Feed Matters: Satisfying the Feed Demand of Aquaculture

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Feed Matters: Satisfying the Feed Demand of Aquaculture

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The rise of aquaculture has attracted a great deal of attention and this has increased since the sector is now providing more fish and crustaceans than capture fisheries. This global prominence has been partly facilitated by the availability and on-farm provision of feed inputs within the major aquaculture producing countries. More than 70% of the total global aquaculture production is dependent upon the supply of external feed inputs. For the aquaculture sector to maintain its current growth rate, the supply of nutrient and feed inputs will have to grow at a similar rate, while aquatic ingredients production remains static and other sectors compete for same feed resources. This paper attempts to make a global analysis of aquaculture growth, its role in global food production, and to update the estimates of compound feed dependent fish and crustacean species.

Keywords feeds, aquaculture, food security, dependency

DEPENDENCE UPON CAPTURE FISHERIES

Global aquaculture production has more than doubled since 2000, increasing from 41.7 million tonnes to a new high of over 90.4 million tonnes in 2012, with production growing at an annual average rate of 6.7% since then (FAO, 2014a). In marked contrast, wild capture fisheries landings have remained static, with total landings decreasing by 2.4% from 94.7 to 92.4 million tonnes over the same period (FAO, 2014a). Notwithstanding the above decrease, capture fisheries supplied the aquaculture sector with valuable marine feed inputs; 21.7 million tonnes of total capture fisheries landings being destined for non-food uses in 2012, of which 75% (16.3 million tonnes) was reduced to fishmeal and fish oil (FAO, 2014b).

In particular, the fish and crustacean aquaculture sector (estimated at over 50.6 million tonnes or 55.9% of total global aquaculture production in 2012; FAO, 2014a) has been the largest consumer of captured non-food products for over a decade (Naylor et al., 2009; Tacon and Metian, 2009), either in the form of fishmeal and fish oil used within industrially compounded aquafeeds (Mallison, 2013) or in the form of whole/processed fish used as a direct feed or within farm-made aquafeeds (Hasan, 2012). Not surprisingly, aquaculture's consumption of captured non-food fish products as feed inputs consequently results in "double counting" global fisheries production – once as non-food-capture fisheries landings and again as aquaculture production (Tacon, 1997). Clearly, the proportion of the non-food fisheries catch destined for aquaculture use should be excluded when estimating total global fisheries landings for any given year (Figure 1).

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Global Aquaculture Feed Demand

In contrast to capture fisheries, where fish and crustacean landings are based upon the natural productivity of the aquatic ecosystem in which they are fished and the degree of fishing effort and management, the production of farmed fish and crustaceans is dependent upon the external provision of feed or nutrient inputs to the culture system. Feed or nutrient inputs range from the direct use of commercially manufactured compound aquaculture feeds, the use of on-farm prepared aquaculture feeds, the use of lower market value fish as a direct feed, to the indirect use of fertilizers for increased production of natural live feed organisms within the culture system (Hasan et al., 2007).

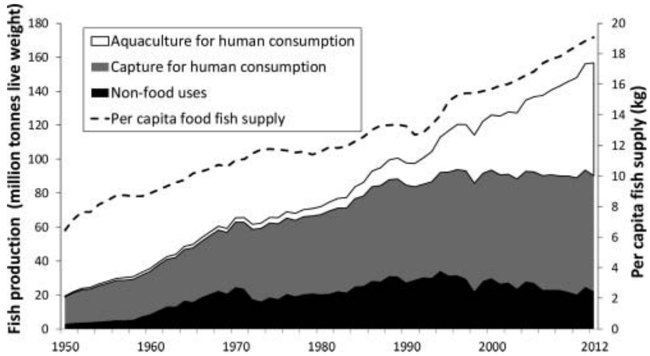

Figure 1 Total landings from capture fisheries and aquaculture destined for food and non-food uses and the trends of per capita supply (data from FAO, 2014b). *Note: Production includes, fish, crustaceans, and molluscs, but excludes aquatic plants.*

The choice of feed input employed by a farmer for a particular fish or crustacean species depends upon a variety of factors and considerations, with the main ones being:

- The feeding habit and market value of the target species (i.e., herbivorous, omnivorous, or carnivorous species, higher or lower market value species) and the ability of the target species to use natural available food organisms present within the intended culture system.
- The culture system (earthen pond, pen enclosure, raceway, or cage) and intended stocking density (extensive, semi-intensive, or intensive) of the target species.
- The market availability of existing commercially available formulated commercial feeds for the target species or not.
- The local market availability and cost of suitable feed ingredient sources and/or lower value fish species for the production of farm-made feeds; and last but not least
- The financial resources of the farmer, and his or her ability to purchase feeds and allocate resources (in terms of credit, feeding/labor requirement, feed storage, etc.) for feeding the intended target species and culture system employed (Tacon et al., 2013).

