Feeds and fertilizers: the key to long-term sustainability of Asian aquaculture

Sena S. De Silva[1]
School of Life and Environmental Sciences, Deakin University
PO Box 423, Warrnambool, Victoria 3280
Australia
Mohammad R. Hasan
Aquaculture Management and Conservation Service
FAO Fisheries and Aquaculture Department, Rome 00153
Italy

De Silva, S.S. and Hasan, M.R. 2007. Feeds and fertilizers: the key to long-term sustainability of Asian aquaculture. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 19–47.

[1] Network of Aquaculture Centres in Asia-Pacific, Bangkok, PO Box 1040, Kasetsart Post Office, Bangkok, 10903, Thailand.

SUMMARY

Asian aquaculture is dominated by inland, semi-intensive finfish culture and production has been increasing over the years. However, the rate of increase is decreasing, except in Viet Nam, and overall production is likely to stabilize around year 2015. The major factors that will sustain aquaculture production in Asia are feeds and feed management. Asian aquaculture is still largely a rural and semi-intensive activity, baring exceptions such as shrimp culture, and consequently the sector to a large extent is dependent on farm-made feeds. However, the use of commercial feeds in Asia is also increasing. There have been substantive improvements in farm-made feed formulation and manufacturing. Throughout the region there is an increase in the number of small-scale processors who make customised feeds, according to required specifications and this has lead to greater feed efficacy, reduction in feed costs and improved feed quality. There is an urgent need to investigate ways and means to further improve farm-made feeds through suitable research and development programmes in collaboration with farmers and small scale processors and to develop appropriate policies to encourage growth in this sector. The first step towards achieving these goals will be to assess the types of feed produced by small-scale producers and the magnitude of the sector and to evaluate the current efficacies of non-commercial feeds.

Asian finfish mariculture is almost totally dependent on the use of trash fish, a resource that is declining and a practice that results in much environmental degradation. As such there is an urgent need to encourage farmers to change to farm-made and or commercial feeds. If this is not accomplished the sector is unlikely to be sustainable.

Asia is a net importer and the biggest user of fishmeal and fish oil. It is therefore not immune to global issues in respect of fishmeal and fish oil usage in aquafeeds. Overall, the use of animal by-products and fishing industry wastes for aquafeeds is restricted. There is a need to encourage the use of such ingredients in aquafeeds. Although many studies have been undertaken on fishmeal replacement the results are rarely translated into practices, and as such there is a need to bring about an effective dialogue between research and development and the feed industry. Throughout the region there are growing concerns with regard to feed quality and consequently suitable guidelines and certification processes have to be introduced.

1. INTRODUCTION

Over the last three decades food fish production has become the domain of the developing world, in particular Asia (Delgado *et al*., 2003). In 2004, world aquaculture contributed nearly 33 percent to the global food fish supply, amounting to 54.8 million tonnes and valued at US$67.3 billion. To this, Asia contributed 91.2 percent (49.98 million tonnes), valued at US$55.1 billion (FAO, 2006). Asia has an estimated human population of 3.68 billion that is expected to increase to 4.78 billion by 2025 (http://esa.un.org/unpp/). Most of the worlds major fish stocks are over fished and catches in many of the major fisheries are either static or are declining. Aquaculture is the only option to increase fish production and to narrow the gap between supply and demand. Because of its rapid growth in the last three decades the aquaculture sector now faces new and demanding environmental, social, resource allocation and technological challenges. These must now be addressed and overcome to maintain the momentum in the sector.

This paper considers the current use of feeds and other nutrients in Asian aquaculture as key components for the sustainable development of the sector in the next two to three decades. This synthesis is mostly based on comparable analyses undertaken for Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam, which are the major contributors to aquaculture production in the region, a review of the relevant literature and FAO (2006) production statistics.

Recent trends in aquaculture in the region are briefly summarized to place the significance of feeds and feeding into perspective within the context of Asian aquaculture. This provides the background for the analysis and is used to assess possible future trends that might impact on the sustainable development of the sector as a whole.

1.1 Brief review of the Asian aquaculture sector

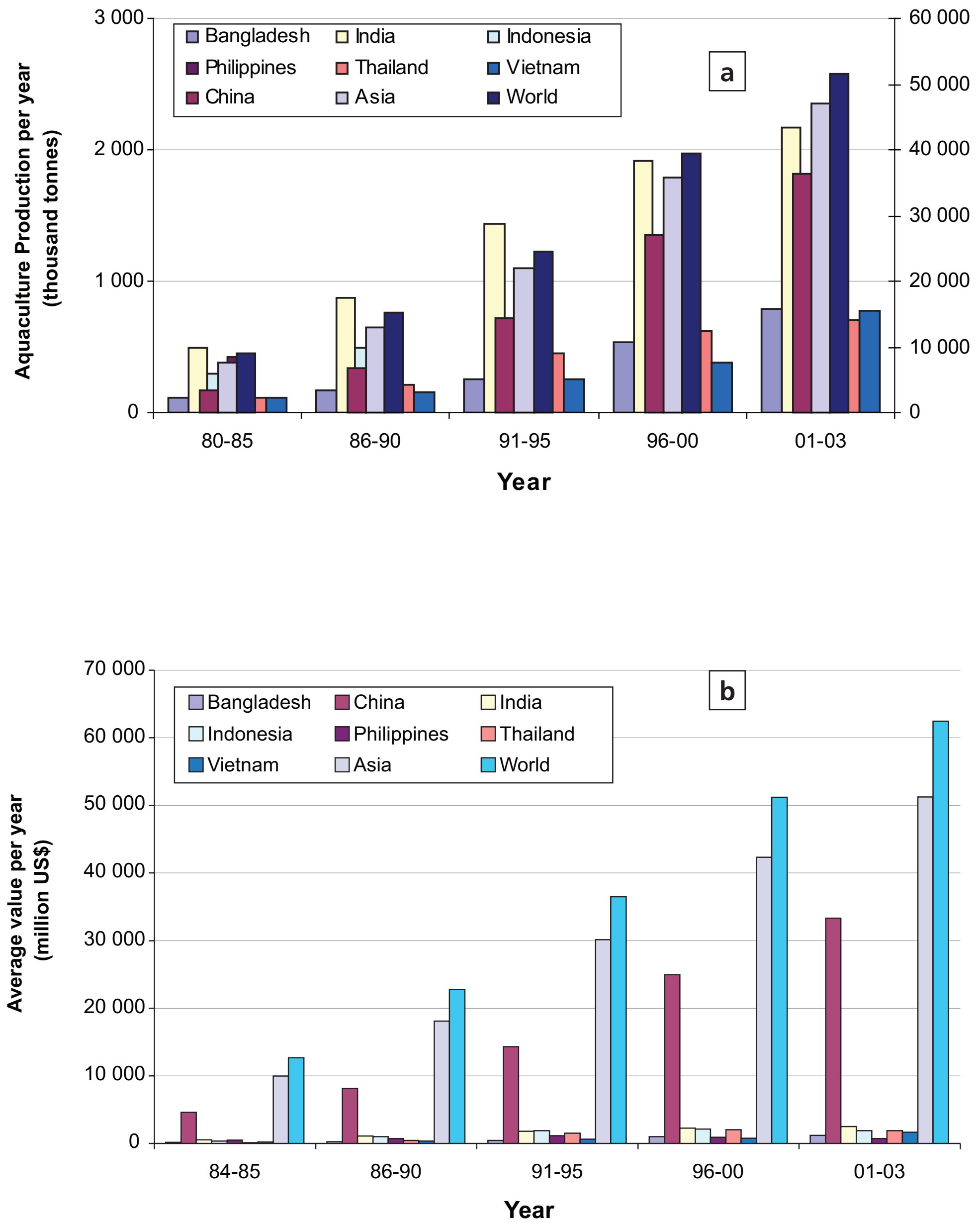
The trends and most of the key aspects of global and Asian aquaculture up to the year 2000 are summarized in NACA/FAO (2001). Table 1 summarizes the trends and developments in freshwater, brackish-water and marine aquaculture for the 15 year period from 1995 to 2004. From these data it is evident that aquaculture production by volume and value has increased substantially in all of the major producer countries. Over the 15 year period the seven countries, which form the basis of this review, contributed over 85 percent to the total Asian aquaculture production and over 70 percent globally. However, the contribution by value of marine aquaculture has remained below 50 percent of the global total and there is no discernable up or downward trend in this regard (Table 1). The data also clearly show the dominance of China in aquaculture production in all three environments.

Aquaculture in the seven countries was dominated by finfish production (Table 2). The seven countries contributed in excess of 90 percent to Asian and 80 percent to global fish production, although the bulk of finfish produced are relatively low value species. These trends are further summarized in Figures 1 to 4, using five year averages for the period 1980 to 2004. The trends can be summarized as follows:

- aquaculture production, by volume and value, has increased significantly in all of the countries under consideration;
- the main contributor has been China;
- marine and freshwater aquaculture have contributed almost equally to the total production (including seaweeds and molluscs);
- in terms of finfish and crustaceans, fresh and brackish-water aquaculture production is considerably higher than the output from mariculture; and
- apart from Viet Nam, there has been a significant decrease in the rate of growth in production in Asia and globally.

In a nutshell, aquaculture production is still increasing in most countries in Asia and globally. However, the rate of increase is declining and is likely to reach a plateau within the next two decades. As such, it is imperative that measures are taken to curtail the decline in the growth rate of the sector.

FIGURE 1
Annual mean aquaculture production by volume (a) and value (b) in the seven target countries, Asia and the world for the period 1980–2004. The mean is based on five-year averages, except for the period 2000–2004



Source: FAO (2006)

TABLE 1

Freshwater, brackish-water and marine aquaculture production by volume and value (excluding aquatic plants) in Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam, for 1995, 2000 and 2004

	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam	Asia	%Asia	World	%World
Production (tonnes)											
1995											
Brackish	45 735	78 416	70 000	361 247	237 091	265 889	71 816	1 226 824	92.1	1 556 967	72.6
Freshwater	271 338	9 407 600	1 588 799	279 845	97 664	200 782	295 933	12 633 079	96.1	13 529 722	89.7
Marine	0	6 369 637	8	0	26 829	92 833	13 320	7 817 311	83.2	9 295 327	70.0
Total	**317 073**	**15 855 653**	**1 658 807**	**641 092**	**361 584**	**559 504**	**381 069**	**21 677 214**	**91.2**	**2 438 2016**	**81.1**
2000											
Brackish	86 944	217 994	96 715	422 802	241 455	319 171	93 502	1 584 101	93.3	2 134 481	69.3
Freshwater	570 176	15 169 365	1 844 236	363 111	112 033	271 012	365 015	19 268 522	97.0	20 420 935	91.6
Marine	0	9 193 312	1253	2587	40 375	147 972	40 000	10 627 795	88.7	12 918 891	73.0
Total	**657 120**	**24 580 671**	**1 942 204**	**788 500**	**393 863**	**738 155**	**498 517**	**31 480 418**	**94.0**	**35 474 307**	**83.4**
2004											
Brackish	97 537	789 435	120 367	547 008	262 555	406 988	339 555	2 714 471	94.4	3 369 563	76.1
Freshwater	817 215	18 514 778	2 351 968	488 079	180 875	365 478	703 827	24 426 877	95.9	25 751 633	90.9
Marine	0	11 310 785	0	22 955	68 790	400 400	155 235	13 333 283	89.7	16 360 181	73.1
Total	**914 752**	**30 614 998**	**2 472 335**	**1 058 042**	**512 220**	**1 172 866**	**1 198 617**	**40 474 631**	**93.8**	**45 481 377**	**83.4**
Value (US$ thousand)											
1995											
Brackish	204 784	588 120	485 034	1 265 468	1 084 858	1 619 858	397 517	6 174 534	91.4	7 471 128	75.6
Freshwater	410 477	8 993 265	1 461 414	684 320	163 399	217 869	488 290	15 451 048	80.4	17 756 250	70.0
Marine	0	6 122 494	11	0	5 558	34 591	14 652	10 317 059	59.9	13 947 110	44.3
Total	**615 261**	**15 703 878**	**1 946 459**	**1 949 787**	**1 253 815**	**1 872 318**	**900 458**	**31 942 641**	**75.9**	**39 174 488**	**61.9**
2000											
Brackish	239 218	1 307 964	806 473	1 381 333	541 101	2 226 488	440 297	7 428 577	93.5	9 165 349	75.8
Freshwater	799 884	14 941 990	1 704 376	854 825	121 295	246 009	511 021	21 594 939	88.8	24 410 584	78.6
Marine	0	8 067 186	331	9 537	18 332	41 349	40 000	11 825 944	69.1	17 502 750	46.7
Total	**1 039 102**	**24 317 140**	**2 511 179**	**2 245 695**	**680 728**	**2 513 846**	**991 318**	**40 849 460**	**84.0**	**51 078 683**	**67.2**
2004											
Brackish	244 789	2 683 980	718 936	1 434 487	493 448	1 175 581	1 232 614	8 585 414	93.0	10 307 611	77.7
Freshwater	1 118 391	19 870 645	2 217 543	504 489	161 736	349 589	1 05 5741	28 452 981	88.8	31 755 255	79.6
Marine	0	8 314 984	0	191 028	45 670	61 456	155 235	12 990 642	67.5	21430 417	40.9
Total	**1 363 180**	**30 869 609**	**2 936 479**	**2 130 004**	**700 854**	**1 586 626**	**2 443 589**	**50 029 036**	**84.0**	**6 3493 284**	**66.2**

