Scientific Opinion

on

The Current and Potential use of Blood products and Blood meal in Aquafeeds

Report Prepared
For

European Animal Protein Association

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By

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1. AQUACULTURE PRODUCTION TRENDS

1.1 Global overview

In just over 50 years total global aquaculture production has grown over 85-fold from 638,577 tonnes in 1950 to 54,785,841 tonnes in 2003 (Figure 1); the sector growing at an average compound rate of 8.8% per year since 1950, compared with 3.0% per year for total capture fisheries landings (FAO, 2005a). Moreover, whereas in the early fifties aquaculture consisted mainly of small-scale farming operations for local domestic consumption (54 reported species from 42 countries) by the third millennium aquaculture had grown into a multi billion dollar industry, with total production in 2003 valued at over US $ 67.3 billion and the number of farmed species and countries reporting aquaculture increasing to 246 and 164, respectively (FAO, 2005a).

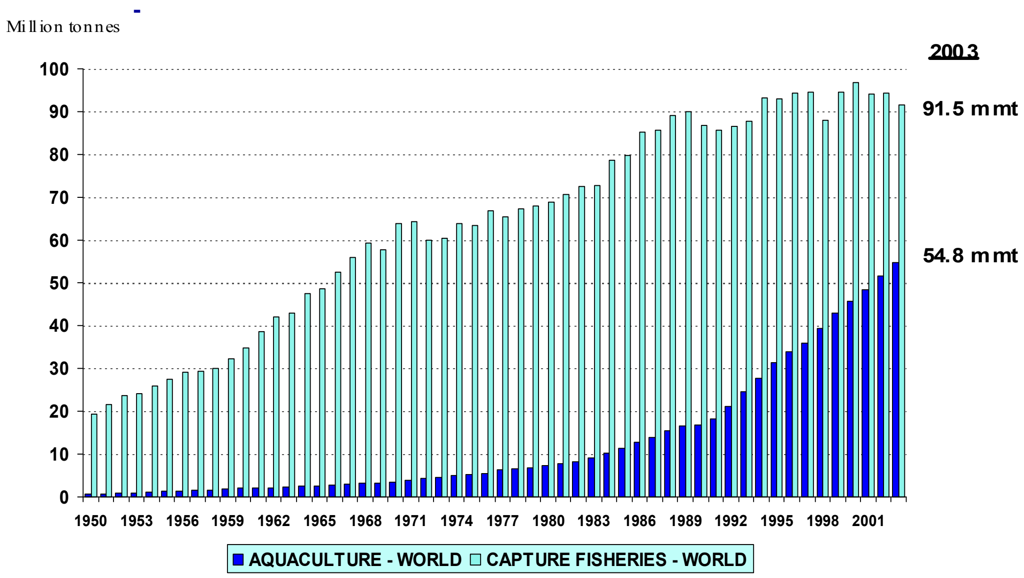


Figure 1. Contribution of aquaculture to total world fisheries landings (FAO, 2005a)

Over half of total global aquaculture production in 2003 was in the form of finfish (27.04 million tonnes, valued at $ 35.55 thousand million), followed by aquatic plants (12.48 million tonnes, $ 6.33 thousand million), molluscs (12.30 million tonnes, $ 11.50 thousand million), crustaceans (2.79 million tonnes, $ 13.34 thousand million), amphibians and reptiles (151,269 tonnes, $ 565 million), and miscellaneous aquatic invertebrate animals (20,937 tonnes, $ 20.8 million; FAO, 2005a).

1.2 Production by geographic region

By region over 91% of total aquaculture production was produced within the Asia Pacific region (49.88 million tonnes, Figure 2) in 2003, followed by the Western European region (1.96 million tonnes or 3.57%, Figure 3), the Latin America and the Caribbean region (1.25 million tonnes or 2.28%, Figure 4), the North American region (695,593 tonnes or 1.27%, Figure 5), the Eastern Southern Mediterranean and the Near East region (666,589 tonnes or 1.22%, Figure 6), the Central Eastern European region (246,763 tonnes or 0.45%, Figure 7) and the sub-Saharan African region (81,672 tonnes or 0.15%, Figure 8). It is important to highlight here that mainland China produced 38.64 million tonnes of aquaculture products in 2003 or over 70.5% of total global aquaculture production (Figure 9). Table 1 and Table 2 shows the main aquaculture producers by country and the major cultivated finfish and crustacean species within the above named regions.

1.3 Production by major fed cultivated finfish and crustacean species

On a global basis the major fed cultivated finfish and crustacean species in 2003 were reported by FAO (2005a) as follows (values given in tonnes and US $ billion):

1.	Silver carp	3,828,248 tonnes, $ 3.19 billion	4, ranking by value)
2.	Grass carp	3,682,994 tonnes, $ 2.99 billion	6
3.	Common carp	3,239,712 tonnes, $ 3.01 billion	5
4.	Bighead carp	1,928,622 tonnes, $ 1.66 billion	8
5.	Crucian carp	1,794,167 tonnes, $ 1.26 billion	11
6.	Nile tilapia	1,367,679 tonnes, $ 1.44 billion	10
7.	Atlantic salmon	1,131,241 tonnes, $ 3.40 billion	3
8.	Whiteleg shrimp	723,858 tonnes, $ 3.84 billion	1
9.	Roho labeo	713,267 tonnes, $ 0.95 billion	12
10.	Giant tiger prawn	666,071 tonnes, $ 3.43 billion	2
11.	Catla	566,051 tonnes, $ 0.54 billion	14
12.	Milkfish	552,043 tonnes, $ 0.48 billion	15
13.	White amur bream	524,927 tonnes, $ 0.60 billion	13
14.	Mrigal carp	514,662 tonnes, $ 0.47 billion	16
15.	Rainbow trout	490,652 tonnes, $ 1.45 billion	9
16.	Chinese river crab	368,050 tonnes, $ 1.84 billion	7
17.	Channel catfish:	301,192 tonnes, $ 0.38 billion	17

Figure 2. Growth of capture fisheries and aquaculture sector within the Asia Pacific region

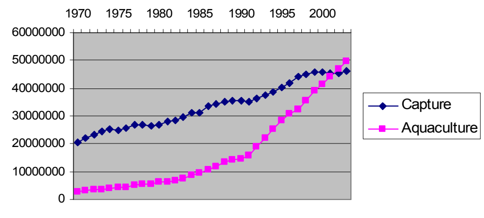


Figure 3. Growth of capture fisheries and aquaculture sector within Western Europe

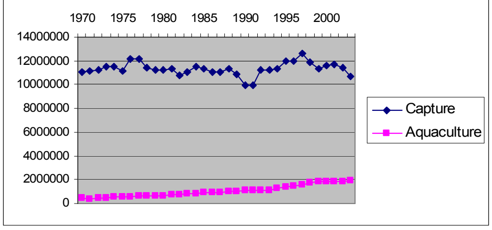


Figure 4. Growth of capture fisheries and aquaculture sector within the Latin America & Caribbeanm region

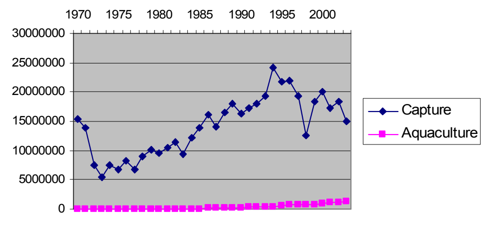


Figure 5. Growth of capture fisheries and aquaculture sector within the North American region

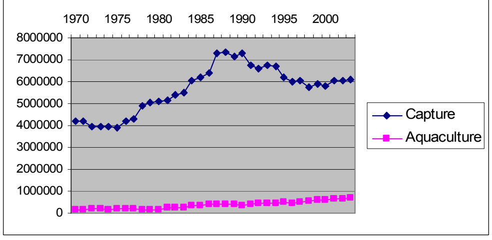


Figure 6. Growth of capture fisheries & aquaculture sector in East South Mediterranean & Near East region

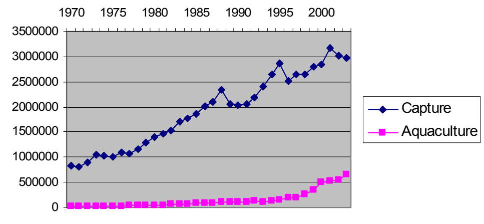


Figure 7. Growth of capture fisheries and aquaculture sector within the Central Eastern European region

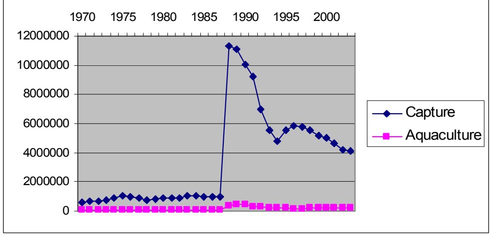


Figure 8. Growth of capture fisheries and aquaculture sector within the sub-Saharan African region

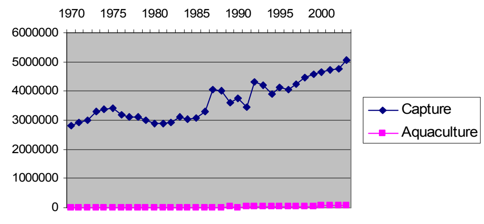


Figure 9. Growth of capture fisheries and aquaculture sector in mainland China

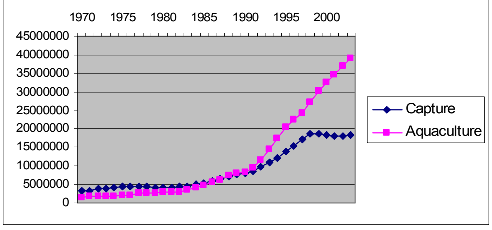


Table 1. Top 10 aquaculture producing countries by weight within the major geographical regions (values given in metric tonnes; FAO, 2005a)

