3055	835	–	783
2007	25,708	16,575	27,397	–	24,427	3641	–	3020	778	–	777

Table 4 (*continued*)

Conclusion for reported farmed species-group											
	Total species production[g]	Total fed production[h]	Total feeds used[i]	Total feeds estimates[j]	IFFO feed estimates[f]	Total fish meal used	Total fish meal estimates	IFFO fish meal estimate	Total fish oil used	Total fish oil estimates	IFFO fish oil estimate
2010	31,632	21,351	34,647	27,744	28,060	3291	2478	3286	770	534	826
2015	44,143	31,578	48,874	–	–	3111	–	–	756	–	–
2020	60,014	45,557	66,636	–	–	2385	–	–	712	–	–

Note: The revised figures show a significant increase in fish meal and fish oil use due to increased global trends in aquaculture production, including markedly increased shrimp production in China, Vietnam and Ecuador (and increased fish meal inclusion levels), increased marine finfish production in China (although percent on compound aquafeeds was reduced due to high use of trash fish as feed in China), markedly increased catfish production in China and Vietnam, increased freshwater crustacean and carnivorous miscellaneous freshwater fish production in China, and increased proportion of the estimated total tilapia production based on the use of formulated feeds.
Calculations adapted from Tacon (1998), Tacon and Barg (2000), Tacon and Forster (2001), Tacon (2003), Tacon (2004), Tacon et al. (2006) and the International Fishmeal and Fish Oil Organization: IFOMA (2000) and Jackson (2006).

[a] Total reported farmed species-group production for 2004, 2005 and 2006 is taken from FAO (2008a), and estimates for 2007, 2010, 2015 and 2020 are calculated based on expected growth.

[b] Mean estimated Annual Percent Rate of Growth (APR,%) of farmed species-group production from 2003 to 2004, 2004 to 2005, 2005 to 2010, 2010 to 2015, and 2015 to 2020.

[c] Estimated percent of total species-group production fed on compound aquafeeds.

[d] Estimated average species-group economic feed conversion ratio (total feed fed / total species-group biomass increase).

[e] Estimated total species-group aquafeed used (total species-group production x FCR [feed conversion ratio]).

[f] International Fishmeal and Fish Oil Organization (IFFO) estimates provided by IFOMA (2000) and Jackson (2007).

[g] Includes total reported farmed finfish and crustacean production, excluding filter feeding fish species such as silver carp, bighead carp, rohu and catla, which are not usually fed on industrially compounded aquafeeds. The value also excludes non-species specific production, including freshwater fishes nei (2, 074 612 tonnes in 2006), cyprinids nei (254,916 tonnes), marine crustaceans (41,721 tonnes), and minor cultivated species such as turtles (211,266 tonnes), Characidae (Cachama/Colossoma sp: 159,211 tonnes), Silver barb (104,385 tonnes), Frogs and other amphibians 86,937 tonnes, and miscellaneous diadromous fish species (barramundi, sturgeon, Nile perch: 88,751 tonnes) and Gourami sp. (500 tonnes in 2006: FAO, 2008a).

[h] Includes total global aquafeed fed species production (summation of total species-group production x estimated percent of total species-group production fed compound aquafeeds (according to FAO 2008a total reported production of these species was 8,793,141 tonnes in 2005).

[i] Total global compound aquafeed used.

[j] Total global aquafeed estimates of Tacon (1998), Tacon and Barg (2000), Tacon and Forster (2001); Tacon et al. (2003, 2004, 2006).

estimates of 551.8 and 813 thousand tonnes in 2005 (61.3 and 90.4% total fish meal production in 2005: Tacon et al., 2006 and Jackson, 2006, respectively), and 783 thousand tonnes in 2006 (83.0% total fish meal production in 2006: Jackson, 2007).

The top consumers of fish meal in 2006 were marine shrimp, followed by marine fish, salmon, Chinese carps, trout, eel, catfish, tilapia, freshwater crustaceans, miscellaneous freshwater fishes, and milkfish (Fig. 1), and this sequence compares very closely with that estimated by IFFO (Jackson, 2007), except for catfish and Chinese carps. By contrast, the top consumers of fish oil in 2006 were salmon, followed by marine fish, trout, shrimp, catfish, eel, tilapia, freshwater crustaceans, miscellaneous freshwater fishes, and milkfish (Fig. 2), and again this sequence compares almost exactly with that estimated by IFFO (Jackson, 2007), with the exception of carp (no fish oil consumption in the present study).

Despite increases in the total global consumption of fish meal and fish oil by the aquaculture sector, the average dietary fish meal and fish oil inclusion levels within compound aquafeeds have been steadily declining (with the exception of catfish, for the period between 1995 and 2006), including shrimp from 28 to 20%, marine fish from 50 to 32%, salmon from 45 to 30%, trout 40 to 30%, carp 10 to 5%, catfish 5 to 10% (levels increasing due to the rapid increase in catfish production in Vietnam; Hung and Merican, 2006; Nguyen, 2007), eel 65 to 55%, miscellaneous freshwater carnivorous fish 55 to 40%, freshwater crustaceans 25 to 15%, tilapia 14 to 6%, and milkfish from 15 to 3% (Table 4). In the case of fish oil, these decreases have been as follows, shrimp 2% (no change), marine fish from 15 to 8%, salmon from 25 to 20%, trout 20 to 15%, carp 0%, catfish 1 to 1.7%, eel 8 to 5%, miscellaneous freshwater carnivorous fish 8 to 5%, freshwater crustaceans 2 to 1.5%, tilapia 1 to 0.5%, and milkfish from 3 to 1%.