According to our latest global estimates, about 70% of fish and crustacean aquaculture production are direct-fed species (35.7 million tonnes in 2012), including Chinese carps, tilapia, shrimp, catfish, salmon, marine fish, other miscellaneous freshwater and diadromous fishes, freshwater crustaceans, milkfish, and eel (Table 1), with the remaining 30% of fish and crustacean aquaculture production being predominantly filter-feeding fish species, including silver carp, bighead carp, catla, rohu, and mrigal carp (11.8 million tonnes in 2012), and other non-identified freshwater fish species (2.1 million tonnes in 2012; FAO, 2014a). Moreover, it is estimated that about 68% of direct-fed species production (24.3 million tonnes in 2012) are currently dependent upon the use of commercially manufactured aquaculture feeds (Table 1), with total global commercial aquaculture feed consumption for these species estimated at 39.6 million tonnes in 2012 (Table 1; Figure 2) and with feed production growing at an average annual rate of 10.3% per year since 2000, and expected to grow to 49.7 million tonnes by 2015, 65.4 million tonnes by 2020, and 87.1 million tonnes by 2025 (Figure 2).

The global feed estimate of 39.6 million tonnes for 2012 (Tables 1 and 2) is in close agreement with the estimate of 37.6 million tonnes made by IFFO (Dr. Andrew Jackson, The Marine Ingredients Organization, personal communication, April 2014), but differs slightly from the feed industry estimates of Alltech for 2012 (34.4 million tonnes; Alltech, 2014) although are similar to their aquafeed production estimates for 2013 (40.4 million tonnes; Alltech, 2014). However, it should be stated that the present estimates and that of IFFO are based on global reported fish and crustacean aquaculture production data (FAO, 2014a) and a series of species assumptions (i.e., percent of production on feeds, FCR; Tables 1 and 2), whereas the estimates of Alltech are based on an assessment of compound animal feed production from only 130 countries (Alltech, 2014). Surprisingly, despite the different approaches, the estimates were in close agreement.

By far the largest consumers of commercial aquaculture feeds were the herbivorous and omnivorous carp species at 11.03 million tonnes (27.8% global aquaculture feed production in 2012), followed by tilapia (6.67 million tonnes), shrimp (6.18 million tonnes), catfish (4.27 million tonnes), salmon (2.98 million tonnes), marine fish (2.98 million tonnes), other miscellaneous freshwater and diadromous fish (1.31 million tonnes), freshwater crustaceans (1.80 million tonnes), milkfish (1.14 million tonnes), and eel (370,000 tonnes; Figure 2). Of particular note was the rapid growth of fed species fish and crustacean aquaculture production (mean APR 8.1% from 2000 to 2012), and consequent demand for compound aquaculture feeds, with the fastest growing species sectors being other freshwater and diadromous fish species (APR 18.3%), followed by catfish (APR 18.1%), freshwater crustaceans (APR 12.8%), shrimp (APR 11.8%), tilapia (AR 11.7%), salmon (APR 6.9%), marine fish (APR 6.9%), milkfish (APR 6.0%), trout (APR 4.7%), carps (APR 4.7%), and eels (APR 1.1%; Table 1).

In contrast to commercially prepared aquaculture feeds, the total global usage of farm-made aquaculture feeds and low-value fish as a direct feed is still largely undocumented, with the global production of farm-made aquaculture feeds estimated to be between 15 and 30 million tonnes, and the direct use of low-value fish as feed estimated at being between 3 and 6 million tonnes, respectively (FAO, 2012, 2014c; Hasan and Halwart, 2009; Hasan, 2012; Tacon et al., 2011). Farm-made aquafeeds may range from the use of simple feed mixtures composed of one or more feed ingredients or agricultural residues, the preparation of moist or cooked feed ingredient mixtures (usually presented as a semi-moist feed ball or pellet), to the production of a nutritionally complete formulated diet in dry pelleted form (Hasan et al., 2007; Hasan and New, 2013). At present, the use of farm-made aquaculture feeds is

Table 1 Estimated global usage of commercial aquaculture feeds by major species grouping (values given in thousand tonnes; adapted from Tacon and Metian (2008a), Tacon et al. (2011), and FAO (2014a)