Source: FAO (2006)

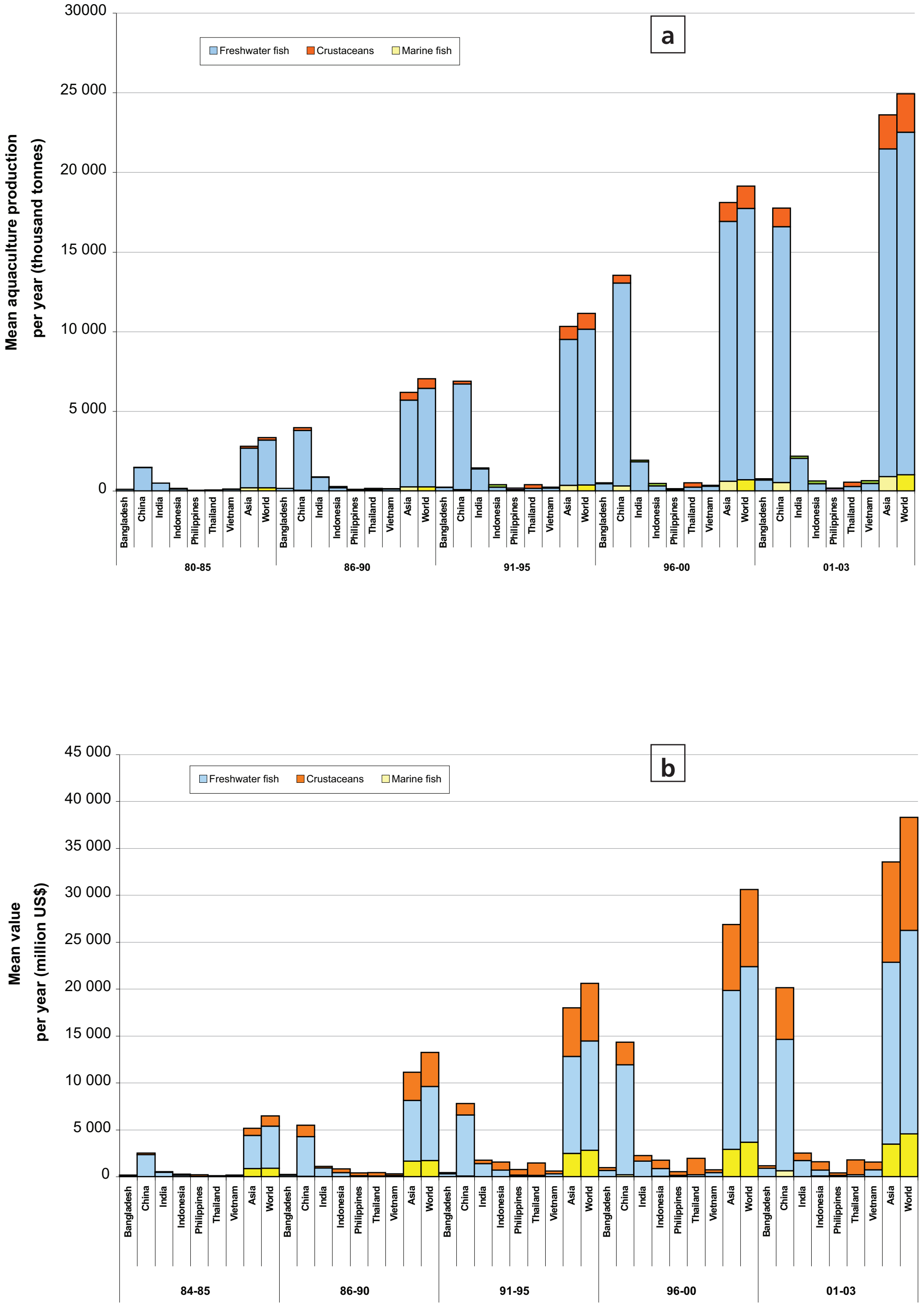
TABLE 2

Aquaculture production by volume and value of finfish, crustaceans and molluscs in Bangladesh, China, India, Indonesia, the Philippines, Thailand, and Viet Nam, for 1995, 2000 and 2004, in Asia and globally

	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam	Asia	%Asia	World	%World
Production (tonnes)											
1995											
Finfish	283 043	9 493 597	1 588 799	492 578	241 703	197 904	295 933	13 420 931	93.8	14 994 370	84.0
Crustaceans	34 030	181 880	70 000	148 514	93 275	268 550	71 816	906 026	95.8	1 101 693	78.7
Molluscs	0	6 162 731	8	0	26 606	92 833	13 320	7 295 062	86.3	8 230 344	76.5
Total	**317 073**	**15 838 208**	**1 658 807**	**641 092**	**361 584**	**559 287**	**381 069**	**21 622 019**	**91.4**	**24 326 407**	**81.2**
2000											
Finfish	592 473	15 074 183	1 827 636	641 677	315 865	268 995	365 015	20 013 066	95.4	22 745 339	83.9
Crustaceans	64 647	807 095	113 315	146 823	46 819	319 788	93 502	16 44 365	96.8	1 820 196	87.5
Molluscs	0	8 607 050	1 253	0	31 179	147 972	40 000	9 686 477	91.1	10 771 451	82.0
Total	**657 120**	**24 488 328**	**1 942 204**	**788 500**	**393 863**	**736 755**	**498 517**	**31 343 908**	**94.1**	**35 336 986**	**83.5**
2004											
Finfish	839 585	17 834 881	2 300 350	803 135	437 051	349 356	761 566	24 757 653	94.2	28 165 039	82.8
Crustaceans	75 167	1 995 164	171 985	241 874	44 216	418 510	281 816	3 338 706	96.7	3 679 753	87.7
Molluscs	0	10 438 313	0	12 991	30 953	400 400	155 235	11 998 256	92.0	13 255 852	83.3
Total	**914 752**	**30 268 358**	**2 472 335**	**1 058 000**	**512 220**	**1 168 266**	**1 198 617**	**40 094 615**	**93.8**	**45 100 644**	**83.4**
Value (US$ thousand)											
1995											
Finfish	410 810	8 781 638	1 461 414	1 084 314	469 697	207 479	488 290	18 681 500	69.1	23 686 176	54.5
Crustaceans	204 451	1 122 471	485 034	865 473	779 135	1 628 238	397 517	5 894 083	93.0	6 976 619	78.6
Molluscs	0	5 721 267	11	0	4 983	34 591	14 652	7 191 233	80.3	8 332 397	69.3
Total	**615 261**	**15 625 376**	**1 946 459**	**1 949 787**	**1 253 815**	**1 870 308**	**900 458**	**31 766 816**	**76.1**	**38 995 192**	**61.9**
2000											
Finfish	788 363	13 161 581	1 649 596	1 383 896	382 538	234 280	511 021	23 119 776	78.3	31 048 878	58.3
Crustaceans	250 739	3 640 098	861 253	861 799	293 363	2 231 269	440 297	8 990 595	95.4	10 088 486	85.0
Molluscs	0	7 173 792	331	0	4 827	41 349	40 000	8 318 827	87.3	9 515 080	76.3
Total	**1 039 102**	**23 975 471**	**2 511 179**	**2 245 695**	**680 728**	**2 506 898**	**991 318**	**40 429 197**	**84.0**	**50 652 444**	**67.0**
2004											
Finfish	1 038 702	15 937 967	1 950 815	939 396	434 691	311 556	1 142 349	27 888 121	78.0	37 920 700	57.4
Crustaceans	324 478	7 201 207	985 663	1 053 692	262 596	1 199 547	1 146 005	12 849 252	94.7	14 360 890	84.8
Molluscs	0	6 557 577	0	136 764	3 567	61 456	155 235	8 055 705	85.8	99 71 105	69.4
Total	**1 363 180**	**29 696 751**	**2 936 479**	**2 129 852**	**700 854**	**1 572 559**	**2 443 589**	**48 793 079**	**83.7**	**62 252 695**	**65.5**

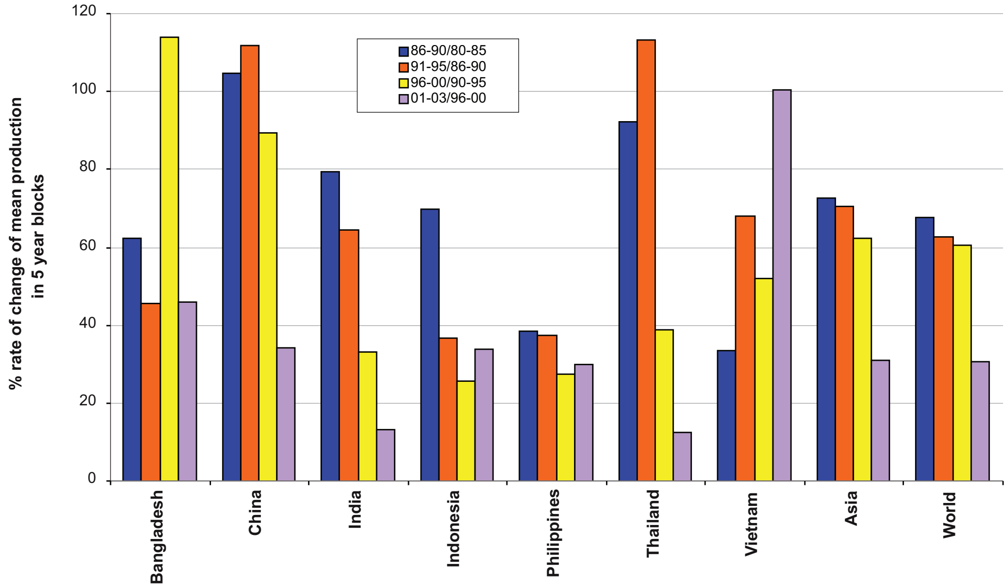
Source: FAO (2006)

FIGURE 2
Mean aquaculture production by volume (a) and value (b) by species groups for the period 1980–2004 in Asian countries