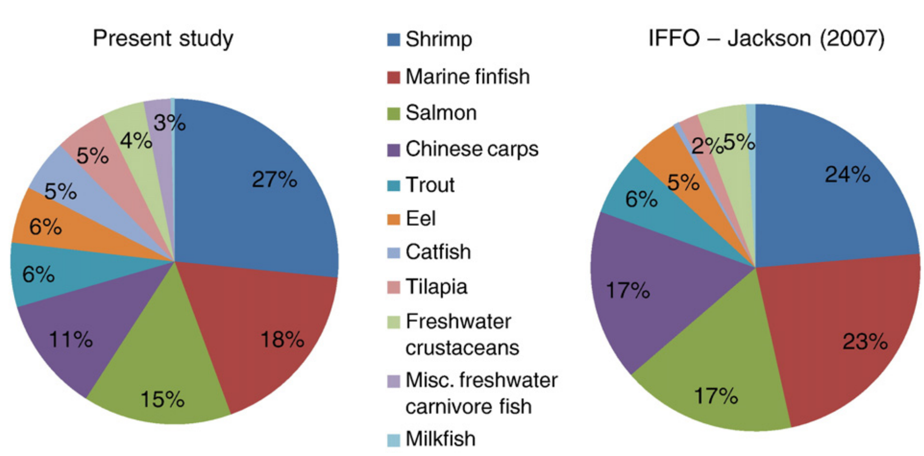

Fig. 1. Estimated global use of fish meal within compound aquafeeds in 2006 from the present study and from IFFO estimations (values given as percent total aquafeeds; Jackson 2007).

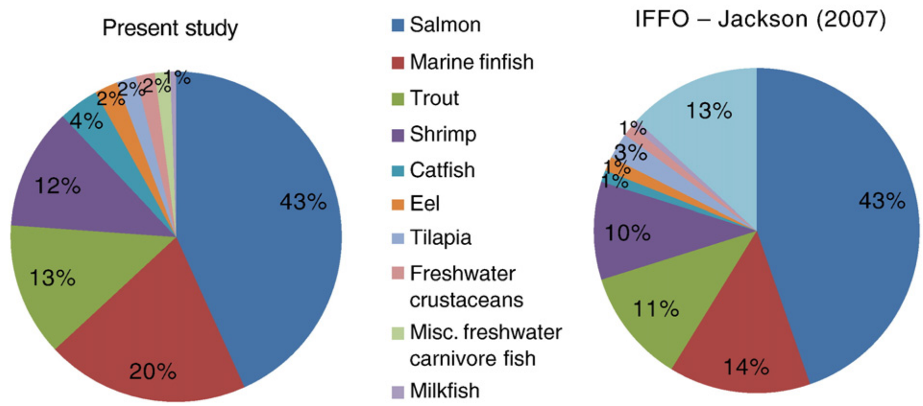

Fig. 2. Estimated global use of fish oil within compound aquafeeds in 2006 from the present study and IFFO estimation (values given in percent total aquafeeds: Jackson, 2007).

For example, in the specific case of Chile, fish meal levels in salmon feeds have fallen progressively from 45% in 2000 to below 28% in 2006 (Anon, 2006; see also Table 4). The main reason for the global decrease in reported dietary fish meal and fish oil inclusion levels in compound aquafeeds has been due to the increasing global fish meal and fish oil prices since 2000 (Fig. 3); fish meal prices doubling from US $694 to US $1379 per tonne between July 2005 and July 2006, and fish oil prices almost doubling from US $894 to US $1700 per tonne between March 2007 and March 2008 (Fig. 3). The reason for these price increases have been due to a combination of different factors, including static global supplies of fish meal and fish oil, strong market demand for fish meal and fish oil by the aquaculture and livestock sector in the major importing countries, and in particular China (FAO/GLOBEFISH, 2007; GAIN, 2007; Hongjle, 2007; Tacon and Nates, 2007), and increasing key vegetable oil (rapeseed oil, soybean oil, palm oil) and global petroleum and energy prices (FAO, 2008b; IFFO, 2008a,b).

The effect of increasing fish meal prices on fish meal substitution in compound aquafeed formulations in China is clearly shown in Fig. 4, with average dietary fish meal levels decreasing from 70 to 55% for eel, 40 to 30% for marine finfish, 35 to 25% for shrimp, and 20 to 10% for freshwater fish from 2005 and 2006.

Projections concerning the future availability, price and use of fish meal and fish oil vary widely depending upon the viewpoint and assumptions used (Shepherd, 2005; Tacon, 2005; Jackson, 2006, 2007, in press; Tacon et al., 2006). For example, according to IFFO fish meal and fish oil use is expected to increase from 3055 thousand tonnes in 2006 to 3607 thousand by 2012 (18.1% increase) and from 783 thousand tonnes in 2006 to 836 thousand tonnes by 2012 (6.8% increase), respectively (Fig. 5). These assumptions are based on a constant fish meal and fish oil production of 6 million tonnes and 950,000 tonnes from 2008 to 2012, respectively. By contrast, the results from this and previous estimates (Tacon et al., 2006) suggest that the use of fish meal and fish oil in compound aquafeeds will decrease in the long term; fish meal decreasing by 44.5% from a high of 4300 thousand tonnes in 2005 to 2385 thousand tonnes in 2020, and fish oil use decreasing by 15.5% from a high of 843 thousand tonnes in 2005 to 712 thousand tonnes by 2020 (Fig. 5).