Year	Total production[1]	Growth (%/year)[2]	Percent on feeds[3]	Species EFCR[4]	Total feeds used[5]
Chinese fed carps: includes Grass carp, Common carp, Crucian carp, Wuchang bream, and Black carp; major country producers in 2012 being China 90.8%, Indonesia 3.0%, India 1.0%, Vietnam 0.8%, and Bangladesh 0.7%, with production increasing at an APR of 4.7% per year from 2000 to 2012					
2000	7,184	3.9	37	2	5,316
2001	7,730	7.6	38	1.9	5,581
2002	8,105	4.8	42	1.9	6,468
2003	8,467	4.5	43	1.9	6,917
2004	8,195	−3.2	44	1.9	6,851
2005	8,622	5.2	45	1.8	6,984
2006	8,916	3.4	46	1.8	7,382
2007	9,305	4.4	47	1.8	7,872
2008	9,758	4.9	48	1.8	8,431
2009	10,483	7.4	49	1.8	9,246
2010	11,287	7.7	50	1.8	10,158
2011	11,771	4.3	51	1.7	10,205
2012	12,473	6.0	52	1.7	11,026
2015	14,440	5	55	1.7	13,501
2020	17,568	4	60	1.6	16,865
2025	20,366	3	65	1.6	21,181
Tilapia: includes Nile tilapia, Tilapia nei, Blue-Nile tilapia, Mozambique tilapia, Blue tilapia, Three spotted tilapia, Longfin tilapia, Redbreast tilapia, Sabaki tilapia, Redbelly tilapia, Blackchin tilapia,and Mango tilapia; major country producers in 2012 being China 34.4%, Egypt 17.0%, Indonesia 15.9%, Brazil 6.3%, and the Philippines 5.8%, with production increasing at an APR of 11.7% per year from 2000 to 2012					
2000	1,190	14.7	75	1.9	1,696
2001	1,302	9.4	76	1.9	1,880
2002	1,417	8.2	77	1.8	1,953
2003	1,587	12.0	78	1.8	2,215
2004	1,795	13.1	79	1.8	2,530
2005	1,992	11.0	80	1.8	2,852
2006	2,234	12.1	81	1.7	3,056
2007	2,554	14.3	82	1.7	3,493
2008	2,826	10.6	83	1.7	3,948
2009	3,109	10.0	84	1.7	4,440
2010	3,497	10.0	85	1.7	5,053
2011	3,976	13.7	86	1.7	5,813
2012	4,507	13.3	87	1.7	6,666
2015	5,999	10.0	90	1.7	9,178
2020	8,814	8.0	95	1.6	13,397
2025	12,950	8.0	100	1.6	20,720
Catfishes: includes order Siluriformes – Pangas catfishes, Torpedo-shaped catfishes, Amur catfish, Channel catfish, Yellow catfish, North African catfish, Striped catfish, Hybrid catfish, Sorubims, Philippine catfish, Upsidedown catfishes, Asian redtail catfish, Stinging catfish, South American catfish, Wels catfish etc; major country producers in 2012 being Vietnam 32.2%, China 23.4%, Indonesia 20.2%, and Bangladesh 6.8%, with production increasing at an APR of 18.1% per year from 2000 to 2012					
2000	529	−2.3	72	1.8	772
2001	559	5.6	73	1.8	794
2002	667	19.3	73	1.7	873
2003	1,034	55.0	74	1.7	1,318
2004	1,269	22.7	74	1.6	1,523
2005	1,500	18.2	75	1.6	1,752
2006	1,792	19.5	75	1.5	1,908
2007	2,265	26.4	76	1.5	2,446
2008	2,816	24.3	76	1.5	3,041
2009	2,838	0.8	77	1.5	3,108
2010	3,205	12.9	77	1.5	3,509
2011	3,387	5.7	78	1.4	3,699
2012	3,909	15.4	78	1.4	4,269

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Table 1 Estimated global usage of commercial aquaculture feeds by major species grouping (values given in thousand tonnes; adapted from Tacon and Metian (2008a), Tacon et al. (2011), and FAO (2014a) *(Continued)*