Region	1970	1980	1990	2000	2001	2002	2003
Asia Pacific							
China	1369911	2841660	8306896	32705584	34528234	36927608	39004750
India	121671	365180	1017136	1942204	2119839	2187189	2215590
Philippines	101651	332642	671116	1100902	1220456	1338394	1448504
Japan	597310	1085608	1369680	1291705	1311221	1384504	1327361
Indonesia	108706	225296	599824	993727	1076749	1137151	1228559
Viet Nam	65350	99160	162076	513517	608098	728041	967502
Bangladesh	64716	91030	192592	657120	712640	786604	856956
Korea, Republic of	124058	545133	788565	667883	668022	794340	839845
Thailand	80876	95966	291719	738156	714291	621501	772970
Korea, Dem. People's Rep	71743	347299	900000	467700	507995	507995	507995
Western Europe							
Norway	480	7980	150583	491930	510748	551314	582016
Spain	156200	205638	203766	312171	312647	322714	313288
France	106444	207039	256653	266802	251655	252008	245846
Italy	28632	74640	153744	216525	218269	183962	191662
United Kingdom	444	2855	50044	152485	170516	179036	181837
Greece	1040	1963	9523	95418	97512	87928	101209
Germany	23477	38789	64435	65891	53409	49852	74280
Netherlands	86000	77052	100997	75339	57064	54442	67025
Faeroe Islands	0	222	13076	32610	51749	50952	65517
Ireland	3701	5639	26673	51247	60940	62568	62516
Latin America & Caribbean							
Chile	183	2088	70464	425058	631634	617303	633085
Brazil	19	3737	20490	172450	203710	242590	277640
Mexico	540	8626	22348	53918	76075	73675	73675
Ecuador	50	9565	77730	61311	52428	55638	67220
Colombia		224	10455	61786	57660	57160	60895
Cuba	350	2309	9174	32780	25569	27044	26897
Costa Rica		27	573	9708	10520	17892	20546
Honduras		86	3401	9080	12130	14557	20035
Venezuela	20	272	638	13505	16647	18020	15712
North America							
United States of America	168681	168365	315448	456045	479254	497346	544329
Canada	3591	3566	41216	127558	153218	171036	151264

Table 1. Continuation

Region	1970	1980	1990	2000	2001	2002	2003
ES Mediterranean & Near East							
Egypt	6000	19000	61916	340093	342864	376296	445181
Iran (Islamic Rep. of)		9263	27147	40550	62550	76817	91714
Turkey	400	1370	5782	79031	67244	61165	79943
Israel	12815	11391	14638	20098	21318	22261	20776
Saudi Arabia			1988	6004	8218	6744	11824
Syrian Arab Republic	8	509	2729	6797	5880	5988	7217
United Arab Emirates							2300
Tunisia		56	1023	1553	1868	1975	2130
Morocco	28	98	415	1889	1403	1670	1538
Iraq	10	3622	1600	1745	2000	2000	1500
Central Eastern Europe							
Russian Federation			259735	77132	90449	101483	108751
Poland	9833	9636	26400	35795	35460	32709	34526
Ukraine			81639	30969	31037	30819	25616
Czech Republic				19475	20098	19210	19670
Hungary	19500	22570	17600	12886	13056	11574	11870
Romania	18850	34676	34950	9727	10818	9248	9042
Croatia				6674	10166	8416	7605
Bosnia and Herzegovina						4685	6635
Belarus			16638	6716	4666	6523	5393
Bulgaria	5600	11500	7849	3654	2938	2308	4465
Sub-Saharan Africa							
Nigeria	3809	6028	7347	25718	24398	30663	30677
Madagascar		53	280	7280	7749	9713	9507
South Africa		13	3873	4108	4329	5555	7720
Tanzania, United Rep. of			1575	7210	7300	7630	7002
Uganda			52	820	2360	4915	5500
Zambia		27	1460	4240	4520	4630	4501
Congo, Dem. Rep. of the			700	2076	2744	2965	2965
Zimbabwe		75	157	2151	2285	2213	2600
Sudan			234	1000	1000	1600	1600
Togo			22	102	120	1025	1221

Table 2. Major cultured finfish and crustacean species within the major geographical regions (values given in metric tonnes; FAO, 2005a)

Region	1970	1980	1990	2000	2001	2002	2003
Asia Pacific							
Silver carp	262349	407154	1421175	3376079	3831570	3758418	3729636
Grass carp	90686	145670	1036762	3312498	3382949	3513018	3587209
Common carp	85712	123718	678734	2441181	2814377	2878763	2982293
Bighead carp	121682	193436	670445	1626304	1649333	1713763	1920075
Crucian carp	19857	31269	215573	1378751	1525857	1700243	1792501
Nile tilapia	9464	31781	198916	849982	920013	982601	1116295
Roho labeo	31388	90134	244678	733869	601233	666502	713267
Giant tiger prawn	2122	16549	289720	628317	670545	584884	657787
Catla	30743	86751	235253	602320	484691	553567	566051
Milkfish	167319	245242	434123	466990	494284	527021	550551
White amur bream	29097	45100	161615	511730	541115	564086	524927
Mrigal carp	11348	46482	160107	552122	445468	503522	514662
Whiteleg shrimp				2310	105809	227633	462729
Western Europe							
Atlantic salmon	294	5261	201304	621765	649763	674360	730023
Rainbow trout	43571	101699	206099	274254	307216	301011	280708
Gilthead seabream	10	257	3185	58720	63598	59634	64735
European seabass		130	3350	40823	41404	39270	44508
Common carp	9300	16690	25425	17870	17432	18078	22215
European eel	1073	2741	6745	10657	10077	8041	8814
Turbot			656	4785	4856	5267	5321
Latin America & Caribbean							
Atlantic salmon			9478	166897	253850	265726	280481
Whiteleg shrimp	50	8286	87244	140912	170728	199292	256510
Rainbow trout	79	923	10163	96476	126561	127744	124760
Coho(=Silver)salmon		64	13298	93419	136870	102522	95261
Tilapias nei	200	6925	5491	61115	64956	67900	86513
Common carp	200	1205	8332	64489	69023	69268	64797
Nile tilapia		129	5774	28325	26383	35948	40075
Cachama		32	201	13300	23442	35349	30082
Characins nei			10	5101	18112	22365	22365
Penaeus shrimps nei		73	4106	10236	14073	19018	21356
Freshwater fishes nei		3291	18704	36602	25301	27048	15977
Silver carp			2457	17530	12979	12773	13136
Freshwater siluroids nei				2475	3490	5297	5297

Table 2. Continuation

Region	1970	1980	1990	2000	2001	2002	2003
North America							
Channel catfish	18144	34855	163491	269257	270846	286039	300056
Atlantic salmon		27	12810	94890	116375	126455	106465
Red swamp crawfish	800	10849	32205	7713	13847	27825	33498
Rainbow trout	10091	22446	29404	32360	30518	26733	24155
Chinook(=Spring=King)salmon			12182	8000	7500	10400	15700
Tilapias nei			2041	8051	8051	9000	9000
Trouts nei			4497	6407	6685	7120	6830
Cyprinids nei	5700	6500	9802	6330	6330	6329	6329
Striped bass, hybrid			721	5052	4946	4758	5192
Whiteleg shrimp			900	2163	3564	4026	4577
ES Mediterranean & NE							
Nile tilapia	2500	9000	26829	161340	156449	169605	201973
Flathead grey mullet	170	372	6811	82488	98987	115173	137650
Grass carp	900	5652	11533	68586	76940	80100	93122
Common carp	13183	23730	44253	36410	39784	43463	44932
Trouts nei	10	190	3212	44533	38067	34553	40868
Silver carp	916	2892	13699	18344	27403	34961	38854
Rainbow trout	154	353	1473	10065	12998	17180	24240
Gilthead seabream			1335	27741	17507	16712	23769
Seabasses nei			102	17877	15546	14339	20982
Indian white prawn				6011	11757	10610	16622
Tilapias nei	1400	2614	5444	10248	11952	10930	10940
Central Eastern Europe							
Common carp	41300	55383	346432	119679	125398	126524	122479
Silver carp	3900	7531	82918	37713	46130	44684	46620
Rainbow trout	133	997	6433	15524	16394	17260	19750
Cyprinids nei	200	100	1160	7059	7744	11366	16178
Sub-Saharan Africa							
Tilapias nei	2129	2982	4858	7451	8127	10405	10229
Nile tilapia	94	447	2080	8066	10801	12383	9271
Torpedo-shaped catfishes nei	1491	2287	1583	4321	3021	6993	9192
Giant tiger prawn			26	5225	5681	8047	8257
Freshwater fishes nei		33	615	11324	6841	7324	6652
North African catfish		51	955	1416	3984	5056	4982
Common carp		87	671	2914	2946	2866	2967

2. AQUAFEED PRODUCTION TRENDS

2.1 Farming systems and feeding methods

In general terms, the farming systems currently employed by finfish and crustacean farmers can be broadly divided into three basic categories, namely extensive, semi-intensive or intensive farming systems. Although the precise definition of these systems vary from country to country, farmer to farmer, and author to author, the following generalizations can be made regarding the operating characteristics of these different farming systems:

Extensive Farming Systems (EFS) – usually realized within large earthen ponds, employing low water exchange, low fish/shrimp stocking densities, no artificial aeration, little or no fertilization and/or supplementary feeding, low labor inputs, producing low fish/shrimp yields, and having low production costs;
Semi-Intensive Farming Systems (SIFS) – usually realized within small to moderate sized earthen ponds, employing moderate water exchange, intermediate fish/shrimp stocking densities, partial or continuous aeration (particularly during the final phase of production), fertilization and/or supplementary/complete diet feeding, moderate labor inputs, producing moderate fish/shrimp yields, and having moderate to low production costs; and
Intensive Farming Systems (IFS) - usually realized within small sized earthen/lined ponds/raceways/tanks or cages/pen enclosures, employing high water exchange rates (although not always, as in the case of closed culture systems), high fish/shrimp stocking densities, partial and/or continuous aeration (particularly during the final phase of production), fertilization and/or complete diet feeding, high labor inputs, producing high fish/shrimp yields, and having generally high production costs.

In general, the feeding methods employed by fish/shrimp farmers include:

No Fertilizer or Feed Application typical of traditional extensive farming systems where shrimp growth and production is totally dependent upon the consumption of food organisms naturally present within the pond ecosystem and influent water;
Fertilizer Application as above, but with the application of chemical fertilizers and/or organic manures to stimulate and enhance the natural productivity of the pond ecosystem and so increase natural food production and availability for the cultured fish/shrimp;
Fertilizer and/or Supplementary Feed Application typical of semi-intensive farming systems where shrimp growth is depended upon the co-feeding of *endogenously* supplied natural food organisms (the production of which is usually enhanced through the application of fertilizers) and *exogenously* supplied supplementary feeds (the latter usually in form of simple farm-made moist/dry aquafeeds or industrially formulated commercial aquafeeds; and
Fertilizer and/or Complete Feed Application typical of intensive farming systems where shrimp growth is almost totally dependent upon the external provision of a nutritionally complete diet for the entire culture period; the latter usually supplied in the form of a

formulated commercial aquafeed or to a lesser extent, in the form of a farm-made aquafeed or fresh food item such as *trash fish*;

The choice of the feeding method employed by individual farmers is largely dependent upon the intended farming system, fish/shrimp species grown, and fish/shrimp stocking density employed (and consequent natural availability per stocked animal), the resources available to the farmer in terms of inputs and financial, and the market value of the cultured species. Thus feeding methods typically may range from low cost extensive/semi-intensive fertilization/supplementary feeding methods (the latter usually employing locally available feed resources in the form of farm-made aquafeeds) in the case of small-scale farming operations, to the use of intensive fertilization/feeding methods (the latter usually in the form of industrially compounded aquafeeds) in the case of large-scale commercial farming operations.