Source: FAO (2006)

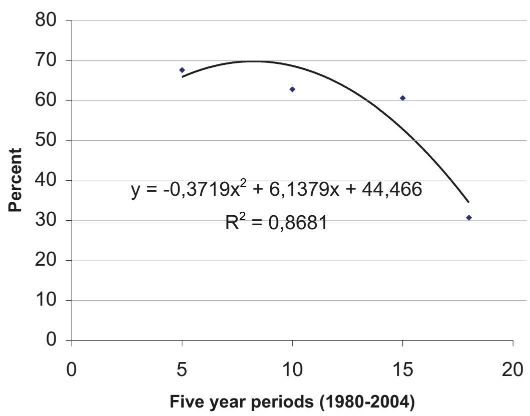
FIGURE 3
Percent rate of change in mean aquaculture production (in five year blocks) for selected Asian nations, whole of Asia and the world



Source: calculated from FAO (2006)

1.2 Strategies for increasing aquaculture production in a sustainable manner

FIGURE 4
Percent change in Asian aquaculture production over time



Source: calculated from FAO (2006)

While retaining a rural base, many factors were responsible for the upsurge in Asian aquaculture production. In addition to technological advances and improvements, the foremost factors that led to the rapid growth of aquaculture in the region were the increasing gap between food fish demand and supply and the subsequent support by governments to develop rural and industrial scale aquaculture. The main technological advances that contributed to the increases in production were:

- advances in hypophysation techniques and the virtual elimination of the dependency on wild juveniles (apart from a few cultured species);
- advances in husbandry techniques, such as the adoption of "polyculture" systems and improved management procedures;
- genetic improvement of a number of species and the development of monosex tilapia culture
- improvements in disease prevention and control; and
- improvements in feed formulations and manufacture and feeding practices.

The surface area used for aquaculture in Asia has been increasing. The area currently used for aquaculture in the region is summarized in Table 3. There is little scope to increase production by increasing the area under culture, especially in inland waters. The reason for this is although Asia has the largest inland/freshwater resources

TABLE 3
Estimated area (ha) available and/or documented to be used for aquaculture in different environments in seven Asian countries

Environment	Country						
	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam
Freshwater (finfish)							
Ponds	305 025	1.858×10^6	247 500	97 821	14 531	118 002	120 000
Depressions	5 488		130 000			2 007	
Reservoirs/lakes		2.334×10^6	270 000		219 000		340 000
Cages				466*		59	
Others		471 600		151 414**		23 432**	580 000**
Freshwater (prawn etc)							
Ponds			41 870				
Brackish water							
Pond	217 877		154 600	370 824	239 323	83 919	
Cages							
Marine				-			
Cage units		715 750		196 198			660 000***

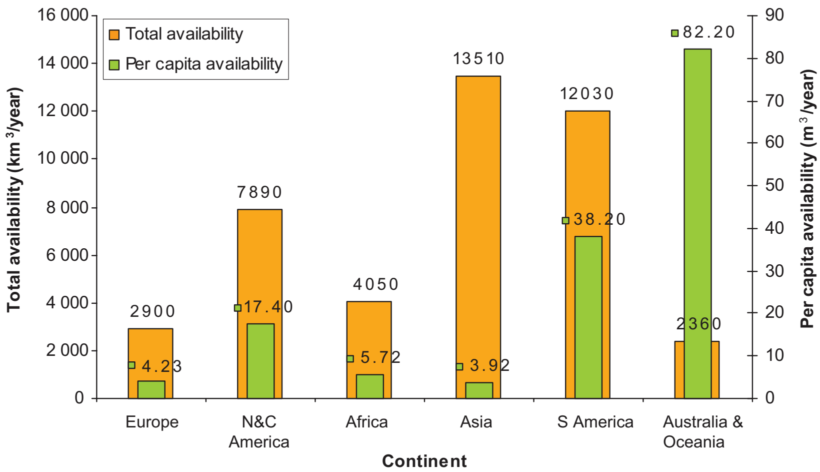
* Inland cages; **primarily paddy fields; *** tidal flats; empty spaces = no data

Source: data for Bangladesh, China, India, Indonesia, Philippines, Thailand and Viet Nam were obtained respectively from Barman and Karim (2007); Cen and Zhang (1999); Ayyappan and Ahamad Ali (2007); Nur (2007); Sumagaysay-Chavoso (2007); Thongrod (2007); and Hung and Huy (2007)

among all continents, the per caput availability is lowest (Nguyen and De Silva, 2006; Figure 5). As such, increasing competition for this relatively scarce primary resource (in addition to the demand for land) will probably not permit significant expansion of inland aquaculture, except perhaps the use of reservoirs for cage and cove culture and culture-based fisheries (De Silva, 2003). On the other hand, unplanned and overly ambitious developments in reservoir cage culture can be counter productive, as has been the case in certain Asian countries (Abery *et al*., 2005).

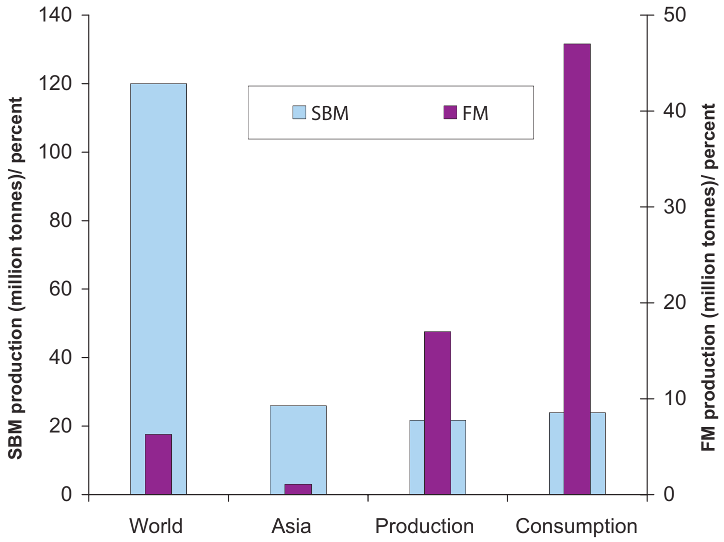
In essence there are two possible strategies to increase future aquaculture production in Asia. These are genetic improvements and advances in feed and feed technology. The most notable advances in genetic improvements have been made for salmonids and tilapias (Gedram, 2000) and these have to be emulated for some of the more important aquaculture species in Asia. In following this approach care has to be taken to preserve the genetic integrity of individual species and to conserve biodiversity. Some genetic manipulations such as the hybridisation of the Asian catfish (*Clarias macrocephalus*) with the African catfish (*C. gariepinus*) could have long term negative impacts on

FIGURE 5
Total and per caput inland water availability per continents



Source: Nguyen and De Silva (2006)

FIGURE 6
Global and Asian production of soybean meal and fishmeal (in million tonnes) and the percent contribution by Asia to global production and consumption



Source: Tacon (2004)

natural population structure and the conservation of biodiversity (Na-Nakorn, 2005) and could lead to negative public perception on aquaculture developments.

Developments in feeds and feed management have a crucial role to play in the future expansion of Asian aquaculture, particularly with respect to the rapidly increasing demand for commercial feeds by the shrimp, marine and freshwater finfish sectors (Chamberlain, 1993; Gill, 1997; New and Csavas, 1995; Tacon and De Silva, 1997; De Silva, 1999; Hasan, 2001; Tacon, 2004; Tacon, Hasan and Subasibghe, 2006). The demand for commercial aquaculture feeds has also recently become more contentious, particularly with regard to the supply of fishmeal and fish oil. Aquaculture has become the single largest consumer of these commodities of all animal husbandry sectors. Aquaculture's share of fishmeal use has increased from 10 percent in 1988 to 46 percent in 2002 (Barlow and Pike, 2001; Pike, 2005). Similarly, there has been a drastic increase in the share of fish oil usage from 16 percent in 1988 to 81 percent in 2002. Pike (2005) further predicted that in 2012, aquaculture will use 50 and 88 percent fishmeal and fish oil, respectively. Aquaculture's share of total fishmeal and fish oil use is therefore expected to increase, respectively, from 46 percent and 81 percent in 2002, to 50 percent and 88 percent by 2012. The consequences of these trends to the Asian region, that accounts for over 90 percent of global aquaculture production, is immediately obvious. Moreover, the demand and use of fishmeal in some of the emerging aquaculture countries in Asia is increasing rapidly. For example, Viet Nam already uses approximately 62 500 tonnes of fishmeal per year, solely for aquaculture (see Figure 6 and also refer to www.gafta.com/fin/finfacts3.html.)

2. FEEDS AND FEEDING PRACTICES IN ASIAN AQUACULTURE

Aquaculture is very diverse because of the number of species cultured, singly and or in combination, the differences in the environment – freshwater, brackish water or marine, the intensity of the practice, the nature of the containment – ponds, cages, raceways, etc, as well as the socio-economic *milieu* in which it occur. This diversity is similarly reflected in the array of different feeds, feeding practices and the use of organic or inorganic fertilizers. For the purposes of this paper, feeds and feeding practices in Asian aquaculture are considered in relation to culture intensity, i.e. extensive, semi- and intensive culture practices.

Feed efficacy also has the potential to bring about major changes in culture practices, even in the case of small-scale, rural aquaculture enterprises. For example, in the Mekong Delta in southern Viet Nam it has been reported that high feed costs in pangasiid cage culture has brought about a significant shift to pond culture (Hung and Merican, 2006). The significant point is that the overall production cost per kg ranged from VND 8 000 to 11 000 in ponds as opposed to VND 8 153 to 11 619 in cages (US$1.00 = VND 15 000), of which feeds accounted for 78 to 90 percent of total production costs, respectively, indicating that even minor reductions in unit production cost can result in major shifts from one production system to another.

2.1 Extensive systems

Extensive aquaculture in Asia is practised in several ways. In all countries considered here, large areas are devoted to extensive earthen pond aquaculture, primarily for finfish and shrimp culture. By definition, external feeds are not applied in extensive systems, but more often than not organic and inorganic fertilizers are applied to augment natural food production in the systems.

2.2 Semi-intensive systems

Asian aquaculture is dominated by semi-intensive freshwater, earthen pond culture systems. In these systems natural productivity is enhanced with fertilizers and the fish or shrimp are provided with supplemental feeds. Feeds are mostly farm-made or made according to farmer specifications by local feed processing plants. For example, in India and Bangladesh almost all inland finfish production is semi-intensive and is based on farm-made feeds. There is an increasing trend in some Asian countries for small-scale, commercial feed manufacturers to produce relatively large quantities of feeds, for a particular species and hence supply the demands within a region. Good examples are the pangasiid feed producers in the Mekong delta in Viet Nam (Hung, Truc and Huy, 2007). These feeds are not necessarily nutritionally wholesome and indeed need not be so.

2.3 Intensive systems

Intensive aquaculture practices in Asia are by and large restricted to shrimp culture, inland and marine finfish cage culture, as well as freshwater culture of some high value species such as eels in China. In intensive systems the cultured stock has to be provided with a complete feed that meets all the nutritional requirements of the species. Such feeds are species specific and in most culture practices will account for 40 to 60 percent of recurrent production costs.

3. FERTILIZER USAGE IN ASIAN AQUACULTURE

There is a long history of organic and inorganic fertilizer use in pond culture of filter feeding finfish species in Asia. The dynamics of fertilizer use and its efficacy in aquaculture is fairly well understood (Hepher, 1988; New, Tacon and Csavas, 1994). In extensive systems fertilizers are often the only input and in semi-intensive systems fertilizer may be regularly and or infrequently applied. Culture systems in which fertilizer is the only input are more often than not small-scale, single pond operations, except perhaps milk fish culture operations in which even large operations use fertilizers to induce the growth of “lab lab”.