Year	Total production[1]	Growth (%/year)[2]	Percent on feeds[3]	Species EFCR[4]	Total feeds used[5]
2015	4,924	8.0	80	1.4	5,515
2020	6,589	6.0	82	1.3	7,024
2025	8,817	6.0	85	1.3	9,743
Other freshwater & diadromous fishes: includes the families: Channidae, Synbranchidae, Percichthyidae, Characidae, Centrarchidae, Centropomidae, Osphronemidae, Belontidae, Osmeridae – Snakehead, Asian swamp eel, Mandarin fish, Largemouth black bass, Piarpatinga, Cachama, Japanese seabass, Giant gourami, Barramundi, Tambacu hybrid, Snakeskin gourami, Pacu, Indonesian snakehead, Tambatinga hybrid, Pond smelt, Striped snakehead, Nile perch; major country producers in 2012 being China 73.3%, Brazil 11.5%, and Indonesia 5.5%, with production increasing at an APR of 18.3% per year from 2000 to 2012					
2000	285	7.5	10	2	57
2001	244	–14.4	12	2	58
2002	291	19.3	14	2	81
2003	842	189.3	16	2	269
2004	948	12.6	18	2	341
2005	1,064	12.2	20	2	426
2006	1,163	9.3	22	2	512
2007	1,331	14.4	24	2	639
2008	1,390	4.4	26	2	723
2009	1,527	9.8	28	2	855
2010	1,660	8.7	30	2	996
2011	1,957	17.9	32	2	1,252
2012	2,136	9.1	34	1.8	1,307
2015	2,691	8.0	40	1.8	1,937
2020	3,601	6.0	50	1.7	3,061
2025	4,596	5.0	60	1.7	4,688
Salmon: includes Atlantic salmon, Coho salmon, Chinook salmon, Salmonids/Salmonoids nei; major country producers in 2012 being Norway 53.7%, Chile 24.5%, and UK 7.2%, with production increasing at an APR of 6.9% per year from 2000 to 2012					
2000	1,025	12.3	100	1.3	1,332
2001	1,205	17.6	100	1.3	1,566
2002	1,224	1.6	100	1.3	1,591
2003	1,281	4.7	100	1.3	1,665
2004	1,380	7.7	100	1.3	1,794
2005	1,403	1.7	100	1.3	1,824
2006	1,471	4.8	100	1.3	1,912
2007	1,527	3.8	100	1.3	1,985
2008	1,590	4.1	100	1.3	2,067
2009	1,656	4.1	100	1.3	2,153
2010	1,622	–2.0	100	1.3	2,109
2011	1,939	19.5	100	1.3	2,521
2012	2,294	18.3	100	1.3	2,982
2015	3,053	10.0	100	1.3	3,969
2020	4,486	8.0	100	1.3	5,832
2025	5,725	5.0	100	1.3	7,442
Trout: includes Rainbow trout, Trouts nei, Sea trout, Brook trout, Sevan trout; major country producers in 2012 being Chile 28.9%, Iran 14.9%, Turkey 13.0% and Norway 8.5%, with production increasing at an APR of 4.7% per year from 2000 to 2012					
2000	508	7.6	100	1.3	660
2001	565	11.2	100	1.3	734
2002	560	–0.9	100	1.3	728
2003	565	0.9	100	1.3	734
2004	572	1.2	100	1.3	744
2005	566	–1.0	100	1.3	736
2006	610	7.8	100	1.3	793
2007	667	9.3	100	1.3	867
2008	677	1.5	100	1.3	880
2009	752	11.1	100	1.3	978
2010	752	0.0	100	1.3	978

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Table 1 Estimated global usage of commercial aquaculture feeds by major species grouping (values given in thousand tonnes; adapted from Tacon and Metian (2008a), Tacon et al. (2011), and FAO (2014a) *(Continued)*

Year	Total production[1]	Growth (%/year)[2]	Percent on feeds[3]	Species EFCR[4]	Total feeds used[5]
2011	790	5.1	100	1.3	1,027
2012	879	11.3	100	1.3	1,143
2015	1,107	8.0	100	1.3	1,439
2020	1,481	6.0	100	1.3	1,925
2025	1,890	5.0	100	1.3	2,457
Milkfish: major country producers in 2012 being Indonesia 51.2%, Philippines 41.0% and Taiwan 7.6%, with production increasing at an APR of 6.0% per year from 2000 to 2012					
2000	468	5.9	34	2	318
2001	495	5.8	35	2	347
2002	528	6.7	36	2	380
2003	552	4.5	37	2	408
2004	574	4.0	38	2	436
2005	595	3.7	39	2	464
2006	585	–1.7	40	2	468
2007	667	14.0	41	2	547
2008	676	1.3	42	2	568
2009	718	6.2	43	2	617
2010	809	12.7	45	2	728
2011	891	10.1	46	2	820
2012	943	5.8	47	2	886
2015	1,188	8.0	50	1.8	1,069
2020	1,590	6.0	55	1.6	1,399
2025	2,029	5.0	60	1.5	1,826
Eel: includes all family Anguillidae – Japanese eel, European eel, Short-finned eel, and River eels nei; major country producers in 2012 being China 88.0%, Japan 7.2%, and Korea Rep. 1.8%, with production increasing at an APR of 1.1% per year from 2000 to 2012					
2000	212	6.7	92	1.8	351
2001	210	−0.9	92	1.7	329
2002	210	−0.2	93	1.7	332
2003	210	0.2	93	1.7	332
2004	224	6.5	94	1.6	337
2005	217	−2.9	94	1.6	327
2006	239	9.9	95	1.6	363
2007	273	14.2	95	1.6	415
2008	265	−2.9	95	1.6	403
2009	275	3.8	95	1.6	418
2010	271	−1.4	96	1.6	416
2011	254	−6.3	96	1.6	390
2012	241	−5.1	96	1.6	370
2015	241	0	97	1.5	351
2020	241	0	98	1.5	354
2025	241	0	100	1.5	361
Marine fish: includes all ISSCAAP division – Marine fishes nei, Gilthead seabream, Japanese amberjack, European seabass, Flathead grey mullet, Japanese seabass, Pompano, Groupers nei, Large yellow croaker, Turbot, Red drum, Silver seabream, Lefteye flounders nei, Bastard halibut, Cobia, Korean rockfish, Atlantic cod, Tiger pufferfish, Eastern pomfred, Amberjacks nei etc; major country producers in 2012 being China 47.3%, Japan 11.0%, Egypt 7.7%, Greece 5.4%, Turkey 4.5%, and India 3.8%, with production increasing at an APR of 6.9% per year from 2000 to 2012					
2000	977	16.4	60	2	1,172
2001	1,051	7.6	62	2	1,303
2002	1,162	10.5	65	2	1,511
2003	1,227	5.6	67	2	1,644
2004	1,276	4.0	70	1.9	1,697
2005	1,441	12.9	70	1.9	1,916
2006	1,643	14.0	71	1.9	2,216
2007	1,737	5.7	72	1.9	2,376
2008	1,951	12.3	72	1.9	2,669
2009	1,950	–0.1	73	1.9	2,705