At a species level (Table 4), fish meal use from 2006 to 2020 is expected to decrease by 37.7% for shrimp, 31.3% for marine fish, 47.2% for salmon, 44.1% for trout, 57.0% for carp, 0% for catfish, 48,0% for eel, 26.2% for freshwater crustaceans, 34.1% for tilapia and 34.5% for milkfish (Table 4). In the case of fish oil, usage is expected to increase from 2006 to 2020 by 24.6% for shrimp, 3.0% for marine fish, 119.6% for catfish, 159.8% for miscellaneous carnivorous freshwater fish species, 10.7% for freshwater crustaceans. However, fish oil use is expected to decrease by 39.7% for salmon, 39.3% for trout, 54,2% for eel and 1.7% for milkfish from 2006 to 2020 (Table 4). The main reason why fish meal and fish oil use is expected to decrease in the long run is due to a combination of a decreasing market availability of fish meal and fish oil from capture fisheries, increasing market cost for these finite commodities and increased global use of cheaper plant and animal alternative protein and lipid sources (for reviews see Tacon et al., 2006 and Gatlin et al., 2007).

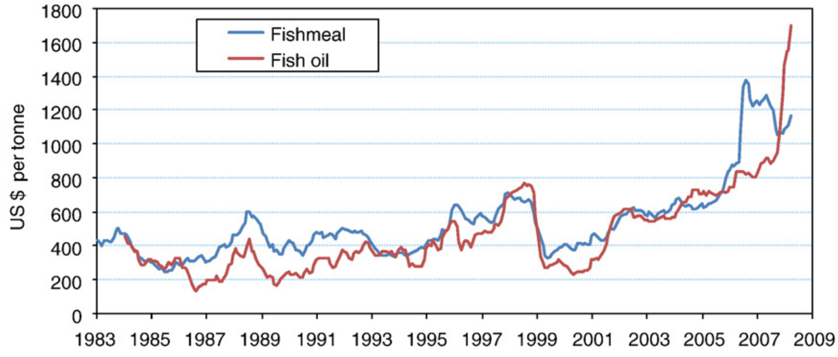

Fig. 3. International market price for fish oil and fish meal (monthly average, 64/65% crude protein), any origin, wholesale, CIF Hamburg (US $ per tonne: Helga Josupeit, FAO GLOBEFISH Database — personal communication, May 2008).

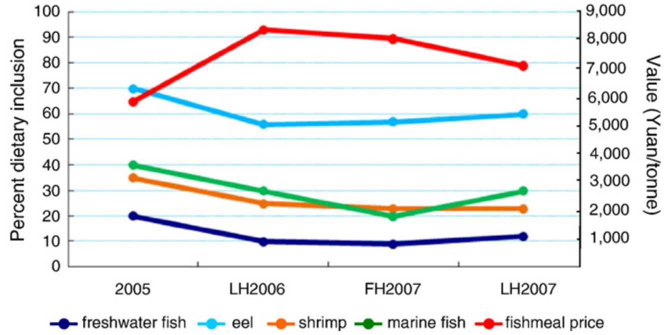

Fig. 4. Effect of fish meal price on fish meal use in aquafeeds in China 2005–2007 (LH — Last Half, FH — First Half; Huang, 2007).

4. Fish-in fish-out balance sheet

In the case of the long term sustainability of fishery resource use within the aquaculture sector, it is perhaps useful here to transform fish meal and fish oil use levels back to live fish weight equivalents and by so doing have a more accurate assessment of the quantity of live fish from capture fisheries required for each unit of farmed fish or shrimp produced. Thus, using a global average wet fish to fish meal processing yield of 22.5% (from industry sources: Shepherd, 2005; Anon, 2006) and wet fish to fish oil processing yield of 5% (Anon, 2006), pelagic forage fish live weight equivalent values have been calculated for the different major species groups based on the estimated fish meal and fish oil used

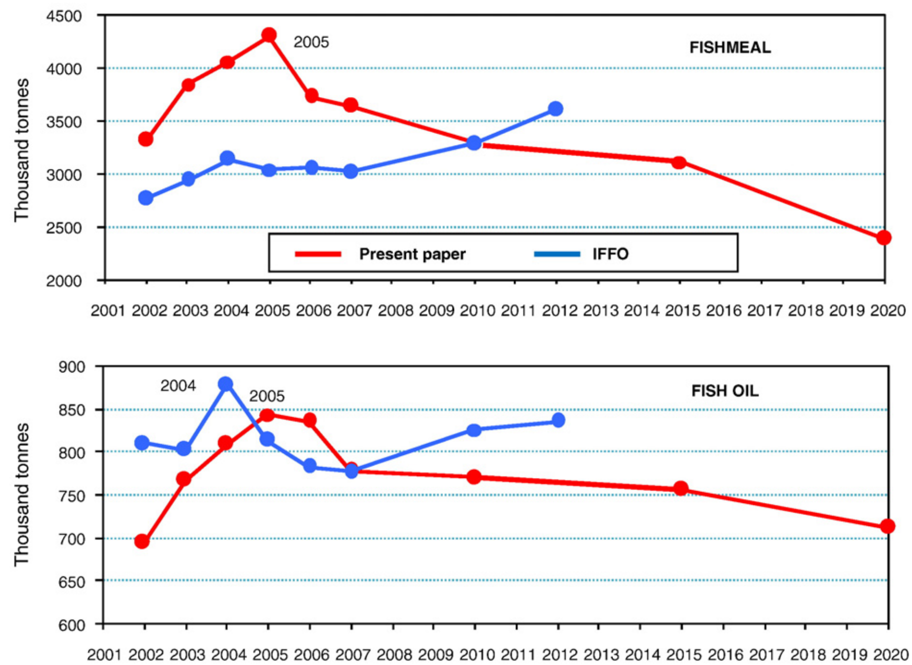

Fig. 5. Comparison of current and projected use of fish meal and fish oil within compound aquafeeds from 2002 to 2020 (IFFO — Jackson, 2006, 2007: and present study).