Almost all extensive and the majority of semi-intensive aquaculture operations in Asia, with minor exceptions, are dependent on the use of fertilizer and organic manures. Fertilizer and manure usage in aquaculture varies considerably among Asian countries (Table 4). In general, the use of fresh manure is preferred over the application of dry manure. This is because nutrient delivery from wet manure is faster and more efficient. In India and Bangladesh cattle and buffalo manure is extensively used in

TABLE 4
Fertilizer use/availability (2003-04) in some Asian countries

Country/species	Culture period (days)	Yield (kg/ha/year)	Fertilizer use (kg or tonnes/ha/year)		Total usage		Projected requirement (2020)
			Organic	Inorganic	Organic	Inorganic	
Bangladesh							
Shrimp spp.*	100–120	200–400	BDT 200**		Solid biodegradable from market waste etc are also used		
India							
Freshwater finfish (Indian major and Chinese carps)	Variable	Variable; >2 000	20 tonnes (cattle dung and poultry manure)	Nitrogen fertilizer 200 kg; phosphate fertilizer 200 kg	100 million tonnes (cattle dung and poultry manure)	Nitrogen fertilizer 100 000 tonnes; phosphate fertilizer 100 000 tonnes	Organic manure 190.15 million tonnes; nitrogen fertilizer 190 000 tonnes; phosphate fertilizer 190 000 tonnes
Freshwater prawn	NA	860 (40–1 180)	2 500 kg (cattle dung and poultry manure)	Nitrogen fertilizer 45 kg; phosphate fertilizer 45 kg	86 600 tonnes (cattle dung and poultry manure)	Nitrogen fertilizer 1 600 tonnes; phosphate fertilizer 1 600 tonnes	Organic manure 164 500 tonnes; nitrogen fertilizer 3 050 tonnes; phosphate fertilizer 3 050 tonnes
Shrimp	NA	730 (460–1 890)	1 250 kg	Nitrogen fertilizer 15 kg; phosphates 10 kg	125 000 tonnes	Nitrogen fertilizer 1 500 tonnes; phosphate fertilizer 1 000 tonnes	Organic manure 187 500 tonnes; nitrogen fertilizer 2 250 tonnes; phosphate fertilizer 1 500 tonnes
Indonesia							
Finfish (freshwater)	NA	Variable	118 kg	29 kg	19 600 tonnes	7 600 tonnes	
Shrimp (brackish water)	NA	Variable	22 kg	13 kg			
Philippines							
All fish species			2 000 kg	670 kg	489 998 tonnes	190 930 tonnes	Projected requirement will remain same for the next 10 years

*Extensive shrimp aquaculture in Bangladesh is primarily dependent on natural recruitment of shrimp post-larvae.**Quantitative information on fertilizer use for Bangladesh is not available, although farmers spend an average of 200 Bangladesh taka (BDT) per ha per year (US$1.00 = BDT 65.00)

Source: data for Bangladesh, India, Indonesia and Philippines were obtained respectively from Barman and Karim (2007); Ayyappan and Ahamad Ali (2007); Nur (2007); and Sumagaysay-Chavoso (2007) and personal observations.

aquaculture. With the increasing industrialisation of poultry production in most Asian countries, in the last ten to fifteen years, poultry manure has become readily available for use in aquaculture. In the Philippines poultry manure, which ranges in price from US$16.36 to 21.82/tonne, is preferred over other organic fertilizers. Other livestock manure, mudpress (agricultural waste from sugar mills) and rice bran are also used to enhance natural pond productivity but to a much lesser extent. In most countries, fish farmers usually only apply organic fertilizers during pond preparation, although some also apply fertilizers during the rearing period to maintain the growth of phyto- and zooplankton.

The availability of manure, particularly in rural areas has continued to sustain carp culture practices in many countries, and milk fish culture in the Philippines in particular. Improved manure and system management has contributed significantly towards the growth of the carp and milkfish sectors and indirectly has made farmers independent of commercial feeds. In Viet Nam, the use of fertilizers and manure in aquaculture is less common than in other Asian countries and is often confined to the nursery stages when juvenile fish generally perform better on natural food organisms. On the other hand, sewage cum fish culture in urban areas in Viet Nam is popular and encouraged. In the Philippines, there is a greater dependence on inorganic fertilizers in comparison to most other countries. In some countries there are increasing bio-security concerns with regard to the use of animal manure, especially in shrimp culture in Indonesia.

4. AQUAFEEDS

4.1 General considerations

It is difficult, if not impossible, to differentiate accurately between industrial aquafeed production and total animal feed production. This is because the same ingredients are often used for aqua- or other animal feeds and similar industrial production processes. However, only a small proportion of feed production plants in Asia is dedicated aquafeed manufacturers and the bulk of feeds used in Asian aquaculture are non-industrial feeds and hence estimates can be made of total aquafeed production and consumption.

China and India are among the world's top ten animal feed producers, accounting for 11.9 percent (72.7 million tonnes) and 1.6 percent (9.6 million tonnes) respectively of global industrial animal feed production (Gill, 2006). As will become apparent later, only a very small proportion of the industrially produced feeds in both of these countries, and Asia in general, are used in aquaculture. For example, aquaculture in India used 0.24 millon tonnes of industrial feed in 2003 amounting to only 3.7 percent of the total aquafeed of 6.4 million tonnes (Victor Suresh, pers. comm.).

4.2 Types of aquafeeds

Asian aquafeeds can be broadly divided into four categories. The potential of each of these feed types in relation to production/yield is shown in Figure 7.

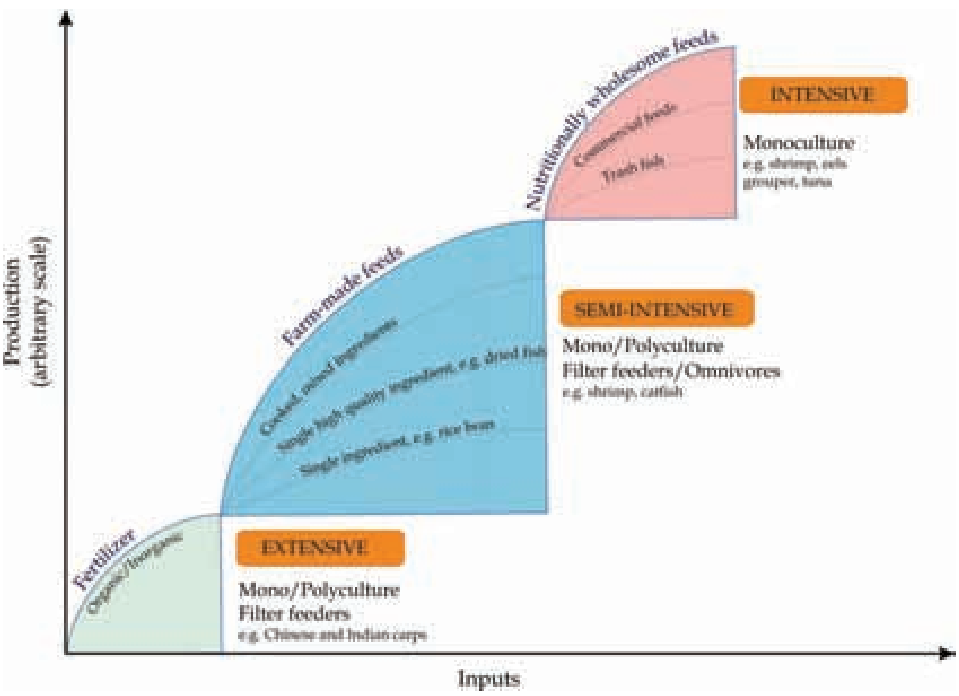
1. Materials and or ingredients of plant origin that are used singly or in combination with others (of plant or animal origin) but with little or no processing. Such feeds are mostly used at the lower end of the semi-intensive culture spectrum, for example in home ponds. The feeds/ingredients vary in quality and nutrient content, e.g. rice bran of rather limited nutritional value and/or mixed with dried fish of high nutritional value.
2. Materials of animal origin, primarily trash fish that is used singly or in combination with others but with little or no processing. Such feeds are mostly used at the upper end of semi-intensive to intensive culture practices and mainly in marine fish culture, e.g. grouper (*Epinephelus* spp.), Asian seabass (*Lates calcarifer*) and cobia (*Rachycentron canadum*).
3. Mixtures of ingredients that are subjected to some form of processing (simple grinding, mixing and cooking resulting in a moist dough or in simple pellets).

Processing is done on farm or in small processing plants, according to the specifications of the farmer. Collectively these feeds are designated as farm-made feeds, and often are the main stay in semi-intensive aquaculture. In the literature they are also commonly referred to as supplementary feeds (De Silva, 1994).

4. Feeds that are manufactured by industrial feed milling plants that are distributed and sold using conventional market chains. Such feeds are expected to fulfil all the nutrient requirements of the cultured species and are mostly used in intensive practices, often by relatively large-scale aquaculture operations. The ingredient composition and all aspects pertaining to feed formulation and manufacturing processes are normally based on research findings and farmers normally do not make any input into ingredient selection and or feed formulations. These feeds are sold under different trade names, generally in 20–25 kg bags and are available for post-larval and shrimp grow-out, tilapia fingerlings and grow-out, common carp, eels, seabass and so forth. The nutrient specifications (percent moisture and protein, lipid, ash, energy content and certain manufacturers will also provide percent nitrogen free extract and fibre content data) as well as the pellet size are indicated on the packaging.

Irrespective of the feed category the majority of the ingredients used in the feeds, particularly in categories (iii) and (iv) are fairly common ingredients. The key ingredients, fishmeal, soybean meal, various oilseed cakes are also used in the production of other animal feeds and hence aquaculture is a direct competitor with other animal husbandry practices. For Asia as a whole the situation is further exacerbated as its contribution to the world supply of these three principal ingredients is minimal in comparison to the proportion that is used by the regional animal feed industry (Figure 6). For example, while Asia produces only 17 percent it consumes 47 percent of the global fishmeal supply.

FIGURE 7
A schematic representation of the effectiveness of fertilizers and different feed types on aquaculture production



4.3 Current usage

A conservative estimate of current aquafeed use in Asia, based on data provided for the target countries, is 19.3 and 10.3 million tonnes of farm-made and commercial feeds, respectively (Tables 5 and 6). It is likely that the consumption of farm-made feeds is significantly underestimated in view of the difficulties in accurately assessing feed use. For example, feed usage in back yard pond culture, which is widespread throughput the region, is rarely accounted for. Also, some countries with limited aquaculture activities have not been taken into account in the above estimates. For example, Hong Kong used 9 600 tonnes of trash fish in 2002 in its relatively small mariculture sector (Chau and Sadovy, 2005), and Sri Lanka used 4 104 tonnes of shrimp feed in 2004 (Weerakoon, pers. comm.).

Based on the above feed use estimates and assuming, rather conservatively that farm-made and commercial feeds have food conversion ratios of 2.0 and 1.3:1, respectively, the total estimated feed use is expected to yield 17.6 million tonnes of finfish and crustaceans. However, the recorded production for 2003 was 24.04 million tonnes (marine finfish = 531 556 tonnes, freshwater finfish = 21 146 200 tonnes and crustaceans = 2 361 055 tonnes), a difference of nearly 6.5 million tonnes. The question therefore, arises whether feed usage is grossly under-represented and/or that the 6.5 million tonne difference is accounted for by extensive practices, although this is highly unlikely. Unfortunately, data pertaining to production in relation to feed use in the different countries are not available and are difficult to collate, except of course for the use of commercial feeds in some practices (Abery *et al*., 2005). However, such data may be very useful in evaluating the efficacy of feed types, which in turn would be of use in bringing about improvements, especially in the case of farm-made feeds that are extensively used in some countries in the region, e.g. India and Viet Nam.