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Table 1 Estimated global usage of commercial aquaculture feeds by major species grouping (values given in thousand tonnes; adapted from Tacon and Metian (2008a), Tacon et al. (2011), and FAO (2014a) *(Continued)*

Year	Total production[1]	Growth (%/year)[2]	Percent on feeds[3]	Species EFCR[4]	Total feeds used[5]
2010	1,840	–5.6	74	1.9	2,587
2011	2,046	11.2	75	1.8	2,762
2012	2,181	6.6	76	1.8	2,984
2015	2,746	8.0	80	1.7	3,734
2020	3,675	6.0	85	1.6	4,998
2025	4,691	5.0	90	1.5	6,333
Shrimp: includes all FAO ISSCAAP group for shrimp – Whiteleg shrimp, Giant tiger prawn, Penaeus shrimp nei, Kuruma prawn, Fleshy prawn, Metapenaeus shrimp nei, Indian white prawn, Speckled shrimp, Banana prawn, Blue shrimp, Greasyback shrimp etc; major country producers in 2012 being China 39.2%, Thailand 13.8%, Vietnam 11.3%, Indonesia 8.5%, Ecuador 6.5% and India 6.2%, with production increasing at an APR of 11.8% per year from 2000 to 2012					
2000	1,137	8.6	77	2	1,751
2001	1,311	15.3	78	2	2,045
2002	1,467	11.9	78	1.9	2,174
2003	2,051	39.8	79	1.9	3,006
2004	2,364	15.3	79	1.9	3,548
2005	2,668	12.9	80	1.9	4,055
2006	3,111	16.6	80	1.8	4,480
2007	3,294	5.9	81	1.8	4,803
2008	3,400	3.2	81	1.8	4,957
2009	3,532	3.9	82	1.8	5,213
2010	3,779	7.0	82	1.7	5,268
2011	4,185	10.7	83	1.7	5,905
2012	4,327	3.4	84	1.7	6,179
2015	4,729	3.0	85	1.7	6,833
2020	5,482	3.0	87	1.6	7,631
2025	6,354	3.0	90	1.5	8,578
Freshwater crustaceans: includes all ISSCAAP group for freshwater crustaceans – Chinese mitten crab, Red swamp crawfish, Oriental river prawn, Giant river prawn, River prawns nei, Danube crayfish, Marron crayfish, Red claw crayfish, Yabby crayfish etc; major country producers in 2012 being China 90.4%, Bangladesh 2.7%, USA 2.4%, India 1.7% and Thailand 1.3%, with production increasing at an APR of 12.8% per year from 2000 to 2012					
2000	429	57.1	40	2.4	412
2001	521	21.4	41	2.4	513
2002	577	10.7	42	2.3	557
2003	785	36.0	43	2.3	776
2004	846	7.8	44	2.2	819
2005	914	8.0	45	2.2	905
2006	955	4.5	46	2.1	922
2007	1,272	33.2	47	2.1	1,255
2008	1,374	8.0	48	2	1,319
2009	1,555	13.2	49	2	1,524
2010	1,692	8.8	50	2	1,692
2011	1,665	–1.6	51	2	1,698
2012	1,827	9.7	52	1.9	1,805
2015	2,115	5.0	55	1.9	2,210
2020	2,699	5.0	60	1.8	2,915
2025	3,445	5.0	65	1.7	3,807

[1]Total reported species group production for 2000–2012 are taken from FAO (2014a), and estimates for 2015, 2020, and 2025 are calculated based on expected growth. [2]Mean annual percent growth. [3]Estimated percent of total species-group production fed on commercial aquaculture feeds. [4]Estimated average species-group economic feed conversion ratio (total feed fed/total species-group biomass increase). [5]Estimated total species-group aquaculture feed used (total species-group production × FCR [feed conversion ratio]).

restricted to small-scale farmers within the Asian and African region for the production of a variety of fish and crustacean species, including Indian major carps, catfish, tilapia, freshwater crustaceans, and marine fish (Ramakrishna et al., 2013; Shipton and Hasan, 2013); the latter also being particularly reliant upon the use of low-value fish as a direct feed (Hasan, 2012; Huntington and Hasan, 2009).