2.2 Intensively fed species and aquafeed production by species

Although no official statistical information exists concerning the farming systems and feeding regimes employed by farmers for each of the major cultivated finfish and crustacean species, it is estimated only 22.8 million tonnes or 41.6% of global aquaculture production in 2003 is currently dependent upon the supply and use of compound aquafeeds, including all non-filter feeding cyprinids, tilapia, miscellaneous freshwater fish species, diadromous fish species, marine fish species, and farmed crustacean species (Figure 10).

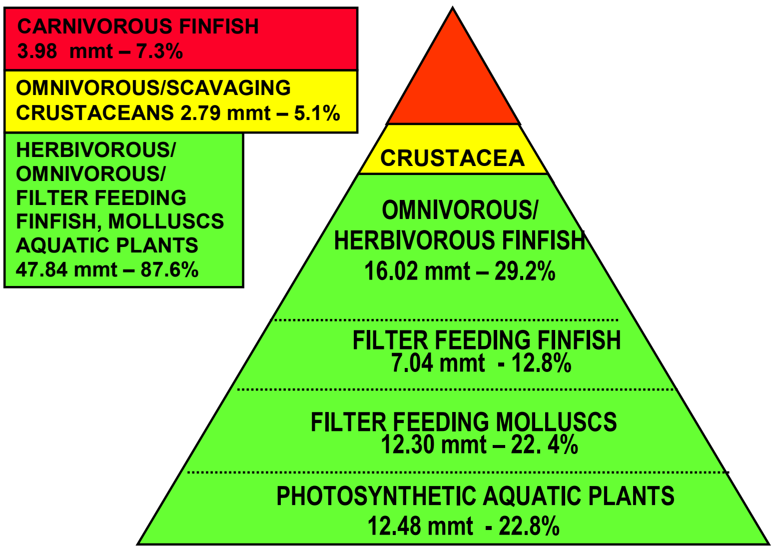


Figure 10. Global aquaculture production pyramid by feeding habit and nutrient supply in 2003 (million metric tonnes; calculated from FAO, 2005a)

Major species groups currently dependent upon the use of compound aquafeeds in 2003 (the latest year for which complete statistical information exists), included:

- **Non-filter feeding carp species** (i.e. grass carp, common carp, Crucian carp, white amur bream etc.), with an estimated 43% of total farmed carp production in 2003 currently using industrially compounded aquafeeds. Assuming a modest economic species Feed Conversion Ratio (FCR) of 2.0 for feeding carp (i.e. 2 units dry feed farm input to 1 unit wet fish farm output) and a total carp species (non-filter feeding species) production of 10.179 million tonnes in 2003 it is estimated that the total production of carp feeds was 8.75 million tonnes or 45.0% of total estimated global aquafeed production of 19.5 million tonnes in 2003 (Figure 11, Annex 1).

- **Salmonid species** (i.e. Atlantic salmon, rainbow trout, coho salmon etc), with an estimated 100% of total farmed salmonid production in 2003 currently using industrially compounded aquafeeds. Assuming an average economic species FCR of 1.3 for salmonids and a total salmonids production of 1.813 million tonnes in 2003 it is estimated that the total production of salmonid feeds was 2.36 million tonnes or 12.1% of total estimated global aquafeed production (Figure 11, Annex 1).

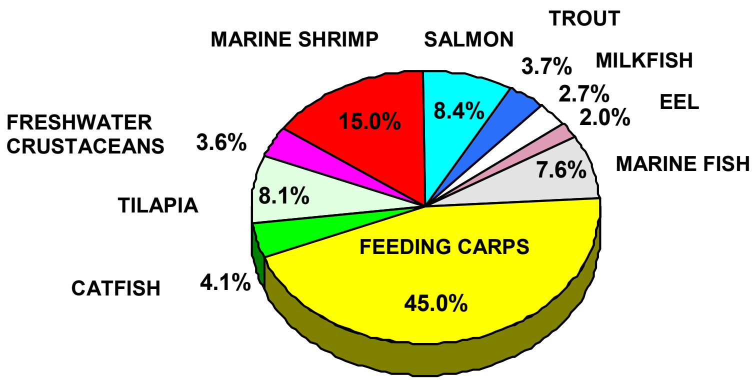


Figure 11. Estimated global compound aquafeed production in 2003 for major farmed species (values expressed as % total estimated global aquafeed production of 19.5 million tonnes, dry as-fed basis)

- **Marine shrimp species** (i.e. whiteleg shrimp, giant tiger prawn, fleshy prawn, , banana prawn etc), with an estimated 85% of total farmed shrimp production in 2003 currently using industrially compounded aquafeeds. Assuming an average economic species FCR of 1.9 for marine shrimp and a total shrimp production of 1.8 million tonnes in 2003 it is estimated that the total production of shrimp feeds was 2.915 million tonnes or 15.0% of total estimated global aquafeed production (Figure 11, Annex 1).

- **Marine finfish species** (i.e. all unidentified reported marine fish species from China, Japanese amberjack, gilthead seabream, silver seabream, European seabass, Bastard halibut, croakers, groupers etc.), with an estimated 67% of total farmed marine finfish production in 2003 currently using industrially compounded aquafeeds. Assuming a modest economic species FCR of 2.0 for marine finfish and a total marine finfish production of 1.101 million tonnes in 2003 it is estimated that the total production of marine finfish feeds was 1.475 million tonnes or 7.6% of total estimated global aquafeed production (Figure 11, Annex 1). However, this figure may be lower since a large proportion of Chinese marine finfish production is still largely fed on low value trash fish and precise data feed production in China is difficult to come by.

- **Tilapia** (i.e. Nile tilapia, unidentified reported tilapia species etc.), with an estimated 47% of total farmed tilapia production in 2003 currently using industrially compounded aquafeeds. Assuming a modest economic species FCR of 2.0 for tilapia and a total tilapia production of 1.678 million tonnes in 2003 it is estimated that the total production of tilapia feeds was 1.577 million tonnes or 8.1% of total estimated global aquafeed production (Figure 11, Annex 1);

- **Catfish** (i.e. Channel catfish, Torpedo shaped catfish, catfish hybrids etc), with an estimated 88% of total farmed catfish production in 2003 currently using industrially compounded aquafeeds. Assuming an average economic species FCR of 1.6 for catfish and a total catfish production of 0.569 million tonnes in 2003 it is estimated that the total production of catfish feeds was 0.801 million tonnes or 4.1% of total estimated global aquafeed production (Figure 11, Annex 1);

- **Freshwater crustacean species** (i.e. Chinese river crab, giant river prawn, red swamp crawfish etc.), with an estimated 44% of total farmed freshwater crustacean production in 2003 currently using industrially compounded aquafeeds. Assuming an modest economic species FCR of 2.3 for these crustaceans and a total species group production of 0.688 million tonnes in 2003 it is estimated that the total production of freshwater crustacean feeds was 0.696 million tonnes or 3.6% of total estimated global aquafeed production (Figure 11, Annex 1);

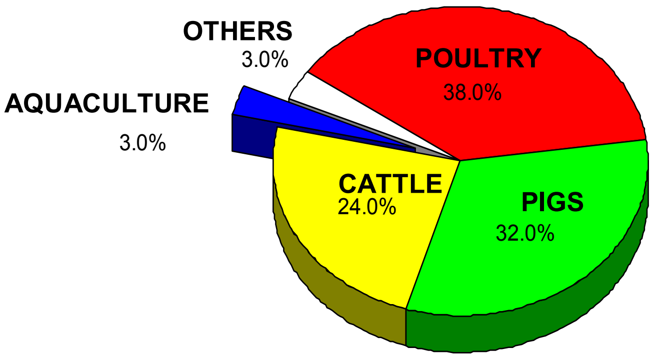
- **Milkfish** with an estimated 47% of total farmed milkfish production in 2002 currently using industrially compounded aquafeeds. Assuming a modest economic species FCR of 2.0 for milkfish and a total milkfish production of 0.552 million tonnes in 2003 it is estimated that the total production of milkfish feeds was 0.519 million tonnes or 2.7% of total estimated global aquafeed production (Figure 11, Annex 1); and

- **Eel** (i.e. Japanese eel, European eel etc.), with an estimated 83% of total farmed eel production in 2003 currently using industrially compounded aquafeeds. Assuming a modest economic species FCR of 2.0 for eel and a total eel production of 0.232 million tonnes in 2003 it is estimated that the total production of eel feeds was 0.385 million tonnes or 2.0% of total estimated global aquafeed production (Figure 11, Annex 1).

2.3 Global aquafeed production by country

Total production of industrially compounded aquafeed production in 2003 was estimated to be about 19.5 million tonnes (Figure 11, Annex 1), with total global aquafeed production representing about 3% of total global industrial animal feed production (estimated at 620 million tonnes in 2004: Figure 12).

Figure 12. Estimated global industrial feed production in 2004
for major farmed animal species
(values expressed as % dry as-fed basis)



Total estimated industrial animal feed production in 2004 – 620 million tonnes (Gill, 2005)

China is currently the world's largest aquafeed producer, with total production of industrially compounded aquafeeds reported as 7.98 million tonnes in 2003, followed by Indonesia 1.0 (million tonnes), Thailand 0.80, Norway 0.7, Chile 0.7, USA 0.5, Philippines 0.5, Japan 0.47, Taiwan 0.39, Brazil 0.37, India 0.33 and Viet Nam 0.30 (Tacon, 2004a). Industry estimates on aquafeed production in 2004 and 2005 for several key South East Asian countries have been reported as Thailand: 832,500 and 893,000; Indonesia: 550,000 and 590,000; India: 210,000 and 250,000; Vietnam: 500,000 and 560,000; Philippines: 265,000 and 265,000; and 59,000 and 60,000 tonnes, respectively (Merican, 2005).