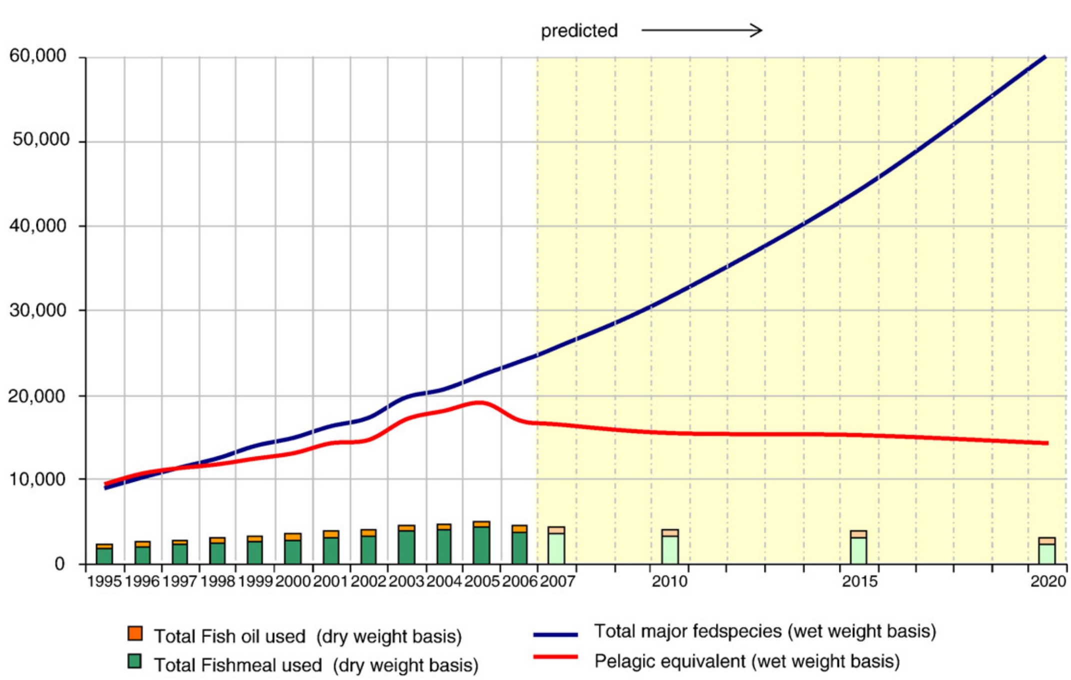

Fig. 6. Total global farmed fed fish aquaculture production, fish meal and fish use, and calculated pelagic forage fish equivalent.

and projected (Table 4; Fig. 6). Before commenting on these transformations, it is important to mention here the wide variability in processing yields possible within and between species, depending on fish age, reproductive state, processing method employed, etc (Tacon et al., 2006). Moreover, in contrast to previous studies (Tacon, 2005; Tacon et al., 2006), transformation yields were calculated separately for fish oil, after first subtracting the possible fish oil yield from the fish meal transformation, and transforming the difference if fish oil use was greater (Anon, 2006). For example, use of 500,000 tonnes of fish meal and 250,000 tonnes of fish oil is transformed to pelagic forage fish equivalents as follows: 500,000÷0.225=2,222,222.2 pelagic equivalents; 2,222,222.2×0.05=111,111.1 fish oil; 250,000–111,111.1=138,888.9 additional fish oil required; 138,888.9÷0.05=2,777,778 pelagic equivalent; total pelagic equivalent 2,222,222.2+2,777,778=5,000,000.

Calculation of pelagic forage fish input per unit of farmed fish or crustacean output showed steadily decreasing fish-in fish-out ratios for all cultivated species, with decreases being most dramatic for carnivorous fish species such as salmon (decreasing from 7.5 to 4.9 from 1995 to 2006), trout (decreasing from 6.0 to 3.4), eel (decreasing from 5.2 to 3.5), marine fish (decreasing from 3.0 to 2.2) and to a lesser extent shrimp (decreasing by 1.9 to 1.4 from 1995 to 2006; Fig. 6). Net fish producing species in 2006 (with fish-in fish-out ratios below 1), included herbivorous and omnivorous finfish and crustacean species, including non-filter feeding Chinese carp (0.2), milkfish (0.2), tilapia (0.4), catfish (0.5), and freshwater crustaceans (0.6; Fig. 6).