Sustaining Feed Supply in a Competing Market

While aquaculture's rise has been rapid over the past quarter century, global aquatic food production is still dwarfed by terrestrial agricultural food production systems; the total food supply of aquatic animal and plant products is estimated at 144 million tonnes in 2011 compared with total food supply from agriculture at 3,982 million tonnes for the same year (over 27-fold greater;

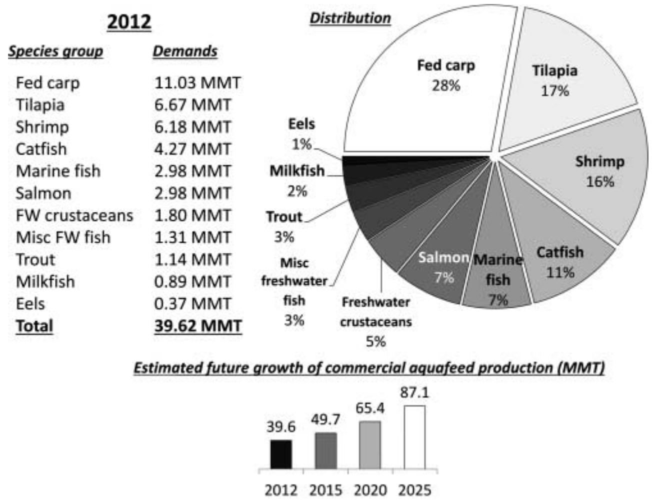

Figure 2 Total estimated usage of commercial aquaculture feeds by major fed species groupings of in 2012, and the expected growth in demand for 2015, 2020, and 2025.

Table 3). In global terms, captured and farmed aquatic food products contributed less than 3.6% of total global agricultural food supply, 1.2% of total calorie supply, 1.5% of our total fat supply, and 6.7% of total protein supply (FAO, 2014b). Similarly, in terms of global animal feed production, aquaculture feeds represented only 3.5% of total global compound animal feed production in 2013 (Alltech, 2014).

Although the relative contribution of aquaculture to global feed and food supply is still small in global terms, this is certainly not the case at a regional or country level, or in the case of several key internationally traded feed commodities (e.g., Thailand, Vietnam, Norway, and Chile). Within the Asian region (over 91.2% of total global aquaculture production), China alone accounted for 53.9 million tonnes or 59.6% of total global aquaculture production in 2012 (FAO, 2014a), with farmed aquatic meat production in China representing the second most produced meat after pork in 2012 (Tacon and Metian, 2013). Moreover, apart from being the world's most populous country (one-fifth of the world's population), China is also the world's largest producer of compound animal feed, including aquaculture feed. According to feed industry estimates, China produced 189.13 million tonnes of animal feed in 2013, including pig feed (38.6% by weight), broiler feeds (26.4%), layer feeds (16.4%), aquaculture feeds (23 million tonnes or 12.2% by weight), dairy feeds (3.2%), and beef feeds (1.0%; Alltech, 2014).

Notwithstanding the above, despite its small size in global terms, the aquaculture sector has been the largest consumer of fishmeal and fish oil for over a decade (Naylor et al., 2009; Tacon and Metian, 2008a), with the sector reportedly consuming 68% of the total global fishmeal production in 2012 and 74% of the total global fish oil production in 2012 (Figure 3; Mallison, 2013). Fishmeal and fish oil represent ideal feed ingredients for the aquaculture sector by possessing a nutritional profile approximating to the nutritional requirements of most farmed aquatic species (NRC, 2011); fishmeal not only being an excellent source of dietary protein and essential amino acids but also being a good source of nucleotides, essential fatty acids, phospholipids, minerals, and trace elements (including calcium, phosphorus, magnesium, zinc, manganese, selenium, iodine, molybdenum, and chromium), and fat soluble and water soluble vitamins (including vitamin A, D, E, choline, inositol, B-vitamins, etc; Tacon et al., 2009).