Conservative projections for global compound aquafeed production have estimated production increasing to 21 and 27.7 million tonnes by 2005 and 2010, respectively (Annex 1). These projections compare favorably with the estimates made by International Fish Meal and Fish Oil Organization (IFFO, 2005), who projected global compound aquafeed production increasing from 15.8 to 35.1 million tonnes from 2002 to 2012, respectively (Annex 1).

3. GLOBAL ISSUES FACING FEED INGREDIENT USE WITHIN AQUAFEEDS

3.1 Current dependency of the sector upon fish meal and fish oil

The finfish and crustacean aquaculture sector is currently heavily dependent upon capture fisheries for sourcing key nutrients and feed ingredients for use within compound aquafeeds, including fishmeal and fish oil (Barlow, 2003; FIN, 2004a; Hardy & Tacon, 2002; Huntington, 2004; Huntington et al. 2004; New & Wijkstrom, 2002; Pike, 2005; Seafeeds, 2003). The current dependency upon fish meal and fish oil is particularly strong for those higher value species feeding high on the aquatic food chain, including all carnivorous finfish species (and in particular marine invertebrate/fish animal consuming finfish species) and to a lesser extent most omnivorous/scavenging crustacean species (Allan, 2004; Hardy, 2003; Pike & Barlow, 2003; Tacon, 2004b; Zaldivar, 2004). The apparent higher dependency of marine/brackishwater carnivorous finfish and crustacean species for fishmeal and fish oil is primarily due to their more exacting dietary requirements for high quality animal protein, essential fatty acids and trace minerals (Hardy et al. 2001; Pike, 1998).

For example, finfish and crustacean species which are currently dependent upon fishmeal as the main source of dietary protein within compound aquafeeds include: Finfish - all farmed marine finfish (excluding mullets and rabbitfish), diadromous species - salmonids (salmon, trout, char), eels, barramundi, sturgeon, freshwater species - mandarin fish, pike, pike-perch, snakehead, certain freshwater Clarias catfishes); and Crustaceans: all marine shrimp, crabs, and to a lesser extent freshwater prawns. A similar dependency also exists for fish oil (as the main source of dietary lipids and essential fatty acids within compound aquafeeds) for the above species, with crustaceans being less dependent than carnivorous finfish due to the lower levels of dietary lipids generally used within commercial shrimp feeds (Coutteau, 2004). In addition to the above species it must also be clearly stated that fishmeal and fish oil are also commonly used as a secondary source of dietary protein (usually included at low dietary inclusion levels) and lipid for many omnivorous cultured finfish species, including freshwater carps, tilapia and catfish. Annex 1 shows the estimated global use of fishmeal and fish oil use within compound aquafeeds for the culture cultured species groups from 1992 to 2012. According to the above estimates, the aquafeed sector currently consumes about 52.6% (Figure 13) and 86.8% (Figure 14) of the total global production of fishmeal and fish oil in 2003.

Figure 13. Estimated global use of fishmeal within compound aquafeeds in 2003 by major species (% total fishmeal used within aquafeeds, dry as-fed basis)

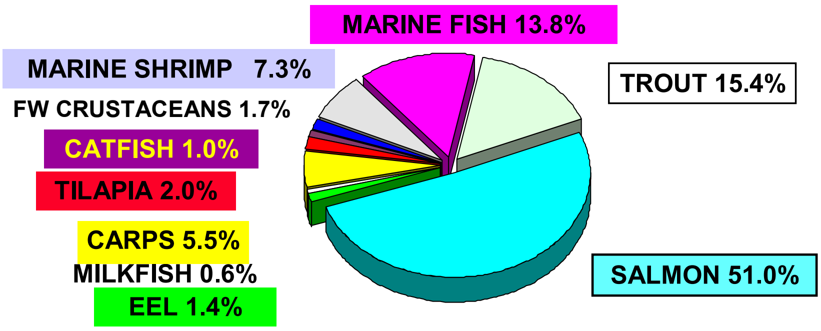
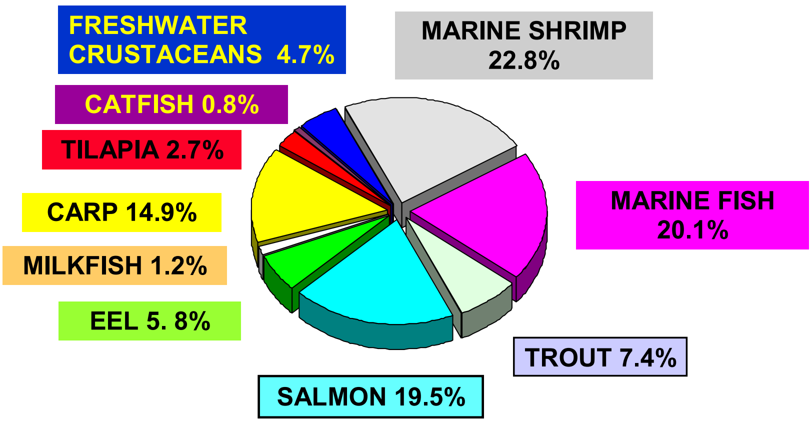


Figure 14. Estimated global use of fish oil within compound aquafeeds in 2003 by major cultivated species (% total fishmeal used within aquafeeds)



Thus, the total mean estimated use of fishmeal and fish oil within aquafeeds in 2003 was 3.74 million tonnes (2.94 and 0.80 million tonnes of fishmeal and fish oil, respectively; Annex 1) was equivalent to the input of 14.95 to 18.69 million tonnes of pelagics (using a dry meal plus oil to wet fish weight equivalents conversion factor of 4 to 5) for the production or output of 29.83 million tonnes of total farmed finfish and crustaceans in 2003 or 18.62 million tonnes of fed finfish and crustacean species production (Annex 1).

At a species group level, net fish consuming species in 2003 (calculated on current pelagic input per unit of output using a 4-5 pelagic:meal conversion factor) included river eels 3.14-3.93, salmon 3.12-3.90, marine fish 2.54-3.18, trout 2.47-3.09, marine shrimp 1.61-2.02, whereas net fish producers included freshwater crustaceans 0.89-1.11, milkfish 0.30-0.37, tilapia 0.23-0.28, catfish 0.22-0.28, feeding carp 0.19-0.24; data calculated from Annex 1).

Moreover, coupled with the use of trash fish as a direct food source for farmed fish (especially marine finfish, and to a lesser extent crustaceans), currently estimated at 5-6 million tonnes, it is estimated that the aquaculture sector consumed the equivalent of 20-25 million tonnes of fish as feed in 2003 (either in the form of fishmeal, fish oil or trash fish, expressed in live weight equivalents) for the total production of about 30 million tonnes of farmed finfish and crustaceans in 2003.

3.2 Sustainable use of available fishery resources

Concerns have been raised considering the long-term sustainability and ethics of using potentially food-grade fishery resources (and in particular jack mackerel, horse mackerel, blue whiting, pilchards, sardines, capelin) for animal feeding rather than for direct human consumption (Best, 1996; Goldburg & Naylor, 2005; Seafeeds, 2003; Tacon, 1997). In particular, in some major fishmeal and salmon producing countries such as Chile there has been a growing (all be it still small) shift toward selling a portion of the fish catch (and in particular the Chilean jack mackerel) for direct human consumption to African countries rather than for reduction (Wray, 2001; Zaldivar, 2004).

In addition to the above, there has been increasing public awareness and concern for the health and management of marine fisheries stocks and ecosystems, and the growing demand for assurance/certification schemes that fishery products are obtained from sustainable sources, including the increasing demand for traceability, labeling and transparency (FIN, 2004a, 2005; Hole, 2004; Huntington, 2004; Huntington et al. 2004; Seafeeds, 2003; Wessells et al. 2001).

Finally, there is also a growing global awareness concerning resource-use efficiency in animal and aquaculture production and the consequent need to improve resource-use efficiency so as to reduce and/or minimize the negative social, environmental and/or ecological impacts of these farming systems (Anderson & Lindroth, 2001; Åsgård & Austreng, 1995; Bailey, 1997; Boyd, 2000; Costa-Pierce, 2003; Craig, 2001; Forster &

Hardy, 2001; Lebel, 2005; Orskov, 2001; Pimentel, 2001; Raven, 2002; Roth et al. 2000; Tidwell & Allan, 2001; Troell et al. 2004; Vorosmarty et al. 2000).

3.3 Strong demand for ingredients and rising prices

Concerns that despite the strong global demand for fishmeal and fish oil (especially for oils and high quality meals, and from major importers such as China), that supply cannot keep pace with demand, and that the prices of these finite commodities will increase in the long term (Delgado et al. 2003; Hinrichsen, 2003; New & Wijkström, 2002; Zaldivar, 2004). A similar situation also exists with plants oils and vegetable proteins, where demand is currently outstripping supply and prices are increasing (Mckee, 2004). For example, recent market developments have included:

- Availability of fishmeal and fish oil for export is decreasing, and increasing demand by the rapidly growing domestic aquaculture sector, particularly for carnivorous fish species, creating a bullish scenario (FAO, 2005b);

- Future emergence of a new generation of high quality (and therefore higher priced) de-contaminated fish oils and fish meals, and improved specialty meals such as food-grade high protein meals, de-boned/low ash meals, de-oiled solvent extracted/low fat meals, improved ruminant bypass protein meals, organic fish meals and oils (Hardy & Tacon, 2002);

- The current dependence of certain segments of the aquaculture sector upon fishmeal and fish oil can be seen by looking at the spectacular growth of the salmonid aquaculture industry in Chile. For example, according to Hinrichsen (2003) the production of over 500,000 tonnes of farmed salmonids in 2002 necessitated the use of 740,000 tonnes of compound aquafeeds, containing 240,000 tonnes of fishmeal and 180,000 tonnes of fish oil. Although total domestic fishmeal production in 2003 (706,300 tonnes) was sufficient to meet demand, this was not the case for fish oil (total domestic production 130,222 tonnes in 2003), where additional supplies had to be imported from Peru (FAO, 2005a).

- Increased global demand and competition for available feed resources, including alternative dietary protein and lipid sources for farmed carnivorous fish and shrimp species and in particular identifying non-food feed ingredients whose production can keep pace with the growth of the sector (Deguara, 2001; Tacon & Forster, 2001).