On a global basis, it is estimated that the production of 23.85 million tonnes of farmed finfish and crustaceans in 2006 (15.07 million tonnes or 63.2% of total production fed compound aquafeeds; Table 4), consumed 25.36 million tonnes of compound aquafeeds in 2006, containing 3.72 million tonnes of fish meal and 0.83 million tonnes of fish oil (Table 4), or the equivalent of 16.6 million tonnes of pelagic forage fish with an overall fish-in fish-out ratio of 0.70 (Fig. 6). Transformation of fish meal and fish oil usage levels to pelagic forage fish live equivalents show a steady decline in projected pelagic forage fish use for compound feed fed finfish and crustacean species after 2005 (Fig. 7). However, it must also be stated that these transformation values only refer to the estimated use of fish meal and

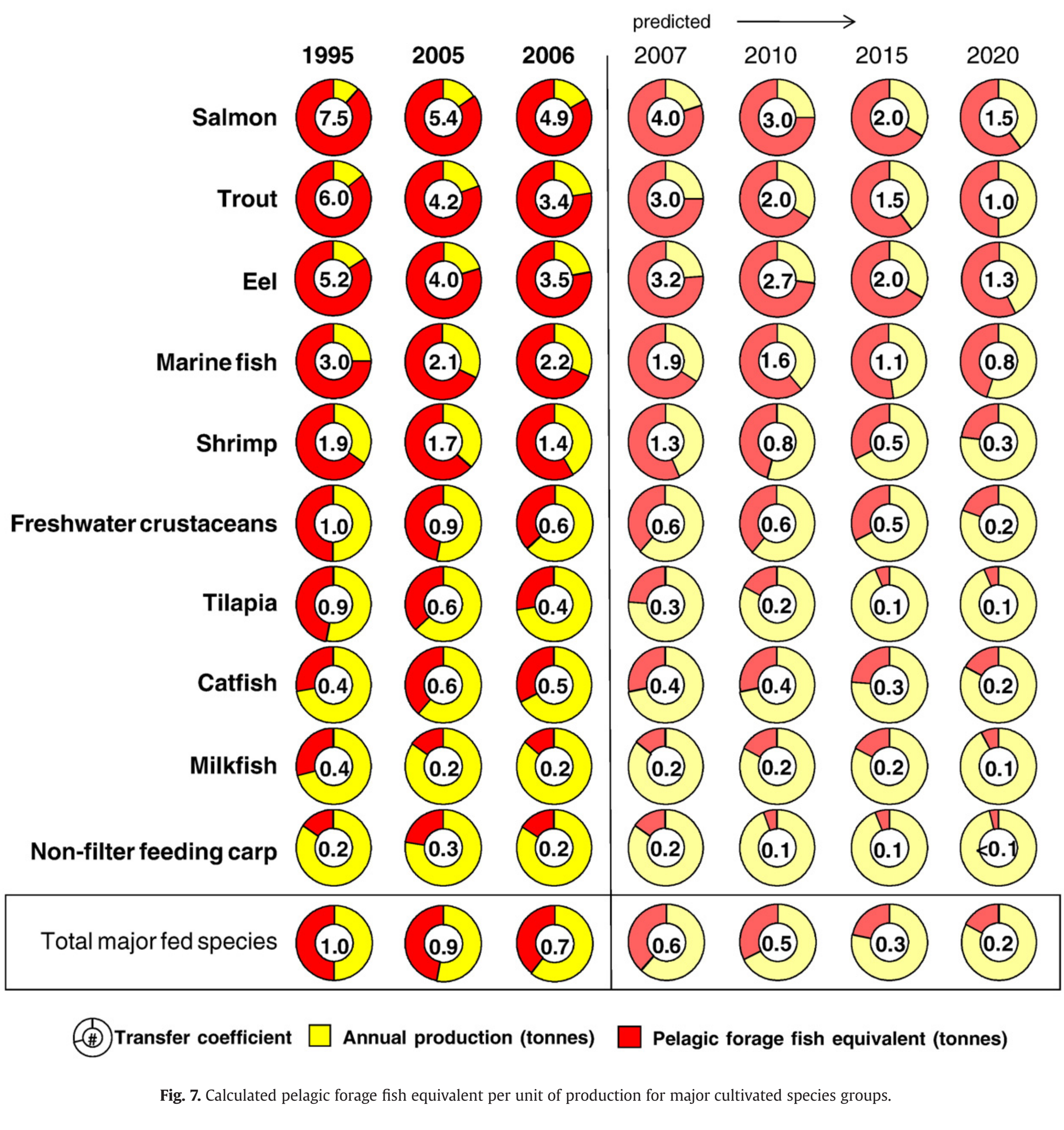

Fig. 7. Calculated pelagic forage fish equivalent per unit of production for major cultivated species groups.

fish oil within industrially compounded aquafeeds, and as such do not take into account the proportion of low value/trash fish used as a direct feed source or within farm-made aquafeeds for marine fish, catfish, eel and freshwater carnivorous fish species (Tacon et al., 2006).

It is also important to remember here that the above estimates only refer to that segment of global finfish and crustacean aquaculture production currently being fed industrially compounded aquafeeds, and as such excludes filter feeding finfish species such as silver carp, bighead carp, rohu and catla (total production of these four species was 9.42 million tonnes in 2006: FAO, 2008a), and other non-species specific reported aquaculture production, marine crustaceans, and minor cultivated species (total production estimated at 4.14 million tonnes in 2006: FAO, 2008a). It follows from the above that for a total global production of 37.41 million tonnes of farmed finfish, crustaceans, amphibians and reptiles in 2006 (FAO, 2008a), the sector consumed the equivalent of 16.5 million tonnes of pelagic forage fish species in the form of fish meal and fish oil within compound aquafeeds, and displayed an overall fish-in fish-out ratio of 0.44.