Moreover, apart from being the world's largest animal and aquaculture feed producer, China is also the world's largest importer and consumer of plant and animal feedstuffs, including fishmeal (Chiu et al., 2013; Tacon and Nates, 2007). However, due to the current limited global supplies of fishmeal and fish oil (Figure 4), and the steadily increasing costs of these much sought after commodities (Figure 4), the aquaculture feed manufacturing sector has learnt how to reduce its dietary

Table 2 Global totals for major fed fish and crustacean aquaculture production and estimated compound aquafeed production (data derived from Table 1)

Year	Total production	Total feeds used
2000	13,943	13,837
2001	15,192	15,15
2002	16,208	16,648
2003	18,601	19,284
2004	19,443	20,62
2005	20,982	22,241
2006	22,719	24,012
2007	24,892	26,698
2008	26,723	29,006
2009	28,395	31,257
2010	30,414	33,494
2011	32,861	36,092
2012	35,717	39,617
2015	43,233	49,736
2020	56,226	65,401
2025	71,104	87,136

Table 3 Global production and utilization of major primary food commodities derived from agriculture and aquatic food production systems in 2011 (values given in 1000 tonnes; data compiled from FAO, 2014c)

Primary food commodity	Total	Food	Feed	Processing	Seed	Waste	Other
Cereals	2,345,593	1,014,082	818,85	89,175	66,918	100,781	228,641
Vegetables	1,087,504	935,189	52,562	611	0	92,94	536
Starchy roots	798,175	437,922	177,249	14,712	35,711	78,068	52,378
Oilcrops	550,913	48,218	35,568	422,535	11,099	13,183	13,652
Fruits	629,018	510,073	5,543	55,318	0	60,12	1,884
Pulses	68,336	47,092	13,244	0	3,966	3,478	710
Treenuts	15,483	15,423	0	0	0	456	67
Terrestrial meat	296,607	290,648	75	453	0	882	1,79
Eggs	70,682	61,563	74	0	4,697	3,291	710
Milk	739,111	621,61	78,961	101	101	18,622	16,752
Total agricultural foods	**6,601,421**	**3,981,820**	**1,182,125**	**582,906**	**122,391**	**371,821**	**317,189**
Fish and seafood	149,508	129,908	23,445	466	466	0	3,868
Other aquatic products	23,127	14,287	159	0	0	0	8,799
Total aquatic products	**172,635**	**144,196**	**23,604**	**466**	**466**	**0**	**12,666**

Bolded values indicate an aggregate volume:
- Total agricultural foods represent the sum of cereals, vegetables, starchy roots, oil crops, fruits, pulses, tree nuts, terrestrial meat, eggs and milk
- Total aquatic products represent the sum of fish and seafood and other aquatic products.

reliance on these finite commodities, by using alternative dietary protein and lipid sources (Bendiksen et al., 2011; Naylor et al., 2009; Rust et al., 2011; Turchini et al., 2009).

As in terrestrial animals, those farmed aquatic species feeding wildly/naturally lower on the aquatic food chain (includes most herbivorous cyprinids, tilapia, and omnivorous catfish species – all freshwater fish species) are more flexible in terms of feed ingredient use (and therefore less dependent upon the dietary use of fishmeal and fish oil use) than shrimp or more carnivorous fish species (includes most salmonids and marine fish species – all diadromous and marine fish species; Figure 5); the latter often having a specific requirement for long-chain polyunsaturated fatty acids and essential amino acids only found in aquatic or terrestrial animal feed ingredient sources (El-Sayed, 2013; Nates, 2013; NRC, 2011). Notwithstanding the above, feed ingredient selection by aquaculture feed compounders are usually based upon series of different considerations, these ranging from market availability and cost, nutritional composition and quality, processing/handling requirements and limitations, target species acceptability, to market acceptability for use. The latter consideration is becoming increasingly important due to the need for market compliance with regulated feed contaminant levels and growing market concerns over food safety issues (both real and perceived; Bøhn et al., 2014; Ran et al., 2009; Tacon and Metian, 2008b; Wang et al., 2014).

Balancing the Scales – Recreation or Food

Although over 94% of global aquaculture production (85.6 million tonnes) and 73% of global fisheries production

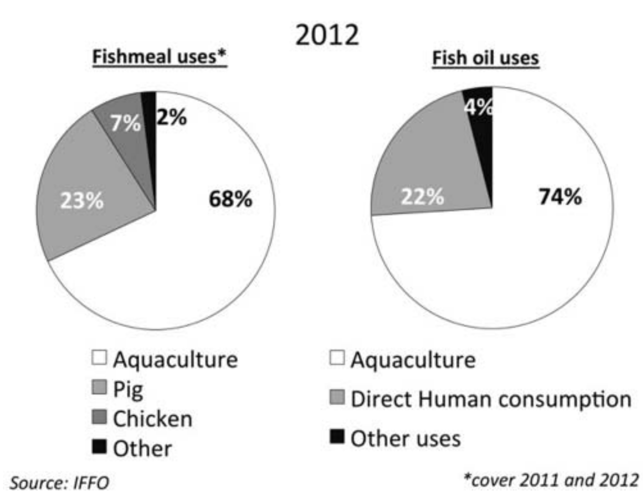

Figure 3 Comparison of world uses of fishmeal and fish oil by market segment in 2012 (data source: Mallison, 2013).