3.4 Increasing possible concerns of consumers for feed and food safety

Concerns raised about the contamination of fish oils, fishmeals and animal feeds by polychlorinated dibenzo-p-dioxins and dibenzofurans (collectively known as dioxins), polychlorinated biphenyls (PCB's), including dioxin-like PCBs (Bell et al. 2005; Fielder et al. 1998; FIN, 2004b, 2005; Hayward et al. 1999; Hites et al. 2004a, 2004b; Ilaria et al., 2004; Isosaari et al. 2004; Jacobs et al., 2002; Karl et al. 2003; Lundebye et al. 2004; Smith et al. 2002) has led to the introduction by the EU of new acceptable limits for Dioxin within fish oil, fishmeal, feed ingredients and compound aquafeeds (Commission Directive 2003/57/EC of 17 June 2003 amending Directive 2002/32/EC of the European Parliament and of the Council on undesirable substances in animal feed. Official Journal of the European Union L 151/38, 19 June 2003, 4p).

As a result of these regulations, new processing techniques are currently being developed by many leading European fishmeal and fish oil producers so as to reduce the burden of these environmental contaminants within their meals and oils (Ley, 2001), and by so doing meeting increasing future market demands for less contaminated fish oils and fishmeals (MacDonald et al., 2004; Zaldivar, 2004). However, the above possible contaminant issue has resulted in increased consumer awareness concerning food safety issues (particular within developed country markets), and in particular concerning the higher possible dioxin and PCB content of fish (including farmed fish) compared with other food products (Bell et al. 2005; Bureau, 2004; Chamberlain, 2004; Connelly, 2004; Flick, 2004; Pike, 2002; Randell, 2004; Soponpong, 2002).

Similarly, concerns have also been raised about the possible transfer of mammalian infectious agents such as Bovine Spongiform Encephalopathy (BSE) and other Transmissible Spongiform Encephalopathies (TSEs) through the use of ruminant animal by-product meals within compound animal feeds (including aquafeeds; FAO, 1998, 2001; FIN, 2004b; Pearl, 2000; SCAHAW, 2003; SSC, 2003). As with the environmental contaminants, this has also led to increased consumer awareness concerning feed and food safety issue, and the consequent introduction of stricter feed assurance schemes, including codes of practice concerning fishery products, fishmeal and feed manufacture and the development of improved rendering techniques and safer animal by-product meals (Gill, 2004; Lebel, 2005; Huntington, 2004; Randell, 2004; Taylor & Woodgate, 2003; Woodgate, 2004; EU-Commission Regulation No. 999/2001, 1774/2002, 1234/2003, and 1292/2005).

4. USE OF BLOOD PRODUCTS & BLOOD MEAL IN AQUAFEEDS

4.1 Products and nutritional characteristics

For the purposes of this report the following non-ruminant blood products can be considered for use within aquafeeds, namely:

Blood meal

Animal blood meal, spray dehydrated (IFN 5-00-381), obtained from clean, fresh blood, exclusive of all extraneous material such as hair, stomach contents or urine, except in such amounts as may occur unavoidably in good manufacturing practice; the moisture being removed from the crude blood by spray drying.

Typical analysis according to the American Feed Industry Association (AFIA) Electronic Feed Ingredient Database is reported as: protein 85%, fat (min-max) 0.5-3%, fiber (max) 2.5%, ash 6.0%, moisture (max) 10.5%, lysine (total) 8.3%, lysine (available) 80-90%; Colour: uniform reddish-brown, Odour: fresh, Screen analysis: 98% to pass a U.S. Standard Sieve No. 10, Solubility: Hygroscopic, soluble in water.

The average essential amino acid composition of spray dried blood meal (% as fed basis, mean dry matter 93%, crude protein 89.2%) has been reported by NRC (1993) as follows: arginine 3.75%, histidine 5.14%, isoleucine 9.97%, leucine 10.82%, lysine 7.45%, methionine 1.08%, cystine 1.24%, phenylalanine 5.92%, tyrosine 2.55%, threonine 3.76%, tryptophan 1.04%, valine 7.48%. The same authors also reported the vitamin and mineral content (as fed basis) as: vitamins - biotin 0.28 mg/kg, choline 600 mg/kg, folacin 0.40 mg/kg, niacin 22 mg/kg, pantothenic acid 3.2 mg/kg, pyridoxine 4.45 mg/kg, riboflavin 2.9 mg/kg, thiamin 0.3 mg/kg, vitamin B12 13.0 ug/kg; minerals - calcium 0.41%, phosphorus 0.30%, potassium 0.15%, chlorine 0.25%, magnesium 0.15%, sodium 0.38%, sulfur 0.34%, copper 8.2 mg/kg, iron 2,769 mg/kg, manganese 6.4 mg/kg, zinc 306 mg/kg (NRC, 1993).

Animal blood meal, flash or ring dehydrated (IFN 5-26-006), obtained from clean, fresh blood, exclusive of all extraneous material such as hair, stomach contents or urine, except in such amounts as may occur unavoidably in good manufacturing practice; the moisture being removed from the crude blood by dewatering and flash drying (the minimum available lysine [as determined by A.O.A.C. Method 43.224, 13th edition] shall be 80 percent);

Typical analysis according to AFIA reported as: protein 86%, fat 1.2%, fiber 1%, ash 4.5%, moisture 11%, lysine (total) 7.6%, lysine (available) 6.6%; Colour: uniform reddish-brown to dark red, Odour: fresh – meat odour, Screen analysis: 98% to pass a U.S. Standard Sieve No. 10, Solubility: insoluble in water.

Animal blood meal, conventional cooker dehydrated (IFN 5-26-005), obtained from clean, fresh blood, exclusive of all extraneous material such as hair, stomach contents or urine, except in such amounts as may occur unavoidably in good manufacturing practice; the moisture being removed from the crude blood by the conventional cooker method.

Typical analysis according to AFIA reported as: protein 80.2%, fat 1%, fiber 1%, ash 4.5%, moisture 11%, lysine (total) 5.3% (sustained high drying temperatures can bind or inactivate a large part of the lysine), lysine (available – variable); Colour: dark red to black, Odour: fresh, meaty odour, Screen analysis: 98% to pass a U.S. Standard Sieve No. 10, Solubility: insoluble in water.

General observations on nutritional characteristics

On a nutritional basis, blood meals with the highest nutritional value are generally those which have been spray dried; the proteins being subjected to the least heat damage and denaturing during the drying process (Luzier et al. 1995). The protein fraction of blood meal is usually highly digestible (being highest for spray dried meals), with blood protein being a good source of the essential amino acids histidine (almost twice that found in other dietary protein sources), leucine, tryptophan, phenylalanine, and lysine, but deficient in isoleucine and methionine (Gaylord et al. 2004; Luzier et al. 1995; Tacon, 1987). Blood meal is a rich dietary source of iron, and a good source of biotin and to a lesser extent B-vitamins.

Apart from the obvious need to use blood meal in combination with other dietary feed ingredient sources with complementary amino acid profiles (including plant proteins such as soy and the diets formulated so as to obtain the desired overall dietary amino acid profile of the intended target species), there is a possibility that the high iron content of blood meal may exert a negative effect on the stability of other dietary nutrients (for example, by promoting the oxidation of liable nutrients such as carotenoid pigments and ascorbic acid within salmonid feeds) or by inhibiting the absorption and metabolism of other essential dietary trace elements such as zinc, copper and manganese within (Anderson et al. 1997). In general, compared with most marine feed ingredient sources, blood meal and blood products contain low levels of environmental contaminants, including persistent organic pollutants and heavy metals (APC Europe, 2004; SCAN, 2000; van der Velden, 2005).

Regarding the risk of possible transfer of Transmissible Spongiform Encephalopathies (TSEs) from non-ruminant derived blood meals, there is no scientific evidence to date which shows that fish, poultry or pigs are susceptible to or develop natural TSEs (APC Europe, 2004; Bradley, 1999; SCAHAW, 2003; SSC, 2003). Moreover, it is important to underline here that the production and use of non-ruminant blood meals in aquafeeds within the EU is clearly defined and controlled (EU regulation 2003/1234/EC); with blood meals and blood products intended for use within fish feeds only being able to be produced from slaughtered healthy non-ruminant Category 3 animals certified by a qualified veterinarian (EU regulation 1774/2002/EC).

The handling of spray dried blood meal usually requires special attention due to its light and powdery nature (98% passing through a U.S. Standard Sieve No. 10), and susceptibility to clumping and caking under prolonged storage under moist humid conditions. Moreover, the hygroscopic nature of blood meal may also lead to product solubilization and nutrient loss through leaching on prolonged immersion in water (as is the case for crustaceans where feeds may remain in water for several hours before being consumed). Finally, one of the many unique physical properties of blood meal is its dark colour, and this asset is commonly exploited by feed manufacturers so as to produce feeds with a beneficial physical appearance to farmers (darker pigmented feeds generally being associated with high quality feeds and the use of higher dietary animal protein levels).

Blood plasma

Animal blood plasma spray dehydrated (or Animal blood serum spray dehydrated or Dried animal blood plasma or Dried animal blood serum) (IFN 5-00-382), being the spray dried plasma fraction obtained from clean, fresh, blood exclusive of all extraneous material such as hair, stomach contents, or urine, except in such amounts as may occur unavoidably in good manufacturing practice.

Typical analysis of spray-dried animal plasma according to the American Protein Corporation (APC Europe, 2003) reported as (as fed basis): crude protein 78% (min), crude fat 2% (max), crude fiber 0.3% (max), ash 10% (max), moisture 9% (max), minerals - sodium 3% (max), phosphorus 1.7%, chloride 1.5%, calcium 0.15%, iron 50 mg/kg, essential amino acids - arginine 4.7%, histidine 2.8%, isoleucine 2.9%, leucine 7.8%, lysine 6.8%, methionine 0.7%, cystine 2.8%, phenylalanine 4.6%, tyrosine 3.6%, threonine 4.8%, tryptophan 1.4%, valine 5.3%, Solubility – 88% soluble in water, Colour – off-white to beige, Odor – neutral.

Blood cells

Animal blood cells, spray dehydrated (or Spray dried animal blood cells), being the product obtained by centrifugation and removal of plasma from clean, fresh blood, exclusive of all extraneous material except in such amounts as may occur unavoidably in good manufacturing practice.

Typical analysis of spray-dried animal blood cells according to the American Protein Corporation (APC Europe, 2003) reported as (as fed basis): crude protein 92% (min), crude fat 2% (max), crude fiber 0.5% (max), ash 3% (max), moisture 8% (max), minerals - sodium 0.8% (max), chloride 1.4%, potassium 0.25%, calcium 0.02%, iron 2,700 mg/kg, essential amino acids - arginine 4.0%, histidine 7.5%, isoleucine 0.6%, leucine 13.4%, lysine 9.0%, methionine 0.8%, cystine 0.6%, phenylalanine 7.1%, tyrosine 2.2%, threonine 3.6%, tryptophan 1.2%, valine 9.2%, Solubility – 80%, Colour – dark reddish/brown, Odor – neutral. For proximate and amino acid composition see also Johnson & Summerfelt (2000).