5. Future prospects

In conclusion, the reason for the belief that the use of fish meal and fish oil (derived from wild capture fisheries) by the aquaculture sector in compound aquafeeds will decrease in the long term is due to a variety of factors, including:

- static and/or diminishing global supplies of wild forage fish destined for reduction into fish meal and fish oil (averaging 23.28 ±3.76 million tonnes between 1970 and 2005: FAO, 2008a; PRODUCE, 2007);
- increasing market price of small pelagic forage fish in the long term due to increasing fishing costs and increasing demand of forage fish for direct human consumption and/or direct animal feeding (De Monbrison and Guillaume, 2003; Zertuche-González et al., 2008);
- increasing global energy, processing (including fish meal/fish oil manufacture) and shipping/transportation costs (FAO, 2008b);
- static and/or diminishing supplies of fish meal and fish oil (derived from wild capture fisheries) for export (FAO, 2008a);
- as a direct result of the aforementioned global trends, increasing fish meal and fish oil prices in the long run (Fig. 3), and consequent pressure on feed manufacturers for dietary substitution so as to remain profitable; and
- increasing market pressure by civil society and retailers to improve the overall sustainability of fishery resource use within the aquaculture sector (Naylor et al., 1998, 2000; Deutsch et al., 2007).

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 in 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. It follows from the above, that future dietary inclusion levels and usage of fish oil and fish meal in aquafeeds and animal feeds in general will decrease in the long run, and be reduced in supplying the necessary minimum essential dietary nutrients for the target species as high value key nutrient additives rather than as major dietary sources of protein and lipid, respectively. We are therefore in agreement with IFFO, in that fish meal and fish oil use in the long term will be increasingly targeted as a specialty feed ingredient for use in higher value starter, finisher and broodstock feeds (Jackson, 2007), and by so doing extending supply and maximizing profit to the ingredient supplier.

Dietary substitution of fish meal and fish oil with alternative feed ingredient sources will be considerably easier for herbivorous/omnivorous aquaculture and animal species than for the more nutritionally demanding carnivorous aquaculture and animal species (Hardy and Tacon, 2002). Notwithstanding the above, fish meal and fish 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.

Notwithstanding the above, it is also important to mention here that as the aquaculture sector grows and matures, then so the production and availability of aquaculture derived fish meals and oils will become increasingly produced and available in the market place (Tacon, 2005; Ramirez, 2007), just as they have become available within the terrestrial livestock production sector; animal by-products arising from the rendering industry being the largest source of high quality feed-grade animal protein and lipid available to animal feed manufacturing sector globally (Tacon and Nates, 2007), estimated at over 8.5 million tonnes in 2007 in the US alone (Swisher, 2008). Although at present no information is available from FAO concerning the total global production of fish meals and oils produced specifically from aquaculture trimmings and offal, aquaculture derived fish meals have been reportedly produced from the processing of farmed salmon (Wright, 2004; Ramirez, 2007), trout (Kotzamanis et al., 2001; Turchini et al., 2003), shrimp (Fox et al., 1994; Pongmaneerat et al., 2001), tilapia (Oyelese, 2006), and more recently basa catfish (http://www.tradeget.com/free_list/p54224/F13413/fish_meal.html). For example, in Chile it is estimated that the production of 600,000 tonnes of salmon yielded 270,000 of processing waste and farm mortalities, which in turn resulted in the production of 48,600 tonnes of salmon oil and 43,200 tonnes of salmon meal (Anon, 2006).

Finally, on a cautionary note, it is important to ensure that the fish meals and fish oils derived from aquaculture process wastes are not fed back to the same species (intra species recycling) so as to prevent the possibility for the spread of diseases and/or recycling of unwanted environmental and/or dietary contaminants (Gill, 2000; FAO, 2001).

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References

Anon., 2006. Alimentacion de peces en la salmonicultura Chilena: tasas de conversion. Temas del Salmon, vol. 1. 7 pp.
De Monbrison, D., Guillaume, B., 2003. Preliminary studies for DOTT Symposium — BFT impacts on local development a socio-economic approach. Cahiers Options Mediterraneenes 60, 127–138.
Deutsch, L., Gräslund, S., Folke, C., Huitric, M., Kautsky, N., Troell, M., Lebel, L., 2007. Feeding aquaculture growth through globalization; exploitation of marine ecosystems for fishmeal. Global Environmental Change 17, 238–249.
El-Sayed, A.-F.M., 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Egypt. In: Hasan, M.R., Hecht, T., De Silva, S.S., Tacon, A.G.J. (Eds.), Study and Analysis of Feeds and Fertilizers for Sustainable Aquaculture Development. FAO Fisheries Technical Paper, vol. 497. FAO, Rome, pp. 401–422.
FAO, 2001. Aquaculture development. 1. Good aquaculture feed manufacturing practice. FAO Technical Guidelines for Responsible Fisheries No.5, Supplement1. FAO, Rome. 47 pp.
FAO, 2006. State of world aquaculture 2006. FAO Fisheries Technical Paper, vol. 500. FAO, Rome. 134 pp.
FAO, 2008a. FAO Fisheries Department, Fishery Information, Data and Statistics Unit. Fishstat Plus: Universal software for fishery statistical time series. Aquaculture production: quantities 1950–2006, Aquaculture production: values 1984–2006; Capture production: 1950–2006; Commodities production and trade: 1950–2006; Vers. 2.30.
FAO, 2008b. Food Outlook — Global Market Analysis. June 2008. FAO, Rome. 95 pp.
FAO/GLOBEFISH, 2007. Fishmeal: higher fishmeal prices result in good business. GLOBEFISH Seafood Highlights 2007, pp. 19–20 (www.infofish.org/pdf/gsh/GSH_2007.pdf).
Fox, C.J., Blow, P., Brown, J.H., Watson, I., 1994. The effect of various processing methods on the physical and biochemical properties of shrimp head meals and their utilization by juvenile *Penaeus mondon* Fab. Aquaculture 122, 209–226.