4.4 Aquafeed projections

In Tables 5 and 6 an attempt is made to predict future feed use in the target countries. The total estimates for farm-made and commercial feeds by 2013 are 30.7 million and 22.2 million tonnes, respectively (Figure 8). These predicted values represent increases of 60 and 107 percent for farm-made and commercial feed use, respectively from current levels. For both groups of feeds the highest demand will be from China. Even

FIGURE 8
Current and predicted use of farm-made and commercial feeds in Asia and projected percent increase

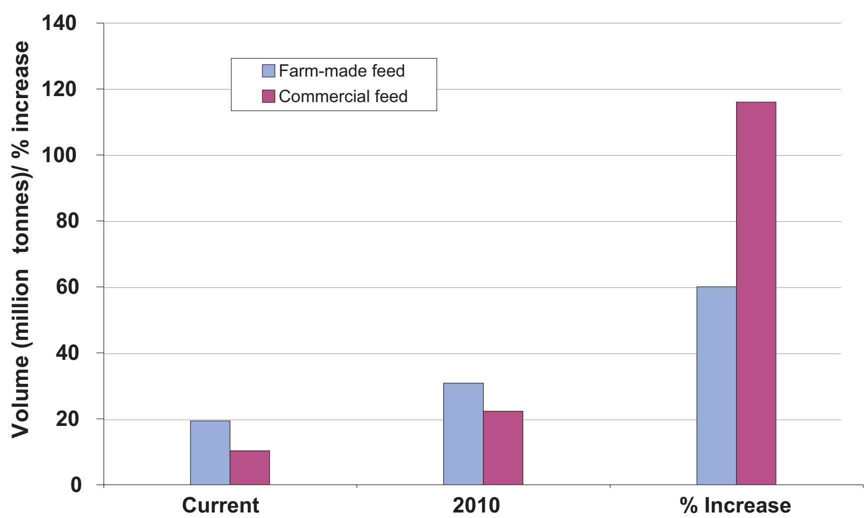


TABLE 5
Current and projected use (tonnes) of single ingredient and farm-made feeds in aquaculture in selected Asian countries

Feeds	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam
Current use							
Finfish	50 000	10 350 000	6 144 947[a]	223 850			500 000
Shrimp	20 000	530 000	~20 000[b]	42 000			
Others				10 000			
Total	70 000	10 880 000	6 164 947	275 850	384 896	762 173[c]	800 000
Projected needs: 2013							
Finfish		13 056 000[d]	7 994 431[e]		828 088		
Shrimp		636 000[d]	276 134				1 500 000
Trash fish		4 000 000					1 000 000
Total	91 000[e]	17 692 000	8 270 565	358 605[e]	828 088[e]	990 824[e]	2 500 000

[a]Rice and wheat bran, oilseed cakes, marine ingredients, others; [b]Fishmeal, squid meal, shrimp meal, mantis shrimp meal, soybean meal, flour, fish oil, lecithin, binders; [c]including trash fish used in diets for seabass and grouper; [d]Based on a 20 percent increase of current usage; [e]Based on a 30 percent increase on current use. Note that in Viet Nam, an estimated 300 000 tonnes of trash fish is used in aquafeeds. Predictions for the increase in shrimp production in India and for finfish and shrimp production and trash fish usage in Viet Nam were made on estimated increases in production volume, and using reasonable FCRs. Calculations were done using 2003 data to ensure consistency between different countries.

Source: Country reviews and personal communications with the authors.

TABLE 6
Number of aquafeed mills operating in selected Asian countries, current and projected production and the major ingredients used (tonnes). Please note that the projections for India are for the year 2020 and the others for 2013

Mills/production	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam
Number							
Fish	-	-	1	-	-	12	13
Shrimp	-	-	28	-	-	34	23
Fish & shrimp	14	360	-	20	78	14	-
Production							
Current							
Fishmeal	NA	1 500 000	48 000[1]	34 485	30 630	248 500	62 500
Soybean meal	NA	2 340 000	33 000	4 523	55 437	145 950	100 000
Corn/wheat	NA	1 550 000	30 000	24 310	NA	78 750	NA
Total	60 000	7 800 000	238 883	490 000	204 396	822 500	696 000
Projected							
Fishmeal	NA	4 050 000	133 147[1]	70 000	105 905	NA	NA
Soybean meal	NA	4 800 000	67 650	15 000	179 146	NA	NA
Corn/wheat	NA	3 004 000	61 500	50 000	297 334	NA	NA
Total	NA	16 000 000	347 500	1 000 000	658 313	2 736 336	1 500 000

[1] Also includes shrimp meal, mantis shrimp meal; NA= data not available or insufficient data available to make predictions. Calculations were done using 2003 data to ensure consistency between different countries.

Source: Country reviews and personal communications with the authors.

in those Asian countries where aquaculture is a relatively minor industry the demand for aquafeeds is expected to increase three to four fold by 2013. For example, in Sri Lanka that has a small aquaculture industry it is projected that feed usage will increase three fold to 12 400 tonnes by 2010 (Weerakoon, pers. comm.). Moreover, Malaysia has adopted a suite of aggressive aquaculture development strategies (Malaysian Ninth Five Year Plan, 2006 to 2010) and envisages to increase aquaculture production from 150 000 tonnes (current) to 600 000 tonnes by the year 2010. Obviously such increases in production (approximately 20 percent per year) have to go hand in hand with feed availability.

4.5 Ingredients used in aquafeeds

As pointed out previously, the key ingredients used in aquafeeds, particularly those used in commercial feeds, are common to those used in terrestrial animal feeds. Consequently, there will be higher levels of competition for these ingredients in the global market, in particular for ingredients such as fishmeal, fish oil, soybean meal and vitamin and mineral pre-mixes. The advantage, if any, in favour of aquafeeds is that aquaculture practices in Asia are predominantly extensive and semi-intensive and for many more years to come will be using farm-made feeds. These feeds allow for the incorporation of a much greater variety of ingredients. Moreover many of these ingredients directly and or indirectly act as nutrient sources that augment natural food production in ponds. These issues have been dealt with in detail previously (De Silva, 1994; Wood *et al*., 1992). The study by Wood (op cit.) raised the question of the value of conventional nutritional wisdom in relation to aquaculture in the tropics and suggested that the provision of nutritionally complete diets in tropical systems may not always be needed.

Ingredients used in aquafeeds are either of plant or of animal origin. Generally, the plant products are less costly and also have the advantage of being relatively easily accessible and available, baring a few exceptions and tend to be the mainstay of farm-made feeds.

4.5.1 Plant and agricultural by-products used in aquafeeds

A large variety of plant by-products are used in the production of aquafeeds, predominantly for the extensive and semi-intensive aquaculture feed categories (i) and (ii) (see above). The exceptions are soybean meal and wheat flour that are also used in feed categories (iii) and (iv). Soybean meal is one of the most widely used ingredients in all types of feeds. This is because of its favourable nutritional composition and digestibility, its availability and long shelf life.

The most commonly used plant based ingredients in Asian aquafeeds and their availability are summarized in Table 7. The data is by no means exhaustive but provides an indication of the main ingredients that are used in the seven target countries. The majority of these ingredients are either used singly or in various combinations. However, the extent of use of plant based agricultural by-products, despite the fact that some have a high protein content, in aquafeeds is limited. Foremost among factors that discourage the use of agricultural plant based by-products are:

- unfavourable amino acid balance;
- inferior digestibility;
- presence of anti-nutritional factors; and
- localised and seasonal availability.

The first three of the above factors have been addressed extensively (Tacon, 1987; De Silva and Anderson, 1995; Hertrampf and Pascual, 2000; and contributions to this volume). Despite extensive research the incorporation of plant based by-products in aquafeeds is limited. This issue is discussed in greater detail later.

In general, Asian aquaculture relies heavily on agricultural produce and by-products. Consequently, there is increasing competition from alternative users and this has led to substantial price increases. Availability, seasonality and the demand for plant based agricultural by-products varies appreciably between countries.

Throughout the region, there is little data on competitive uses of agricultural by-products in animal husbandry and other forms of agriculture. The lack of this crucial information is largely due to the difficulties of data collation and the absence of interdisciplinary approaches to natural resource use patterns in all farming systems. Aquaculture, as the newly emerged farming system, on the present scale of activities, will in all probability have to take the lead in assessing comparative resource use, particularly in rural areas where the issue is pivotal.

TABLE 7
Commonly available and potentially useful agricultural by-products and plants used in Asian aquafeeds. Where available, estimates of availability is in thousand tonnes/year. Figures in parentheses indicate current estimated usage in aquafeeds

Ingredient	Bangladesh	China	India*	Indonesia	Philippines**	Thailand	Viet Nam
Plants/leaf meals							
Azolla				+			
Cassava				+	201	+	
Duckweed	+					+	+
Leucaena				+	0.6		
Spirulina			+			+	
Water hyacinth	+					+	+
Water velvet							
Brans							
Black gram	+						+
Corn					1 137	4 000 (79)	
Lentil	+						
Rice	1 254	+	3 000–3 500	+	1 450	+	3 350 (300–500)
Wheat	+	+	2 000–2 500	+		+	+
Oil cakes							
Coconut	86		140–160	+	704 (9.6)	+	
Cottonseed		4 000–5 000	750–800				
Groundnut	30	14 000–15 000	8 000–8 500			+	
Linseed	+		100				
Mustard/rapeseed	234		5 000–5 800				
Rapeseed		5 000 (4 000)					
Sesame	+		450–500				
Soybean meal/ cake		15 500–17 550	5 000–5 500	+	(55.4)	298 (141)	1 185 (80–132)
Sunflower		+	800–1 000				
Others							
Corn gluten							
Corn meal	+	+	+	+	3 735	+	+
Molasses		+	+			+	
Pulses			+			+	
Rice (broken)	+	+	+			399	2 010
Sorghum			7 500–8 000	+			
Tapioca/cassava			5 600–6 000	+	1 040	+	5 230 (30–45)
Wheat flour	+	+	+			+	+
Wheat gluten		+				+	

*Current usage in aquaculture: rice and wheat bran 85.8 thousand tonnes, oil cakes/meals 39.0 thousand tonnes, marine ingredients 75.5 thousand tonnes, cereal 30.0 thousand tonnes, others 2.6 thousand tonnes; **current usage in aquaculture: rice bran/corn bran/wheat flour 94 thousand tonnes.

Source: data for Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam were obtained respectively from Barman and Karim (2007); Weimin and Mengqing (2007); Ayyappan and Ahamad Ali (2007); Nur (2007); Sumagaysay-Chavoso (2007); Thongrod (2007); and Hung and Huy (2007)

4.5.2 Animal industry by-products used in aquafeeds

a) The animal husbandry industry

Asia, particularly China, India and Thailand, has considerably large animal husbandry industries, in particular poultry and pig industries. The processing waste resulting from these industries are substantial. Overall, the use of animal husbandry by-products, such as bone meal, blood meal and feather meal, is not adequately organized such that the use of many of these highly nutritious materials, even though there are no legal restrictions (e.g. such as in the use of bone meal in Europe), is rather sporadic and isolated. The approximate availability of potentially useful animal industry by-products for aquafeeds is presented in Table 8.

In most instances, animal industry by-products are mainly used for farm-made feeds and are rarely incorporated into commercial feeds.

b) Fishing industry by-products

The nutrient composition of fish by-products, from the surimi industry, fish canning industries, filleting plants and the like has been shown to be very close to that of fishmeal (Gunasekera *et al*., 2002). This clearly indicates the potential of these resources as a possible replacement for fishmeal in aquafeeds. For example, it has been estimated that India produces some 340 000 tonnes of fish industry waste that is available for aquafeeds.