4.2 Use and performance in aquafeeds

Table 3 represents a summary of the published studies conducted over the past 15 years concerning the use of blood meal and blood products within compound aquafeeds. The start of the nineties was chosen as the starting point for this review because prior to this date the origin and quality of the blood meals and products evaluated was not always clearly stated (ie. species origin, dehydration method employed, international feed number, and/or nutritional composition) and so proper scientific analysis of the data not always possible. A total of 63 research studies are presented in Table 3.

It is important to mention here that blood meal products have been successfully used in compound aquafeeds since the early seventies (for review see Tacon, 1993a, 1993b, 1994) with no reported deleterious or negative effects to the health and wellbeing of the cultured species tested. The only negative effects which have been reported from the use of blood meal on fish growth and feed efficiency has been due to the excessive dietary use of cooker/over-heated meals (with consequent low essential amino acid digestibility and availability; Laining et al. 2003; Sampaio et al. 2001) and poor feed formulation (by not using complementary protein sources and/or not supplementing diets with limiting essential nutrients; Lee & Bai, 1997). For example, spray-dried blood meal has been successfully used as a dietary fish meal replacer at dietary levels of up 22.7% in rainbow trout (*Oncorhynchus mykiss*) feeds with no loss in growth or feed efficiency; rations containing 22.7% blood meal being supplemented with 0.5% DL-methionine and 0.6% available phosphorus and replacing 32% herring meal (Luzier et al. 1995).

Although spray-dried blood cell and blood plasma meals are relatively new products in the aquafeed market place, independent published studies with blood cell or haemoglobin powder have been encouraging. Spray-dried blood cell meal has been successfully used at dietary levels of 8.75% within rainbow trout (*O. mykiss*) feeds replacing 13% herring meal with no loss in growth or feed efficiency over a 12-week feeding period (Johnson & Summerfelt, 2000). Similarly, Lee and Bai (1997) reported that haemoglobin powder could replace up to 75% of the white fish meal within juvenile eel (*Anguilla japonica*) feeds with without essential amino acid supplementation. Moreover, with the Australian snapper (*Pagrus auratus*) Booth et al. (2005) showed that the apparent protein digestibility of haemoglobin powder (95.1%) was significantly higher than that of ring-dried blood meal (81.6%). The high protein digestibility of spray-dried blood cells has also been reported in Atlantic salmon (Salmo salar; Cho & Bureau, 1997).

In addition, in the case of blood plasma, studies sponsored by the American Protein Corporation (APC) have reportedly shown a beneficial effect of using dietary plasma meals on the immune response and disease resistance of shrimp (*Penaeus japonicus*, *P. vannamei*; Russell & Campbell, 2000), eel (*A. anguilla*; Jensen & Nielsen, 2003), rainbow trout (*O. mykiss*; Anon, 2003) and grouper (*Epinephelus sp*. Jensen & Nielsen, 2003; APC, 2003, 2004; Van der Velden, 2005). However, to date there have been no independently funded and published studies to confirm these findings.

Table 3. Recent scientific publications concerning the nutritional evaluation and successful use of blood meal and blood products within compound aquafeeds

Salmonids:

- Blood meal – Adelizi et al. (1998), Breck et al. (2003), Bureau et al. (2000), Cho (1992), Cho & Bureau (1997), Glencross et al. (2003), Green et al. (2002), Jang et al. (1999), Luzier et al. (1995), Rasmussen (1994), Riche & Brown (1996), Satoh et al. (2003), Sugiura et al. (2000);
- Plasma – Anon (2003);
- Red blood cells – Johnson & Summerfelt (2000);

Blood meal, Meat & Bone meal, Poultry byproduct meal mixture - Cheng & Hardy (2002), Pfeffer et al. (1995), Yanik et al. (2003), Yu (2004);
Mixture of animal by-products (25% meat and bone meal, 24.5% leather meal, 20% squid liver powder, 15% feather meal, 7.5% blood meal (spray-dried), 7.5% poultry by-product meal, and 0.25% each methionine and lysine – Lee et al. (2001);

Freshwater finfish:

- Blood meal - Abery et al. (2002), Allan & Rowland (2005); Allan et al. (2000), Gaylord et al. (2004), El-Sayed (1998), Eyo & Olatunde (2000), Fagbenro (1996, 2001), Fagbenro & Akegbejo-Samsons (2000), Fasakin et al. (2005), Gallagher & LaDouceur (1995), Jahan et al. (2001, 2003), Lei et al. (1996), Martins & Guzman (1994), Ogunji & Wirth (2001), Saha & Ray (1998), Sampaio et al. (2001), Sullivan & Reigh (1995), Wu et al. (2000), Yousif et al. (1996);
- Meat & Bone meal/Leather meal/Squid Liver Powder/Blood meal mixture – Bai et al. (1998);
- Meat & Bone meal/Blood meal mixture – D'Abramo et al. (2000), Li et al. (2002, 2003), Li & Robinson (1996), Robinson & Lee (1999);

Marine finfish:

- Blood meal – Booth et al. (2005), Da Silva & Oliva-Teles (1998), Kikuchi (1999), Laining et al. (2003), Lee (2002), Lee et al. (1996), Lupatsch et al. (1997), McGoogan & Reigh (1996);
- Haemoglobin powder – Booth et al. (2005);
- Meat meal: Blood meal 4:1 mixture - Millamena (2002);

Marine Shrimp:

Blood meal – Dominy & Ako (1988), Lemos et al. (2004), Liu et al. (2000), Tacon & Akiyama (1997);
Plasma protein – Russell & Campbell (2000);

Met opmaak: opsommingstekens en nummering

Eels:

- Haemoglobin powder - Lee & Bai (1997),
- Plasma – Jensen & Nielsen (2003);

Freshwater crayfish:

Blood meal – Reigh & Ellis (1994);

General reviews:

Blood meal/blood products – Anon (2004a, 2004b, 2004c), APC Europe S.A. (2004), Gui & Dong (1995), Hertrampf & Pascual (2000), Polo & Hoetink (2005), van der Velden (2005);
Procine blood meal – Riis (2004);

4.3 Survey on the current use of blood meal & blood products

In addition to the above published studies, a survey was also undertaken by the author (as part of the present study) of aquafeed nutritionists, feed manufacturers, ingredient suppliers/traders, and farmers concerning the use blood meal and blood products within aquafeeds. Specifically, their opinion/input was asked concerning the current/potential use of blood products and blood meal within aquafeeds, including their current usage or not, nutrient specifications, limitations (including import/certification requirements) and market potential. A total of 70 persons were contacted within the aquaculture/aquafeed industry in over 32 countries, and the survey initiated electronically on 9 August 2005 and terminated on 30 September 2005; a total of 41 replies from 20 countries were received, including 25 feed manufacturers. Annex 2 lists the organizations and persons who replied, and who provided valuable information and/or insights to the author for the preparation of this report.

Feed manufacturers who responded and reported the current use of blood meal and to a lesser extent haemoglobin powder (one manufacturer) within aquafeeds, included feed manufacturers from Australia, Brazil (fish), Canada, Chile, China, Costa Rica, India, Malaysia (fish), Mexico (fish), Taiwan (fish), Thailand, and the USA. The current mean dietary inclusion level was between 2 - 5%, with spray-dried blood meal mainly being used as a cost-effective source of highly digestible animal protein (as a dietary fishmeal replacer) and pellet coloring agent. Surprisingly, however, despite the fact that non-ruminant blood meal and blood products have been allowed in aquafeeds produced within the EU since 2003 (EU regulation 2003/1234/EC) none of the six European feed manufacturers who responded reported the use of blood meals and blood products within their feeds. The reason given was the restrictions imposed upon them by leading European retailers and by several farming industry quality schemes who prohibit the use of land animal proteins (including blood products and meals) within aquafeeds intended for the production of fish sold within their supermarket chains. A similar situation exists for salmon or shrimp feeds where the intended market of the farmed salmon or shrimp is within the European community.

All of the 25 feed manufacturers surveyed during this study responded that they considered non-ruminant blood meal and blood products to be a cost-effective and safe highly digestible protein source for farmed fish and shrimp, and as such believed that the ban on their use by some retailers to be without any scientific foundation and worked against the development of more environmentally responsible and ecologically sustainable aquaculture, by reducing the dependence of the sector upon the use of precious and finite marine protein resources.

4.4 Estimated market and demand for blood meal & blood products

Despite the fact that blood meal and blood products have been shown to be cost-effective nutrient sources for farmed fish and shrimp, it is estimated that less than 5% of total global manufactured aquafeeds (21 million tonnes in 2005; Annex 1) currently use blood meal within their feeds (2 – 5% average dietary inclusion level) or between 20,000 – 60,000 tonnes annually. As mentioned previously, the main reason for this is believed to be due to the perceived retailer demands within the European and Japanese seafood markets. However, it should be mentioned here that countries such as the United States, the largest producers of blood meal and rendered animal by-products, have been successfully using blood meal within their salmonid feeds for over 25 years with no reported deleterious effects on fish or human health (Chris Nelson, Nelson & Sons Inc., personal communication, 9 August 2005; Tim Markey, Zeigler Bros Inc., personal communication, 11 August 2005).