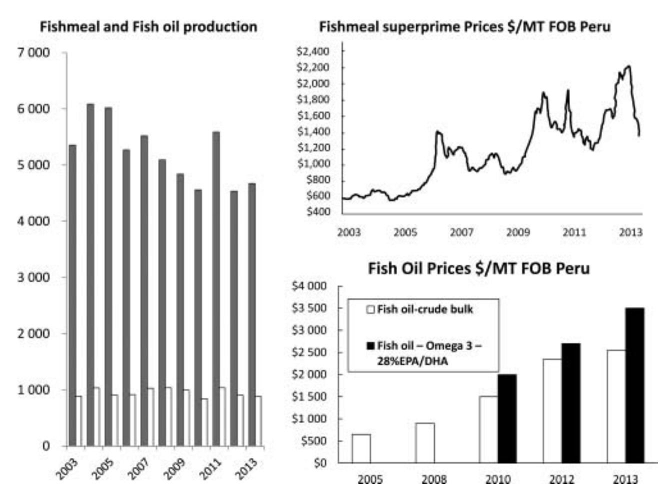

Figure 4 Fish oil and fishmeal: (A) Production trends (B) Trend of fishmeal superprime price in US$ per metric tonne free on-board – FOB – Peru. (C) Trend of fish oil price (crude and specific refined oil) in US$ per metric tonne free on-board – FOB – Peru (data sources: Mallison, 2013; Bimbo, 2013).

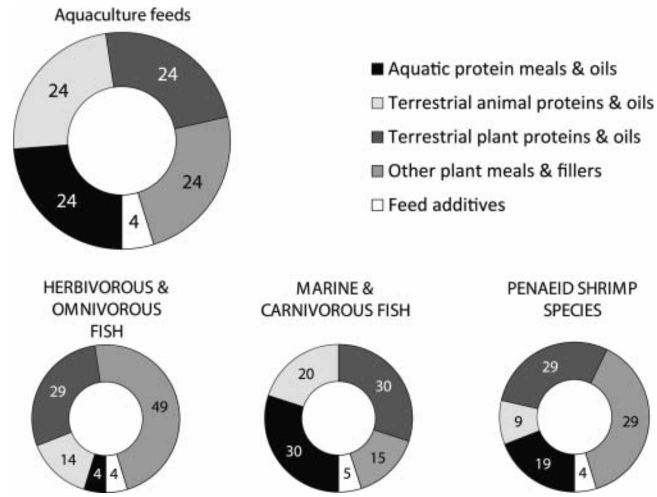

Figure 5 Typical inclusion levels of major categories of feed ingredients within compound aquaculture feeds for major fed species.

(68.0 million tonnes) was produced within developing countries in 2012, developed countries (includes the US, Japan, and the Europe) consumed over 73% of total available seafood exports (FAO, 2014a); the European Union being the single largest market for imported fish and fishery products in 2012 (representing 36% of total world imports at US $46 billion), followed by Japan (US $18 billion) and the US (US $17.6 billion; FAO, 2014a), with the US importing over 90% of its edible seafood requirements at a cost of over US $11.2 billion in 2012 (NMFS/NOAA, 2013; Tacon and Metian, 2013). This is particularly ironic, because the United States has hitherto vast underutilized natural aquatic resources (particularly within the State of Alaska and Hawaii; Corbin, 2010; Goldburg et al., 2001; Knapp, 2012; Rubino, 2008) and available agricultural and fishery feed resources to develop its own resident aquaculture sector into a major global producer. Sadly, the United States currently ranks 17th in the world in terms of global production (420,024 tonnes by weight; FAO, 2014a). This is completely the opposite its livestock sector and agricultural crop sector, where the United States is currently one of the largest livestock and crop producers in the world (Alltech, 2014), and global supplier of feed ingredients to the compound animal feed industry (Hansen and Gale, 2014). In this respect, the United States is totally self-sufficient in terms of its meat and agricultural food supply needs (with the marked exception of its fish and seafood supply).

Moreover, to date the majority of environmental NGOs within Europe and North America have focused their attention more on the conservation of their aquatic resources for fisheries and recreational purposes (Knapp, 2012; SAR, 2014), and ensuring the sustainability of their seafood supply from the fisher/farmer to the port of landing or retailer, rather than promoting increased domestic aquatic food production and supply. Clearly, the scales need to be balanced and self-sufficiency of food supply promoted as a major policy directive over recreation and increased dependency upon imports.

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