With one or two exceptions, the only by-product that has been used to any substantial extent in Asian aquafeeds is shrimp processing waste, primarily in the form of shrimp head meal. A recent development in Viet Nam is the use of processing waste from *Pangasius* catfish culture. Viet Nam is the largest producer of pangasiid catfish (*Pangasius hypophthalamus* and *P. bocoutii*) in the region, producing around 300 000 tonnes per annum, which generates approximately 210 000 tonnes of waste (Hung and Huy, 2007; Hung, Truc and Huy, 2007). The bulk of the waste is used for the extraction of oil and for inclusion in farm-made feeds. This is unique and illustrates how aquaculture waste can be used efficiently and effectively. Considering that aquaculture in Asia is often practised in sizeable clusters, the strategy adopted in the Mekong delta should be replicated in areas where there are adequate volumes of waste products. This could result in significant cost savings and employment in a region.

TABLE 8

Commonly available animal industry by-products (thousand tonnes) in several Asian countries. Figures in parentheses indicate current estimated usage in aquafeeds

Ingredient	Country						
	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam
Blood meal	+	+		+	46.8	+	
Meat and bone meal	+	+	55.2		243.5	+	
Catfish waste							210
Feather meal		+	+		23.0	+	
Fishmeal	+	+	202–208	+	(30.6)	611 (234.5)	248–255 (46.5–62.5)
Fish silage		+					
Krill meal				+			
Nereis meal				+			
Poultry offal			65		45.9	+	
Shrimp meal	+		106	+			
Shrimp head meal			31	+	7.2 (1.7)	+	60–70
Silk worm pupae	+	+	40				
Slaughterhouse waste		+	+			+	
Snail meal				+			
Squid meal		+	19–21			+	
Trash fish		5 316*		+		756* (131.9)	933.2 (176.4–363.4)

Source: data for Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam were obtained respectively from Barman and Karim (2007); Weimin and Mengqing (2007); Ayyappan and Ahamad Ali (2007); Nur (2007); Sumagaysay-Chavoso (2007); Thongrod (2007); and Hung and Huy (2007). *Fung-Smith et al. (2005)

c) Trash fish

Asian finfish mariculture, particularly grouper and cobia farming, is growing rapidly in China, Viet Nam and Indonesia and is largely still dependent on trash fish as a feed. It has been estimated that Viet Nam will use nearly one million tonnes of trash fish and China will require approximately 4 million tonnes of trash fish by 2013 to sustain marine cage culture activities. Trash fish is mainly obtained from commercial marine fisheries although a fair share is also supplied by artisanal fisheries, particularly in Viet Nam. The supply of trash fish in Asia is highly seasonal and dwindling (Edwards, Tuan and Allan, 2004). However, the demand for the commodity by the marine finfish culture sector in many countries is high and increasing. There is a growing concern with regard to the environmental effects of using trash fish in aquaculture. Moreover, its efficacy as an aquafeed is debateable and its preferred use appears in many instances to be based more on farmer perceptions than economic reality. For example, a recent study on grouper cage culture in Viet Nam showed that the average survival, FCR and cost of production using formulated pellets were 62.2 percent, 2.12:1 and US$2.18/kg as opposed to 54.5 percent, 7.38:1 and US$2.58 using trash fish, respectively (Anon., 2006).

There is an urgent need to reduce the dependence of the industry on trash fish in the ensuing years. This can only be achieved through the development of suitable dry, pellet feeds and appropriate on-farm R&D activities to convince farmers of the benefits of being less reliant on trash fish.

4.6 Aquafeed formulations

4.6.1 Farm-made and or "semi-commercial" formulations

As mentioned above, semi-intensive finfish culture is the dominant aquaculture practice in Asia and is primarily dependent on farm-made and/or "semi-commercially" prepared aquafeeds. The formulations of these feeds differ considerably regionally and nationally (Table 9) and are mostly determined by ingredient availability and cost. In general however, a few base ingredients are used and these normally are soybean meal, wheat flour and rice bran, supplemented with fishmeal or with an ingredient that matches the composition of fishmeal as closely as possible. It is however, difficult to generalise as farm-made feeds may be very species specific (Table 10).

Efficacy of farm-made and or "semi-commercial" feeds

Considering that the bulk of aquaculture production in Asia is dependent on farm-made and or "semi-commercial" aquafeeds and the fact that there has been a considerable increase in aquaculture production over the past decade, it is reasonable to conclude that the efficacy of these feeds has contributed substantially to the growth of the sector. However, this fact often goes un-noticed and receives little attention. A possible way to infer the efficacy of these feeds is to consider production levels in different culture systems (Table 11). From these data it is evident that the production levels for a variety of systems are substantial, especially considering the level of inputs and the capital investment. It would be most useful to obtain more detailed data on these aspects and to conduct a comprehensive analysis. This would no doubt provide valuable information to increase production even further. The recent changes in pangasiid culture (see above and Hung, Truc and Huy, 2007) (Figure 9) serves as a good example to illustrate this point. Clearly, many more such focused studies are needed to increase our understanding of farm-made feeds, which can only result in bringing about further improvements in feed efficacy.

TABLE 9

Examples of ingredient composition (arranged in descending order of inclusion level) and other relevant information, where available, for selected farm-made feeds (for grow-out unless otherwise stated) in selected Asian countries

Country/Species	Ingredients	Preparation/ feeding	Cost (US$/kg)	% Protein
Bangladesh				
Carps	MOC, RB/WB	Made into wet balls		
Pangasius (catfish)	RB, MOC, WF, WB, RB, FM, BM	MOC is soaked for 24 h and mixed with other ingredients; made into balls		
Carp and shrimp	MOC, DFM, RB, WF, molasses		0.25	
Shrimp	RB, MOC, WF, molasses			
China (only selected examples are given)				
Tilapia (grow out)	SBM, wheat middling., corn, PBM FM, VO, VMPM	Where needed ingredients are minced and / or ground and mixed and then cooked		28.5
Common carp, crucian carp, tilapia	RSM, SBM, WF, corn, WB, FM, binder		NA	NA
Grass carp, amur bream	RSM, WF, corn, WB, SBM, binder			
Chinese mitten crab	SBM, RSM, FM, WF, WB, shell meal, MIA, others		NA	NA
Giant freshwater prawn	SBM, RSM, WF, FM, WB, shell meal, binder, VMPM		NA	NA
India				
Indian major carps	RB, PC, CSC		0.10	20
Shrimp- made to order	DFM, mantis shrimp, sergestid shrimp, SBM, SWP, MG, WF, GRM, RB, FO		0.45	
Indonesia				
Juvenile grouper	TF, FM, GRM, cassava starch, FO	Moist feed- prepared daily		48
Philippines				
Milkfish	RB, SBM, FM, FO		0.38	26.7
Tilapia	Cassava flour, SBM, FM, CM, RB, VMPM		0.56	28.1
Catfish	SBM, RB, FM, WF, SBO, VMPM		0.40	34.2
Grouper	FM, MBM, BM, SM, SBM, VM, FO, VMPM		1.30	44.0
Mudcrab	MBM, FM, WF, RB, CB, SW		0.78	40.1
Tiger prawn	FM, SBM, SM, WF, RB, SW, FO, SBO, cholesterol, VMPM		0.81	41.7
Thailand				
Walking catfish and tilapia (larvae)	FM, cassava starch, RB, VO, VMPM, binder	Ground, mixed and fed; prepared daily; may use feed bags	0.45	37.5
Walking catfish (grow out)	SMB, dried cassava, coconut meal, CM, FM, FO, VPM		0.24	28
Shrimp, carnivorous marine fish	TF, other ingredients, VMPM	Ground, extruded, cooked; cooked feed cooled; packed and stored in ice; shelf life 1 week	NA	NA
Viet Nam				
Catfish	RB, TF, SBM	Mixed and ground on site		
Grouper	TF	Chopped and fed		

CB- corn bran; CM- coconut meal; CSC- cotton seed cake; DFM- dry fishmeal; FM- fishmeal; FO- fish oil; GRM- groundnut meal; MBM- meat and bone meal; MG- maize gluten; MIA- moult inducing agent; MOC- mustard oil cake; PC- peanut cake; RB- rice bran; RSM- rape seed meal; SM- shrimp meal; SBM- soybean meal; SBO-soybean oil; SW- seaweed; SWP- silk worm pupae; TF- trash fish; VO- vegetable oil; WB- wheat bran; WF- wheat flour, WG- wheat gluten; WM- wheat meal, PBM- poultry by-product meal, VMPM- Vitamin and mineral premix

Source: data for Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam were obtained respectively from Barman and Karim (2007); Weimin and Mengqing (2007); Ayyappan and Ahamad Ali (2007); Nur (2007); Sumagaysay-Chavoso (2007); Thongrod (2007); and Hung and Huy (2007)

TABLE 10
Different feed formulations for two pangasiid catfish (*Pangasius hypophthalamus* and *P. bocoutii*) in the Mekong Delta

Ingredients	Formulation 1	Formulation 2
Trash fish	20–30%	
Rice bran	50–70%	40–50%
Broken rice	10–20%	-
Soybean meal	-	20–30%
Fish by-products	-	10 –30%
Others (corn, vegetables)	-	20%

Source: Hung, Truc and Huy (2007)

TABLE 11
Production levels using farm-made and or “semi-commercial” aquafeeds in different countries

Country/ Species groups	Type of culture	Production (kg/ha/year)
Bangladesh		
Major carps	Pond/polyculture	2 000–3 000
Shrimp/ carps	Pond	2 800–3 000
India		
Major carps	Pond/polyculture	5 000–8 000
Philippines		
Milkfish	Pond/monoculture	1 500–3 500*
Viet Nam		
Pangasiid catfish	Cage culture	150–200**

*kg/ha/crop; **kg/m³/crop

Source: data for Bangladesh, India, the Philippines, and Viet Nam were obtained respectively from Barman and Karim (2007); Ayyappan and Ahamad Ali (2007); Sumagaysay-Chavoso (2007); and Hung and Huy (2007)

The future of farm-made feeds

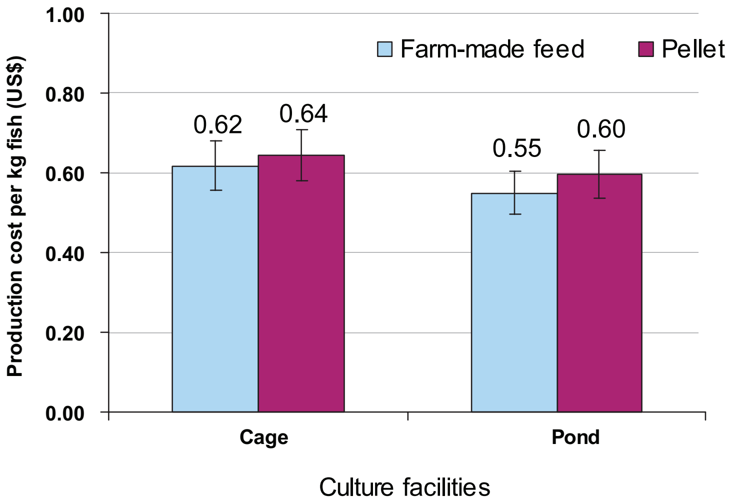
It is important to note that production per unit area has increased over the years with the use of farm-made and or “semi-commercially” aquafeeds. This increase is at least partially attributable to improvements in feed formulations as well as improvements in the processing techniques. As pointed out previously, such improvements as well as the increasing trend to include vitamin and mineral pre-mixes and binders are mostly brought about by farmer interventions and this has led to greater feed utilization efficiency. Over a decade ago, De Silva and Davy (1992) identified the need for a concerted research effort on farm-made feeds. They suggested then that farm-made feeds will continue to constitute the “back-bone” of aquaculture in Asia and those improvements to these feeds could result in very significant production gains. For the following reason this call is made again. Farmers have continued to bring about improvements to feed formulations primarily based on trial and error. If such improvements were to be backed up with focused research then farm-made feeds will make an even greater contribution to the sustainable development of aquaculture in Asia.