The estimated total market demand for non-ruminant blood meal in aquafeeds, if the constraints imposed by European retailers were to be removed, would be as follows:

Shrimp:
2005: 3,420,000 tonnes aquafeed (annex 1), 10% using 2-4% blood meal, estimated market 7,000-14,000 tonnes;
2010: 4,910,000 tonnes aquafeed (annex 1), 50% using 3-6% blood meal, estimated market 74,000-147,000 tonnes (spray dried or higher quality meals);

Salmonids:
2005: 2,370,000 tonnes aquafeed, 10% using 3-6% blood meal, estimated market 7,000-14,000 tonnes;
2010: 3,025,000 tonnes aquafeed, 100% using 4-8% blood meal, estimated market 121,000-242,000 tonnes (spray dried or higher quality meals);

Marine fishes:
2005: 1,678,000 tonnes aquafeed, 5% using 3-6% blood meal, estimated market 2,000-5,000 tonnes;

2010: 2,495,000 tonnes aquafeed, 50% using 4-8% blood meal, estimated market 50,000-100,000 tonnes (spray dried or higher quality meals);

Feeding carps:
2005: 9,090,000 tonnes aquafeed, 5% using 1-2% blood meal, estimated market 4,000-9,000 tonnes;
2010: 11,458,000 tonnes aquafeed, 25% using 2-4% blood meal, estimated market 57,000-115,000 tonnes (lower quality meals);

Eels:
2005: 363,000 tonnes aquafeed, 10% using 3-6% blood meal, estimated market 1,000-2,000 tonnes;
2010: 377,000 tonnes aquafeed, 100% using 4-8% blood meal, estimated market 15,000-30,000 tonnes (spray dried or higher quality meals);

Milkfish:
2005: 537,000 tonnes aquafeed, 10% using 1-2% blood meal, estimated market 1,000-2,000 tonnes;
2010: 670,000 tonnes aquafeed, 50% using 2-4% blood meal, estimated market 7,000-14,000 tonnes (lower quality meals);

Tilapia:
2005: 1,827,000 tonnes aquafeed, 10% using 1-2% blood meal, estimated market 2,000-4,000 tonnes;
2010: 2,625,000 tonnes aquafeed, 50% using 2-4% blood meal, estimated market 26,000-52,000 tonnes (lower quality meals);

Catfish:
2005: 879,000 tonnes aquafeed, 10% using 2-4% blood meal, estimated market 2,000-4,000 tonnes;
2010: 1,093,000 tonnes aquafeed, 50% using 3-6% blood meal, estimated market 16,000-33,000 tonnes (lower quality meals);

On the basis of the above figures, it is estimated that the global market demand for blood meal could increase over 13-fold from the present 26,000-54,000 tonnes to 366,000-733,000 tonnes by 2010; the largest estimated consumers of high quality blood meal and blood products in 2010 being salmonids (33% estimated market share), followed by shrimp (20%), feeding carps (15%), and marine fishes (13%).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- Current dependence of global aquaculture production and commercial aquaculture feeds upon the use of marine fishery resources as feed inputs, including fishmeal and fish oil, and the consequent urgent need to reduce this dependency by using more sustainable feed-grade resources whose production can keep pace with the development and growth of the aquaculture sector;

- Increasing awareness concerning the presence of environmental contaminants within the marine environment, including fishmeal and fish oil, and the urgent need to reduce these contaminant loads either through extraction/purification, increasing legislative controls, or through the use of alternative feedstuffs or dietary feeding strategies;

- As in humans, recognition that farmed aquatic animals do not have a specific dietary requirement for a particular ingredient or food source (such as fishmeal or fish oil in the case of aquafeeds), but rather have a specific dietary requirement for 40 or so essential nutrients (whether the nutrient is contained within a fish, plant, or animal is totally irrelevant);

- Global recognition that terrestrial animal by-product meals, including non-ruminant blood meals and blood products, represent the largest and largely untapped source of source of animal protein and lipid available within the international market place for the aquafeed industry (Bureau, 2000, 2004; Shepherd, 1998; Tacon, 2000);

- Proven ability and 25 year track record of the commercial aquafeed manufacturing sector and research community to safely replace a significant proportion of the fishmeal component of aquafeeds (typically ranging from 5 to 10%) with an equivalent weight (on a digestible protein basis) of spray-dried blood meals, with no loss in growth or feed performance (Table 3);

- Allowance within the EC of the use of blood meal and blood products derived from healthy non-ruminant animals within fish feeds, as of 1st September 2003 (1234/2003/EC); and

- Current major limitation to the use of non-ruminant blood meal and blood products within aquafeeds has been due to the constraints imposed by major European retailers and farmer associations prohibiting the use land animal proteins within aquafeeds, including blood meal and blood products, on the basis of perceived consumer fears and demands regarding feed safety (Bostock et al. 2004; Huntington, 2004).

5.2 Recommendations

- On the basis of the above report and scientific evidence, the use of adequately processed non-ruminant blood meals can and should be used within compound aquafeeds as a much needed source of high quality digestible protein and essential nutrients;

- The need to conduct further extended feeding trials with marine shrimp, from juvenile to market size, with different commercially available blood meals and blood products so as to ascertain the economic cost-effectiveness and nutritional value as dietary fishmeal replacers and potential dietary immune enhancers under both clear-water and green-water culture conditions;

- The need for producers to further improve the physical characteristics and nutritional quality of blood products for aquaculture, including the development of products with improved water and nutrient (reactive iron) stability (so as to minimize nutrient loss through leaching and/or on prolonged storage through increased water activity and oxidation), and/or by dietary supplementation with limiting essential amino acids (isoleucine, and to a lesser extent methionine); and

- The need to present, discuss and disseminate the contents and findings of this report with representatives of leading EU retailers engaged in seafood sales (including Tesco, Sainsbury, Marks & Spencers, Red Lobster, Walmark, Safeway etc.) and major farmer associations (Global Aquaculture Alliance, Brazilian Shrimp Farmers Association, Federation of European Aquaculture Producers etc.) so as to increase market awareness, safety, acceptance and use of non-ruminant blood meal and blood products within commercial aquafeeds for the benefit and continued sustainable development of the aquaculture sector.

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Annex 1. Estimated global use and demand for fishmeal and fish oil 2002-2012

Major species group	2002	2003	2005	2010	2012
	Thousand tonnes (dry as-fed basis)				
SHRIMP					
Total production [1]	1,405	1,805	2,184	3,209	3,605
Predicted growth (APR, %/year) [2]	28.5	10	8	6	-
Percent on feeds (%) [3]	85	85	87	90	91
Species Economic FCR [4]	1.9	1.9	1.8	1.7	1.7
Total aquafeeds used [5]	2,269	2,915	3,420	4,910	5,577
IFFO estimate (%) [6]	*2,086*	-	-	-	*3,081*
Average fishmeal content (%)	24	23	20	15	13
IFFO estimate (%)	*25*	-	-	-	*15*
Average fish oil content (%)	2	2	2	2	2
IFFO estimate (%)	*2*	-	-	-	*2*
Total fishmeal used (tmt)	545	670	684	736	725
IFFO estimate	*522*	-	-	-	*462*
Total fish oil used	45.4	58.3	68.4	98.2	111.5
IFFO estimate	*42*	-	-	-	*62*
FRESHWATER CRUSTACEANS					
Total production	652	688	802	1,091	1,392
Growth (APR, %/year)	5.6	8	6	5	-
Percent on feeds (%)	43	44	45	50	52
Species Economic FCR	2.4	2.3	2.2	2.0	1.9
Total aquafeeds used	673	696	794	1,091	1,375
IFFO estimate (%)	*300*	-	-	-	*590*
Average fishmeal content (%)	20	20	18	12	11
IFFO estimate (%)	*20*	-	-	-	*10*
Average fish oil content (%)	2	2	1.5	1	1
IFFO estimate (%)	*4*	-	-	-	*1*
Total fishmeal used	135	139	143	131	137
IFFO estimate (%)	*60*	-	-	-	*59*
Total fish oil used	13.5	13.9	11.9	10.9	5.9
IFFO estimate (%)	*12*	-	-	-	*5.9*
MARINE FISH					

Total production	1,080	1,101	1,332	1,957	2,198
Growth (APR, %/year)	1.9	10	8	6	-
Percent on feeds (%)	65	67	70	75	77
Species Economic FCR	2	2	1.8	1.7	1.7
Total aquafeeds used	1,404	1,475	1,678	2,495	2,877
IFFO estimate (tmt)	*907*	-	-	-	*2,930*
Average fishmeal content (%)	41	40	36	26	25
IFFO estimate (%)	*45*	-	-	-	*40*
Average fish oil content (%)	8	7.5	6	6	5
IFFO estimate (%)	*6*	-	-	-	*6*
Total fishmeal used	575	590	604	649	719
IFFO estimate	*702*	-	-	-	*1,172*
Total fish oil used	112.3	110.6	100.7	149.7	143.8
IFFO estimate (tmt)	*94*	-	-	-	*176*

SALMON

Total production	1,213	1,259	1,388	1,771	1,953
Growth (APR, %/year)	3.8	5	5	5	-
Percent on feeds (%)	100	100	100	100	100
Species Economic FCR	1.3	1.3	1.2	1.2	1.2
Total aquafeeds used	1,577	1,637	1,665	2,125	2,344
IFFO estimate	*1,300*	-	-	-	*1,978*
Average fishmeal content (%)	35	35	30	20	18
IFFO estimate (%)	35	-	-	-	20
Average fish oil content (%)	26	25	10	8	7
IFFO estimate (%)	*28*	-	-	-	*18*
Total fishmeal used	552	573	499	425	422
IFFO estimate)	554	-	-	-	*396*
Total fish oil used	410	409	166	170	164
IFFO estimate	443	-	-	-	*356*

TROUT

Total production	562	554	588	750	829
Growth (APR, %/year)	1.4	3	5	5	-
Percent on feeds (%)	100	100	100	100	100
Species Economic FCR	1.3	1.3	1.2	1.2	1.2
Total aquafeeds used	731	720	705	900	995
IFFO estimate (tmt)	*600*	-	-	-	*855*
Average fishmeal content (%)	32	30	18	12	10
IFFO estimate (%)	*30*	-	-	-	*15*
Average fish oil content (%)	20	17.5	10	6	5
IFFO estimate (%)	*20*	-	-	-	*12*
Total fishmeal used	168	216	127	108	99
IFFO estimate	*221*	-	-	-	*128*

Total fish oil used	95	126	70.5	54	49.7
IFFO estimate	*147*	-	-	-	*103*

EEL

Total production	232	232	237	262	272
Growth (APR, %/year)	0	1	2	2	-
Percent on feeds (%)	82	83	85	90	92
Species Economic FCR	2	2	1.8	1.6	1.6
Total aquafeeds used	380	385	363	377	400
IFFO estimate	348	-	-	-	328
Average fishmeal content (%)	47	45	40	30	28
IFFO estimate (%)	*50*	-	-	-	*30*
Average fish oil content (%)	4	3	3	2	2
IFFO estimate (%)	*5*		-	-	*5*
Total fishmeal used	179	171	145	113	112
IFFO estimate	*190*	-	-	-	*98*
Total fish oil used	15.2	11.4	10.9	7.5	8.0
IFFO estimate	*10*	-	-	-	*16*