GAIN (Global Agriculture Information Network), 2007. People's Republic of China — Fishery Products Annual 2007. USDA Foreign Agricultural Service, GAIN Report No. CH7094, 12/31/2007. 33 pp. (http://www.fas.usda.gov/gainfiles/200712/146293362.pdf).
Gatlin III, D., Barrows, F., Bellis, D., Brown, P., Campen, J., Dabrowski, K., Gaylord, T.G., Hardy, R.W., Herman, E.M., Hu, G., Krogdahl, A., Nelson, R., Overturf, K.E., Rust, M., Sealey, W., Skonberg, D., Souza, E.J., Stone, D., Wilson, R.F., 2007. Expanding the utilization of sustainable plant products in aquafeeds: a review. Aquaculture Research 38, 551–579.
Gill, T.A., 2000. Waste from processing aquatic animals and animal by-products: implications on aquatic animal pathogen transfer. FAO Fisheries Circular, vol. 956. FAO, Rome. FIIU/C956, 26 pp.
Gill, C., 2007. World feed panorama: bigger cities, more feed. Feed Int. 28, 5–9.
Hardy, R.W., Tacon, A.G.J., 2002. Fish meal: historical uses, production trends and future outlook for supplies. In: Stickney, R.R., MacVey, J.P. (Eds.), Responsible Marine Aquaculture. CABI Publishing, New York, pp. 311–325.
Hongjle, Y., 2007. China: sleeping giant rapidly awakens. Feed Technology 18–21 11.7.2007.
Huang, H., 2007. China fishmeal consumption status and outlook for 2008. Paper Presented at the International Fishmeal and Fish Oil Organisation 2007 Annual Conference, Sydney, Australia, 17 October 2007.
Hung, L.T., Huy, H.P.V., 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Viet Nam. In: Hasan, M.R., Hecht, T., De Silva, S.S., Tacon, A.G.J. (Eds.), Study and Analysis of Feeds and Fertilizers for Sustainable Aquaculture Development. FAO Fisheries Technical Paper, vol. 497. FAO, Rome, pp. 331–361.
Hung, L.T., Merican, Z., 2006. Freshwater fish culture in Vietnam for the global white fish market. AQUA Culture AsiaPacific Magazine 2, 14–16.
IFFO (International Fishmeal and Fish Oil Organisation), 2008a. IFFO Update No. 186, January 2008. 10 pp.
IFFO (International Fishmeal and Fish Oil Organisation), 2008b. IFFO Update No. 187, February 2008. 11 pp.
IFOMA (International Fishmeal and Oil Manufacturers Association), 2000. Predicted use of fishmeal and fish oil in aquaculture—revises estimate. IFOMA Update No. 98, April 2000, Potters Bar, UK.
Jackson, A.J., 2006. The importance of fishmeal and fish oil in aquaculture diets. International Aquafeed 9, 16–19.
Jackson, A.J., 2007. Challenges and opportunities for the fishmeal and fish oil industry. Feed Technology Update 2 (1) 9 pp.
Jackson, A.J., in press. Global production of fishmeal and fish oil. Paper presented at the FAO Expert Workshop on the use of wild fish and/or other aquatic species to feed cultured fish and its implications to food security and poverty alleviation, Kochi (India), 16–18 November, 2007.
Jin, W., 2006. Fishmeal as a dietary ingredient in China — first impressions. Paper Presented at the International Fishmeal and Fish Oil Organisation 2006 Annual Conference, Barcelona, Spain, 23–26 October 2006.
Kotzamanis, Y.P., Alexis, M.N., Andriopoulou, A., Castritsi-Cathariou, I., Fotis, G., 2001. Utilization of waste material resulting from trout processing in gilthead bream (*Sparus aurata* L.) diets. Aquaculture Research 32, 288–295.
Kristofersson, D., Anderson, J.L., 2006. Is there a relationship between fisheries and farming? Inter-dependence of fisheries, animal production and aquaculture. Marine Policy 30, 721–725.
Naylor, R.L., Goldberg, R.J., Mooney, H., Beveridge, M., Clay, J., Folke, C., Kautsky, N., Lubchenco, J., Primavera, J., Williams, M., 1998. Nature's subsidies to shrimp and salmon farming. Science 282, 883–884.
Naylor, R.L., Goldberg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., Troell, M., 2000. Effect of aquaculture on world fish supplies. Nature 405, 1017–1024.
Nguyen, V.H., 2007. Vietnam's catfish and marine shrimp production: an example of growth and sustainability issues. AQUA Culture AsiaPacific Magazine 3 (4), 36–38.
Nur, A., 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Indonesia. In: Hasan, M.R., Hecht, T., De Silva, S.S., Tacon, A.G.J. (Eds.), Study and Analysis of Feeds and Fertilizers for Sustainable Aquaculture Development. FAO Fisheries Technical Paper, vol. 497. FAO, Rome, pp. 245–267.
Oyelese, O.A., 2006. Shelf life of tilapia fishmeal, paste and cake. J. Fish. Int., vol. 1, pp. 98–101.