Finally, there is an unknown factor in relation to the efficacy of farm-made feeds. It is not known how much of the feed provided is utilized directly as opposed to its indirect “fertilizer” value. The latter may be an important factor that could provide clues for further increasing the efficacy of these feeds, therefore bringing about a saving in ingredient use and costs.

Constraints and needs

As pointed out above, the lack of research has impeded and constrained developments in farm-made and or “semi-commercial” aquafeeds. In addition, there are other local constraints that operate and hinder growth in the sector. Foremost among these, is the availability of key ingredients and access to these on a regular basis. This is primarily a consequence of poor market chains, which in turn may be a reflection

FIGURE 9
Comparison of the efficacy of farm-made versus pellet feeds in pangasiid aquaculture in the Mekong Delta



Source: Hung, Truc and Huy (2007)

of the scant recognition by the authorities of the importance of efficient distribution channels to aquaculture production. The provision of suitable credit, storage facilities and the like, in a given region, may mitigate against some of these factors.

Given that a high proportion of aquafeeds is made by small, semi-commercial feed processors there is an increasing need to provide suitable support for this manufacturing sector. This would facilitate greater efficiency, which would result in overall feed cost reductions and enhance productivity. Most importantly, this sector needs easier access to credit such that they can improve their storage as well as processing facilities. The development of this important feed manufacturing sector would also be greatly facilitated by training extension officers to monitor and provide advice on ingredient selection, feed formulation and processing. This will enhance farmer and processor confidence and stimulate the adoption of new and cost effective formulations.

4.6.2 Commercial formulations

Commercial aquafeed formulations are often considered as "trade secrets" and are not generally available to the public. The bulk of aquafeed production in Asia comprises shrimp feeds. Current regulations require the manufacturer to provide information on the quantity in each container, the type of feed and its gross nutrient composition. Needless to say, quality control measures with respect to food products in Asia are not as stringent as in the developed world, and aquafeeds are no exception in this regard. For example, a recent study has shown that in the majority of feeds the protein content was overestimated, whilst the fibre and the fat content were underestimated (Kader, Hossain and Hasan, 2005). Similarly, poor gonadal recrudescence and the consequent inability to artificially propagate two mahseer species (*Tor tambroides* and *T. douronensis*) in Sarawak, East Malaysia, was attributed to sub-standard (no HUFA) commercial feeds on which these fish were reared (Ingram *et al*., 2005).

4.6.3 The need for regulatory measures

Many of the Asian countries have recently introduced and or are in the process of introducing quality control measures for commercial aquafeeds. However, in most cases such regulations are restricted to the minimum and maximum inclusion levels of the gross nutrients for a particular species or life history stage. In general there are no regulations on heavy metal and or other organic compounds contents that may affect human health. Exporters of aquaculture products have to comply with stringent health and quality control measures and for this reason farmers require more detailed information. Moreover, regulations are effectively quite useless if they are not enforced through a regular monitoring programme.

5. MAJOR TRENDS IN RELATION TO AQUAFEEDS IN ASIAN AQUACULTURE

Although there is a general increase in the use of commercial feeds in most Asian countries this trend is often masked by changes that are occurring in semi-intensive aquaculture. Increasingly, small-scale semi-intensive farmers are mechanizing their farm-made feed processing facilities, mostly through improvisation and adaptation of old machinery meant for other purposes. The other notable trend (see above) is the rapid growth of the "semi-commercial" feed processors, who provide customised formulations on demand and in small, affordable quantities. This trend is most prevalent in Bangladesh and India, with the Philippines following suite. This practice enables the farmer to contain feed costs and hence is in a better position to manage the cash flow of the enterprise. This practice also allows the farmer to test various feed formulations at virtually no extra cost. As referred to above, such farmer initiated trials have contributed substantially to increased production levels. If a system were to be introduced to monitor the composition of the feeds on a regular basis and to link this with the seasonal availability of ingredients then further improvements and cost savings could most certainly be achieved.

During the last decade finfish mariculture has become increasingly dependent on trash fish. This is a major concern and for several reasons is unlikely to be sustainable in the long-term. The reasons include the rapidly dwindling "trash fish" resource (Edwards, Tuan and Allan, 2004), environmental degradation resulting from the use of trash fish and most importantly the growing public perception and awareness that the resource should be used for food instead of an animal feed. There is an urgent need to address this dilemma. The only possible option is for finfish mariculture operators to shift from using trash fish to "semi-commercial" or commercial aquafeeds. To expedite this shift may require the setting up of mariculture demonstration units to convince the practitioners of the benefits of using specifically formulated feeds.

6. ASIAN AQUAFEEDS IN A GLOBAL CONTEXT: ISSUES AND CHALLENGES

Since the initial coining of the term "the fishmeal trap" and its potential consequences on aquaculture developments (Wijkstrom and New, 1989), much water has "flown under the bridge". Public concern regarding the use of fishmeal and fish oil in aquaculture has taken centre stage and has generated much controversy and debate (Naylor *et al.*, 2000). Two facts can be discerned from the controversies:

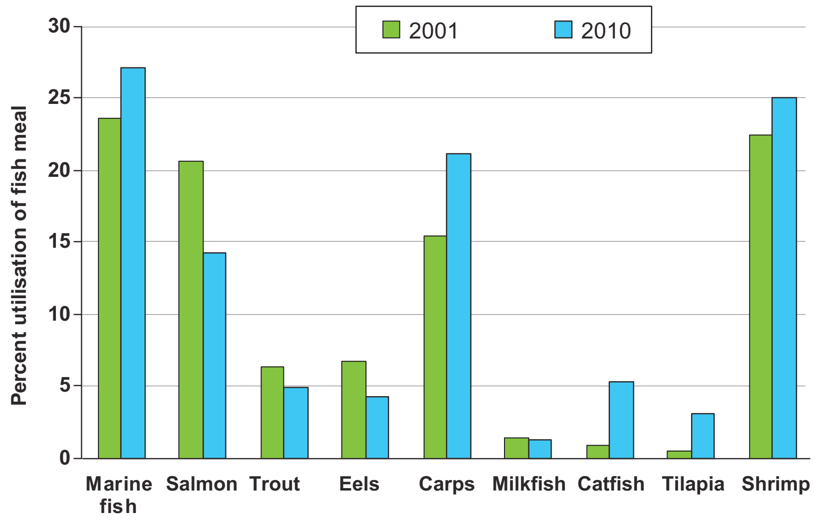
- Most of the criticisms were aimed at salmonid culture; and
- Many of the issues raised can, to a great extent, be refuted as the data that were used for the analyses are not necessarily fool proof in trying to illustrate the detrimental effects of salmon culture on the environment in a holistic manner.

Similarly, there is increasing public concern about the overall impacts of aquaculture on environmental quality. Needless to say, the onus is on aquaculture, particularly salmonid aquaculture, to defend its position and to clean up its act where necessary. But what does all this mean for Asian aquaculture?

Tacon (2004) estimated that fishmeal usage by 2010 (Figure 10) for carnivorous, temperate fish aquaculture will probably decrease by 10.7 percent to 305 378 tonnes and that fishmeal use for tropical fish aquaculture (carps, tilapia, milk fish, Chinese bream, etc), particularly in Asia, will increase by 7 percent to 713 500 tonnes. It is suggested that the reduction in fishmeal usage by carnivorous species aquaculture will be primarily achieved through decreases in the dietary protein content of feeds and therefore the level of fishmeal inclusion. By 2010, Asia is also expected to account for another 25 percent of global fishmeal usage for shrimp feeds and that this will amount to 713 500 tonnes. Based on these estimates Asia will use a minimum of 50 percent of global fishmeal production. Tacon (2004) also projected that "marine species" aquaculture, by 2010, will use 27.1 percent of the global fishmeal supply. Given that Asian marine finfish culture is currently based largely on trash fish it is difficult to estimate what proportion of this will be consumed in Asia.

FIGURE 10

Current and projected commercial feed usage by different categories of cultured finfish groups and shrimp



Source: Tacon (2004)

On the assumption that Tacon's (2004) projections are reasonable it is clear that the aquafeed industry in Asia, in the foreseeable future, will have to find ways and means of reducing fishmeal usage. The biggest challenge lies in the reduction of fishmeal usage in aquafeeds for omnivorous species.

7. POLICY DEVELOPMENTS

It is difficult to pin-point significant policy developments that have facilitated aquafeed production in Asia. One reason for this may be that the aquafeed sector is too small to have gained recognition and attention by government planners, except perhaps in Viet Nam, where the sector is increasingly recognized as a significant contributor to foreign exchange earnings and national GDP.

The aquafeed sector in most Asian countries is dependent on a number of imported ingredients, most notably fishmeal and additives and will continue to be so well into the foreseeable future. Perhaps one of the most important policy developments that should be considered is the provision of appropriate tax incentives to small-scale feed processors and the reduction and/or abolition of import duties on selected ingredients. It is common knowledge that some of the larger aquafeed companies in the major aquaculture countries in the region are recording large profit margins, while the small-scale processors rarely make sufficient profits to enable expansion, resulting in decreasing competitiveness in the market place. This is not a healthy trend for the sector in general. It may be worthwhile for countries to consider levying a fee on unit tonnage production by manufactures whose capacity and market share exceeds a certain proportion. This revenue could be used for research and development activities. However, such steps have to be in conformity with other feed manufacturing industries in the primary production sector and have to be assessed and determined on a country wise basis.

8. FUTURE NEEDS

The foremost future task of the aquafeed industry in Asia will be to reduce its dependence on trash fish and fishmeal (and oil). Clearly, there will have to be a shift from trash fish usage to farm-made, "semi-commercial" feeds and or commercial feeds.

Such changes will have to involve a fair quantum of research and development work, which will have to go hand in hand with extension services to facilitate the change. To reduce the use of fishmeal in commercial feeds will be more difficult and can only be affected by the industry. There has been on-going research on fishmeal substitution for almost all species that are cultured in Asia. Some of the results are encouraging but findings are rarely translated into commercial practice. The reasons for this are not clear but a remedy has to be found. Perhaps feed manufacturers do not perceive the need to change because of their current market share and profit margins. Alternatively, there may be genuine practical problems in translating the research results into commercial practise. Irrespective of the reason or reasons there is a need for urgent dialogue as the sector as a whole faces serious challenges and these can only be wholly or partially solved through cooperation and involvement by all.

It is most likely that the current regional growth of the aquaculture sector will be sustained largely by improvements in farm-made and or “semi-commercial” feed formulation and processing. It was previously concluded that most of the advances in the efficacy of these feed can be attributed to farmers. To meet the needs and future demands of the aquaculture sector it is imperative to launch a concerted research effort on farm-made feeds and in particular on ingredient quality, seasonal variability, marketing and storage, improvements in processing technology, feed formulation and the most effective way of presenting the feeds. As most semi-intensive aquaculture practices and their ancillary industries occur in clusters findings will be easily disseminated and adopted by the practitioners.

More and more farm-made feeds are likely to be processed by dedicated small-scale feed processors in future and feed “manufacturing/ processing” chains are likely to develop in most clusters. To facilitate this process will require the engagement of suitable qualified aquaculture extension workers.