MILKFISH

Total production	528	552	597	762	840
Growth (APR, %/year)	4.5	4	5	5	-
Percent on feeds (%)	45	47	50	55	57
Species Economic FCR	2	2	1.8	1.6	1.6
Total aquafeeds used	475	519	537	670	766
IFFO estimate	*346*	-	-	-	*928*
Average fishmeal content (%)	8	7	5	2	2
IFFO estimate (%)	*12*	-	-	-	*5*
Average fish oil content (%)	1	1	1	1	1
IFFO estimate (%)	*2*	-	-	-	*7*
Total fishmeal used	38	36	27	13	15
IFFO estimate	*57*	-	-	-	*65*
Total fish oil used	4.7	5.2	5.4	6.7	7.7
IFFO estimate	*10*	-	-	-	*33*

FEEDING CARP

Total production	9,881	10,179	11,222	14,323	15,791
Growth (APR, %/year)	3.0	5	5	5	-
Percent on feeds (%)	42	43	45	50	52
Species Economic FCR	2	2	1.8	1.6	1.6
Total aquafeeds used	8,300	8,754	9,090	11,458	13,138
IFFO estimate	*8,415*	-	-	-	*19,915*
Average fishmeal content (%)	5	5	4	2	2
IFFO estimate (%)	*4*	-	-	-	*2*

Average fish oil content (%)	0.5	0.5	1	1	1
IFFO estimate (%)	*0*	-	-	-	*0*
Total fishmeal used	415	438	364	229	263
IFFO estimate	*334*	-	-	-	*398*
Total fish oil used	41.5	43.8	90.9	114.6	131.4
IFFO estimate	*0*	-	-	-	*0*

TILAPIA

Total production	1,486	1,678	2,030	2,983	3,352
Growth (APR, %/year)	12.9	10	8	6	
Percent on feeds (%)	45	47	50	55	57
Species Economic FCR	2	2	1.8	1.6	1.6
Total aquafeeds used	1,337	1,577	1,827	2,625	3,057
IFFO estimate	*1,043*		-	-	*2,900*
Average fishmeal content (%)	5	5	3	2	2
IFFO estimate (%)	*7*	-	-	-	*2*
Average fish oil content (%)	1	1	1	1	1
IFFO estimate (%)	*1*	-	-	-	*0*
Total fishmeal used	67	79	55	52	61
IFFO estimate	*95*	-	-	-	*58*
Total fish oil used	13.4	15.8	18.3	26.2	30.6
IFFO estimate	*14*	-	-	-	*0*

CATFISH

Total production	527	569	651	831	916
Growth (APR, %/year)	8.0	7	5	5	-
Percent on feeds (%)	87	88	90	94	95
Species Economic FCR	1.6	1.6	1.5	1.4	1.4
Total aquafeeds used	734	801	879	1,093	1,218
IFFO estimate	*623*	-	-	-	*979*
Average fishmeal content (%)	3	3	2	2	2
IFFO estimate	*2*	-	-	-	*0*
Average fish oil content (%)	1	1	1	1	1
IFFO estimate	*0*	-	-	-	*0*
Total fishmeal used	22	24	18	22	24
IFFO estimate	*14*	-	-	-	*0*
Total fish oil used	7.3	8.0	8.8	10.9	12.2
IFFO estimate	*7*	-	-	-	*0*

CARNIVOROUS FRESHWATER FISH [7]

Total aquafeeds used	*264*	-	-	-	*611*
Average fishmeal content (%)	*40*	-	-	-	*30*

Average fish oil content (%)	*6*	-	-	-	*7*
Total fishmeal used (tmt)	*124*	-	-	-	*183*
Total fish oil used (tmt)	*19*	-	-	-	*43*
MISCELLANEOUS SPECIES					
Total production [8]	3,536	4,177	-	-	-

TOTAL GLOBAL ESTIMATES	**2002**	**2003**	**2005**	**2010**	**2012**
Total major fed species production	17,566	18,617	21,031	27,939	31,747
Total fin and crustacean production	27,944	29,830			
Total aquafeed production	17,880	19,474	20,958	27,744	31,747
IFFO estimate	*15,794*	-	-	-	*35,095*
Total estimated fish meal used	2,696	2,936	2,666	2,478	2,577
IFFO estimate	*2,873*	-	-	-	*3,019*
Total estimated fish oil used	758.3	802.0	551.8	534.1	664.8
IFFO estimate	791	-	-	-	848
Total fishmeal + fish oil used	3,454	3,738	3,218	3,012	3,242
IFFO calculated this paper	*3,664*	-	-	-	*3,867*
Equivalent pelagics used (CF 4)[9]	13,816	14,952	12,871	12,048	12,967
Equivalent pelagics used (CF 5)[9]	17,270	18,690	16,089	15,060	16,209

[1]Total reported farmed species group production for 2002 and 2003 are taken from FAO (2005a), and estimates for 2005, 2010 and 2012 are calculated based on expected growth. [2] Mean estimated Annual Percent Rate of Growth of farmed species group production from 2002 to 2003, 2003 to 2005, 2005 to 2010, and 2010 to 2012 (APR, %) [3] Estimated percent of total species group production on aquafeeds; [4] Estimated average species group economic food conversion ratio (total food fed / total species group biomass increase); [5] Estimated total species group aquafeed used (total species group production x FCR); [6]International Fishmeal and Fish Oil Organization (IFFO), Use of fish meal and fish oil: revised estimates for 2002 and 2012 (summary tables give in IFFO Update No. 155, February 2004 - provided by Ian Pike, April 2005 – personal communication); [7] Includes Chinese bream, mandarin fish, yellow croaker, long-nose catfish (carnivorous/omnivorous) but excluding eel (IFFO, 2005); [8] Includes total reported farmed finfish and crustacean production, excluding filter feeding fish species (7,036 thousand tonnes in 2003: includes silver carp, bighead carp, rohu and catla which are not usually fed on industrially compounded aquafeeds) and excluding fed major species group production. Species included here include freshwater fish species (species unknown: 3,373 thousand tonnes in 2003), marine crabs and other marine crustaceans (183 thousand tonnes), Mandarin fish (150 thousand tonnes in 2003), and other miscellaneous freshwater fish species (including snakeheads, colossoma, climbing perch, gourami ca. 158 thousand tonnes in 2003). [9]Using a mean fishmeal+fishoil to wet pelagics conversion ratio of 1:4 and 1:5 respectively.

Appendix 2. Organisations and persons consulted who provided information toward the preparation of this report, including the survey on the current use of blood meal & blood products

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Australia:

- Ridley Aqua-Feed Pty Ltd, Queensland
  Richard Smullen Ph.D., Nutritionist, Technical Manager

Belgium:

- European Animal Protein Association, Brussels
  Chris Penning, President
  Dirk Dobbelaere, Secretary General
- VDS bvba, Deerlijk
  Eric De Muylder, Aquaculture Department, Nutritionist

Brazil:

- Mogiana Alimentos (Guabi) S.A., Campinas
  Francisco Olbrich Ph.D., R & D Director – Commercial Feeds

Canada:

- Skretting/Nutreco, Vancouver
  Greg Deacon, Sales Manager/Nutritionist
- Taplow Feeds, Armstrong
  Brad Hicks Ph.D., Vice President

Chile:

- Alitec, Puerto Montt
  Andres Rosa K., Nutritionist
- AquaChile, Puerto Montt
  Marianna Silva, Head of Nutrition & Quality Control
- FeedMaster, Puerto Montt
  Renato Abarca Salas, Manager
- Hinrichsen Trading, Santiago
  Juan Pablo Hinrichsen, Managing Director
- Salmofood, Castro, Chiloe
  Pablo Leyton Miranda, Technical Manager

China:

- National Renderers Association Inc., Hong Kong
  Yu Yu, Asia Regional Manager

Costa Rica:

- AS Oros (subsidory of Rica Foods Inc), Heredia

Jose Fabio Alpizar Bonilla, Nutritionist

Denmark:

- Daka Proteins, Ringsted
  Peter Trads, Sales Director

Germany:

- Naturland – Association for Organic Aquaculture, Grafelfing
  Stefan Bergleiter Ph.D., Aquaculture Department

India:

- Aqua Feeds Consultants, Chennai
  Victor Suresh Ph.D., Aquafeeds Consultant
- Higashimaru Feeds (India) Ltd, Cochin
  Anesh Paul, Chief Operating Officer

Indonesia:

- Charoen Pokphand Indonesia, Jakarta
  Dean Akiyama Ph.D., Senior Vice President

Malaysia:

- Cargill Feed Sdn Bhd, Melaka
  Siow Leng Ng Ph.D., Group Manager - Aquaculture
- Aqua Culture Asia Pacific Magazine, KL
  Zuridah Merican Ph.D., Nutritionist & Editor

Mexico:

- Agribrands Purina Mexico
  Jesus Zendejas Hernandez, Aquaculture Technology Development Director
- National Renderers Association Inc., Mexico D.F.
  German Davalos, Regional Director – Latin America
- Piasa Corporativo S.A., La Paz
  Alejandro Flores Tom, Director General

Norway:

- Nutreco Aquaculture Research Centre A.S., Stavanger
  Viggo Halseth, Managing Director
  Wolfgang Koppe Ph.D., Manager Nutrition

Peru:

- Alicorp, Callao
  Dagoberto Sanchez, Nutritionist

Spain:

- ProAqua Nutrition S.A.,
  Agustin Fernandez Vaquero, Nutrition & R & D

The Netherlands:

- APC Europe S.A.
  Harry Hoetink, Director of Sales
- Provimi Holding BV, Rotterdam
  Hans Boon, Manager Aquaculture Development
- Sonac BV (a Sobel Company), Son
  Geert van der Velden, Sales Manager

Thailand:

- CPM Foods Ltd, Bangkok
  Ming-Dang Chen Ph.D., Nutritionist
- Protector Nutrition, Bangkok
  Suchart Thanakiatkae Ph.D., Managing Director
- Thai Luxe Enterprises Public Co. Ltd., Bangkok
  Tom Wilson, Ph.D., Vice President (Chief Technical Officer)

UK:

- BioMar Ltd., Grangemouth
  Nick Bradbury, Technical Support Manager
- National Renderers Association Inc.,
  Neville Chandler, European Regional Director
- Skretting Ltd, Renfrew
  Paul Morris Ph.D., Research Manager
- Webster Rae, Crieff
  John L. Webster Ph.D., Technical Consultant to SQS

USA:

- H.J.B. Baker & Bro. Inc., Stamford
  Paul Guzman, Feed International Product Manager
- Nelson & Sons Inc., Murray
  Richard Nelson, VP Purchasing & Adminstration
- Zeigler Bros. Inc., Gardners
  Tim Markey, Nutritionist