Pongmaneerat, J., Kasornchandra, J., Boonyaratpalin, S., Boonyaratpalin, M., 2001. Effect of dietary shrimp head meal contaminated with white spot syndrome virus (WSSV) on detection of WSSV in black tiger shrimp (*Penaeus monodon* Fabricius). Aquaculture Research 32, 383–387.
PRODUCE, 2007. Anuario Estadistico 2006. Ministerio de la Producción, Oficina General de Tecnolgia de la Información y Estadistica, San Isidro, Peru. Octubre, 2007. 223 pp. (www.produce.gob.pe).
Ramirez, A., 2007. Salmon by-product proteins. FAO Fisheries Circular, No. 1027. FAO, Rome. 31 pp.
Shepherd, J., 2005. Fishmeal and fish oil: sustainability and world market prospects. International Aquafeed 8, 19–21.
Sumagaysay-Chavoso, N.S., 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in the Philippines. In: Hasan, M.R., Hecht, T., De Silva, S.S., Tacon, A.G.J. (Eds.), Study and Analysis of Feeds and Fertilizers for Sustainable Aquaculture Development. FAO Fisheries Technical Paper, vol. 497. FAO, Rome, pp. 269–308.
Suresh, A.V., 2007. Developments of the aquafeed industry in India. In: Hasan, M.R., Hecht, T., De Silva, S.S., Tacon, A.G.J. (Eds.), Study and Analysis of Feeds and Fertilizers for Sustainable Aquaculture Development. FAO Fisheries Technical Paper, vol. 497, pp. 221–243.
Swisher, K., 2008. Market report 2007: a record year, but will it continue. The Renderer XXXVII (No.2), 10–18 (April 2008).
Tacon, A.G.J., 1998. Global trends in aquaculture and aquafeed production. International Aquafeed Directory and Buyers' Guide 1997/1998, Turret Rai Group PLC, Rickmansworth, UK, pp. 5–37.
Tacon, A.G.J., 2003. Global trends in aquaculture and global aquafeed production. International Aquafeed-Directory and Buyers' Guide 2003. Turret West Ltd, Bartham Press, Luton, UK, pp. 4–25.
Tacon, A.G.J., 2004. Use of fish meal and fish oil in aquaculture: a global perspective. Aquatic Resources, Culture and Development 1, 3–14.
Tacon, A.G.J., 2005. Salmon aquaculture dialogue: status of information on salmon aquaculture feed and the environment. International Aquafeed 8, 22–37.
Tacon, A.G.J., Barg, U.C., 2000. Trends in aquaculture production and nutrient supply. Encyclopedia of Life Support Systems — EOLSS. UNESCO, Paris.
Tacon, A.G.J., Forster, I.P., 2001. Global trends and challenges to aquaculture and aquafeed development in the new millennium. International Aquafeed-Directory and Buyers' Guide 2001, Turret RAI, Uxbridge, Middlesex, UK, pp. 4–25.
Tacon, A.G.J., Nates, S.F., 2007. Meeting the feed supply challenges. In: Arthur, R., Nierentz, J. (Eds.), Global Trade Conference on Aquaculture. Qingdao, China, 29–31 May 2007. FAO Fisheries Proceedings, vol. 9. FAO, Rome. 271 pp.
Tacon, A.G.J., Hasan, M.R., Subasinghe, R.P., 2006. Use of fishery resources as feed inputs to aquaculture development: trends and policy implications. FAO Fisheries Circular No. 1018. FAO, Rome. 99 pp.
Thongrod, S., 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Thailand. In: Hasan, M.R., Hecht, T., De Silva, S.S., Tacon, A.G.J. (Eds.), Study and Analysis of Feeds and Fertilizers for Sustainable Aquaculture Development. FAO Fisheries Technical Paper, vol. 497. FAO, Rome, pp. 309–330.
Tidwell, J.H., Allan, G.L., 2001. Fish as food: aquaculture's contribution: ecological and economic impacts and contributions of fish farming and capture fisheries. European Molecular Biology Organization, EMBO Report 2, 958–963.
Turchini, G.M., Gunasekera, R.M., De Silva, S.S., 2003. Effect of crude oil extracts from trout offal as a replacement for fish oil in the diets of the Australian native fish Murray cod *Maccullochella peelii peelii*. Aquaculture Research 34, 685–783.
Weimin, M., Mengqing, L., 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in China. In: Hasan, M.R., Hecht, T., De Silva, S.S., Tacon, A.G.J. (Eds.), Study and Analysis of Feeds and Fertilizers for Sustainable Aquaculture Development. FAO Fisheries Technical Paper, vol. 497. FAO, Rome, pp. 141–190.
Wright, I., 2004. Salmon by-products. Aqua Feeds: Formulation and Beyond 1, 10–12.
Zertuche-González, J.A., Sosa-Nishizaki, O., Vaca Rodriguez, J.G., del Moral Simanek, R., Yarish, C., Costa-Pierce, B.A., 2008. Marine science assessment of capture-based tuna (*Thunnus orientalis*) aquaculture in Ensenada region of northern Baja California, Mexico. Final Report to The David and Lucile Packard Foundation, 300 Second Street, Los Altos, California, USA. 95 pp.