There is a substantial information on the nutritional requirements of almost all major fish and crustacean species cultured in Asia, as well as information on apparent digestibilities, fishmeal substitution and other related aspects. The synoptic collation of this information for each species will help to eliminate duplication of research efforts and will provide useful information to bring about improved feed formulations.

The commercial aquafeed sector is not without its own problems, particularly the smaller manufacturers and the specialized feed mills that manufacture shrimp feeds. The highly seasonal nature of shrimp production forces many of the manufacturers to operate far below their capacity, often making such operations barely viable. However, these manufacturers are often located in areas where culture practices are clustered, thereby reducing transport and storage costs. It is important that this sector is provided with appropriate incentives to remain economically viable.

9. CONCLUSIONS

Globally and in Asia, aquaculture faces a challenging decade ahead, particularly because of the increasing competition for primary resources and growing public concern and perceptions about the sector. Added to all this are the increasingly stringent quality control measures imposed by exporters that may restrict aquaculture practices in future. Asian aquaculture has a predominantly rural, small-holder base and is likely to continue that way, except perhaps with regard to shrimp culture. This foundation is, in a way, advantageous for it to retain its momentum and sustainability.

However, the momentum of Asian aquaculture can only be sustained if feed inputs do not become a limiting factor, and if further improvements are made to feed quality and availability at reasonable prices. In both semi-intensive and intensive aquaculture feeds often account for 40 to 60 percent of recurrent costs, and as profit margins in most aquaculture practices are relatively narrow, it is imperative that feeds are available at a reasonable price.

Asian aquaculture is dominated by semi-intensive production and the bulk of production is dependent on farm-made and/or "semi-commercial" aquafeeds. Farmer ingenuity has led to significant improvements in feed formulations and processing. To further improve these feeds, which are the key to sustaining the sector and its momentum, there is a need for a concerted research and development effort in all Asian countries, backed up by improved extension services.

There has been a gradual increase in the use of commercial aquafeeds over the years in Asian aquaculture and this is principally attributable to the growth in shrimp culture, which has almost reached saturation levels in most countries. There is evidence to suggest that some aquafeeds do not conform to their specified formulations and hence there is a need for more stringent regulatory measures. Furthermore, throughout Asia there is a need for the commercial feed industry to be more mindful of research results, particularly with respect to fishmeal replacement studies and hence there is a great need for improved dialogue between research and industry.

The Asian finfish mariculture sector has to rapidly reduce its dependence on trash fish. Farmers must be encouraged to switch to commercial or other appropriate farm-made feeds. This may require regional government support. If this switch does not occur then finfish mariculture in Asia is doomed.

The commercial aquafeed sector in Asia is dependent on fishmeal (and fish oil) imports. Furthermore, Asian aquaculture is not immune to global changes and controversies that are emerging in regard to these key ingredients. Such changes tend to influence policy makers at national and international level. Consequently the Asian aquaculture industry needs to be proactive through suitable remedial and or mitigating measures. It is in this context and the fact that the bulk of Asian aquaculture production occurs in semi-intensive systems that it may be advantageous for the sector to concentrate its efforts on improving farm-made and or "semi-commercial" aquafeeds and developing more appropriate feeding practices.

ACKNOWLEDGEMENTS

The authors are thankful to the Food and Agriculture Organization of the United Nations and in particular to the Aquaculture Management and Conservation Service (FIMA) of the FAO Fisheries and Aquaculture Department for initiating the study.

REFERENCES

Abery, N.W., Sukadi, F., Budhiman, A.A., Kartamihardja, E.S., Koeshendrajana, S., Buddhiman & De Silva, S.S. 2005. Fisheries and cage culture of three reservoirs in west Java, Indonesia; a case study of ambitious developments and resulting interactions. *Fisheries Management and Ecology*, 12: 315–330.

Barlow, S.M. & Pike, I.H. 2001. Sustainability of fishmeal and oil supply. Paper presented at the Scottish Norwegian Marine Fish Farming Conference 'Sustainable Future for Marine Fish Farming', 14-15 June 2001, University of Stirling, Stirling, Scotland (available at http://www.stir.ac.uk/aqua.staq/conference).

Pike, I.H. 2005. Eco-efficiency in aquaculture: global catch of wild fish used in aquaculture. International Aquafeed, 8 (1): 38–40.

Anonymous. 2006. First with grouper feeds in Vietnam. *Aqua Culture Asia Pacific*, 2 (3): 8–9.

Ayyappan, S. & Ahamad Ali, S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in India (this volume).

Barman, B.K. & Karim, K. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Bangladesh (this volume).

Cen, D. & Zhang, D. 1998. Development and status of the aquaculture industry in the People's Republic of China. *World Aquaculture*, 29: 52–56.

Chamberlain, G.W. 1993. Aquaculture trends and feed projections. *World Aquaculture*, 24: 19–29.

De Silva, S.S. & Anderson, T.A. 1995. *Finfish Nutrition in aquaculture*. London, Chapman & Hall. 395 pp.

De Silva, S.S. & Davy, F.B. 1992. Strategies for finfish nutrition research for semi-intensive aquaculture in Asia. *Asian Fisheries Science,* 5: 129–144.

De Silva, S.S. 1994. Supplementary feeding in semi-intensive aquaculture systems. pp. 24–60. *In* M.B. New, A.G.J. Tacon & I. Csavas, (eds.) *Farm-made aquafeeds*. FAO Fisheries Technical Paper No. 343. Rome, FAO.

De Silva, S.S. 1999. Feed resources, usage and sustainability. pp. 223–244. *In* N. Svennevig, H. Reinersten & M.B. New, (eds.) *Sustainable Aquaculture. Food for the Future?* A.A. Balkema Publishers, Rotterdam.

De Silva, S.S. 2003. Culture-based fisheries: an underutilized opportunity in aquaculture. *Aquaculture,* 221: 221–243.

Delgado, C.L., Wada, N., Rosegrant, M.W., Meijer, S. & Ahmed, M. 2003. *Fish to 2020. Supply and demand in a changing global market.* International Food Policy Research Institute, Washington, D.C. 226 pp.

Edwards, P., Tuan, L.H. & Allan, G. 2004. *A survey of marine trash fish and fishmeal as aquaculture feed ingredients in Vietnam.* ACIAR Working paper 57, ACIAR, Canberra. 56 pp.

FAO. 2006. FAO Fisheries Department, Fishery Information, Data and Statistics Unit. Fishstat Plus: Universal software for fishery statistical time series. Aquaculture production: quantities 1950-2004, Aquaculture production: values 1984-2004; Capture production: 1950-2004; Commodities production and trade: 1950-2004; Total production: 1970-2004, Vers. 2.30 (available at www.fao.org/fi/statist/FISOFT/FISHPLUS.asp).

Fung-Smith, S., Lindebo, E. and Staples, D. 2005. *Asian fisheries today: the production and use of low value/trash fish from marine fisheries in the Asia-Pacific region*. RAP Publication 2005/16. Bangkok, FAORAP. 38 pp.

Gedram, T. 2000. Genetic improvement of cold water fish species. *Aquaculture Research,* 31: 25–33.

Gill, C. 2006. World feed panorama. Feeds more profitable but disease breeds uncertainty. *Feed International*, January 2006, pp. 5–12.

Gill, C. 1997. World feed panorama. High cost of feedstuffs: Global impact, response. *Feed International*, January 1997, pp. 6–16.

Gunasekera, R.M. , Turoczy, N.J., De Silva, S.S., Gavine, F. & Gooley, G.J. 2002. An evaluation of the potential suitability of selected aquatic food processing industry waste products in feeds for three fish species, based on similarity of chemical constituents. *Journal of Aquatic Food Product Technology,* 11: 57–78.

Hasan, M.R. 2001. Nutrition and feeding for sustainable aquaculture development in the third millennium. pp. 193–219. In R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur, (eds.) *Aquaculture in the Third Millennium*. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000, Bangkok, NACA and Rome, FAO.

Hepher, B. 1988. *Nutrition of pond fishes*. Cambridge, Cambridge University Press. 380 pp.

Hertrampf, J.W. & Pascual, F.P. 2000. *Handbook on Ingredients for Aquaculture Feeds*. London, Kluwer Academic Publishers. 573 pp.

Hung, L.T. & Huy, H.P.V. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Viet Nam (this volume).

Hung, L.T., Truc, L.T.T. & Huy, H.P.V. 2007. Case study on the use of farm-made feed and commercially formulated pellets for pangasiid catfish culture in the Mekong Delta, Viet Nam (this volume).

Hung, L.T. & Merican, Z. 2006. Freshwater fish culture in Vietnam for the global white fish market. *AquaCulture Asia-Pacific*, 2 (3): 14–15.

Ingram, B., Sungan, S., Gooley, G., Sim S.Y., Tinggi, D. & De Silva, S.S. 2005. Induced spawning, larval development and rearing of two indigenous Malaysian mahseer, *Tor tambroides* and *T. douronensis. Aquaculture Research,* 36: 1001–1014.

Kader, M.A., Hossain, M.A. & Hasan, M.R. 2005. A survey of the nutrient composition of some commercial fish feeds available in Bangladesh. *Asian Fisheries Science,* 18: 59–69.

NACA/FAO. 2001. *Aquaculture in the Third Millennium. In* R.P.Subasinghe, P.B. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery, R.J. Arthur, eds. *Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000.* Bangkok, NACA, and Rome, FAO. 471 pp.

Na-Nakorn, U. 2004. A perspective on breeding and genetics of walking catfish in Thailand. *Aquaculture Asia*, IX (4): 10–14.

Naylor, R.L., Goldburg, R.J., Primavera, J., Kautsky, N., Beveridge, M.C.M., Clay, J., Folkes, C., Lubchence, J., Mooney, H. & Troell, M. 2000. Effects of aquaculture on world food supplies. *Nature*, 405: 1017– 1024.

New, M. & Csavas, I. 1995. The use of marine resource in aquafeeds. pp. 43–78. *In* H. Reinersten & H.Haaland, (eds.), *Sustainable Fish Farming*. Proceedings of the First International Symposium on Sustainable Fish Farming, Oslo, Norway, August 1994. A.A. Balkema, Rotterdam.

New, M.B., Tacon, A.G.J. & Csavas, I. (eds.) 1994. *Farm-made aquafeeds.* FAO Fisheries Technical Paper No. 343. Rome, FAO. 434 pp.

Nur, A. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Indonesia (this volume).

Sumagaysay-Chavoso, N.S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in the Philippines (this volume).

Tacon, A.G.J. & De Silva, S.S. 1997. Feed preparation and feed management strategies within semi-intensive fish farming systems in the tropics. *Aquaculture*, 151: 379–405.

Tacon, A.G.J. 1987. The nutrition and feeding of farmed fish and shellfish- a training manual. Nutrient sources and composition. FAO, GCP/RLA/075/ITA, Field Document 5/E. Rome, FAO. 129 pp.

Tacon, A.G.J. 2004. Use of fishmeal and fish oil in aquaculture: a global perspective. A*quatic Resources Culture and Development*, 1: 3–14.

Tacon, A.G.J., Hasan, M.R. and Subasinghe, R.P. 2006. *Use of fishery resources as feed inputs for aquaculture development: trends and policy implications.* FAO Fisheries Circular No. 1018. Rome, FAO. 99 pp.

Thongrod, S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Thailand (this volume).

Weimin, M. & Mengqing, L. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in China (this volume).

Wijkstrom, U.N. & New, M.B. 1989. Fish for feed: a help or a hindrance to aquaculture in 2000? *INFOFISH International*, 6/89: 48–52.

Wood, J.F., Brown, J.H., MacLean, M.H. & Rajendran, I. 1992. *Feeds for artisanal shrimp culture in India- their development and evaluation*. BOBP/REP/52, Bay of Bengal Programme. Madras, India. 60 pp.