Analysis of feeds and fertilizers for sustainable aquaculture development in Thailand

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SUMMARY

Fisheries play an important role in the national economy of Thailand. The export volume and value of fishery products in 2004 amounted to 1.66 million tonnes, valued at US$4 413 million. The total area under inland aquaculture in 2004 was 143 500 ha with a total production of approximately 523 709 tonnes. Over 50 percent of aquaculture production can be attributed to the central region of the country. The most important culture species are Nile tilapia (160 241 tonnes), hybrid clariid catfish (159 314 tonnes), Java barb (66 821 tonnes), snakeskin gourami, *Trichogaster pectoralis* (35 294 tonnes), giant freshwater prawn (32 583 tonnes) and sutchi catfish, *Pangasius hypophthalmus* (30 626 tonnes).

Marine aquaculture on the other hand has posted a rapid growth, particularly because of significant increases in shrimp and shellfish production. The most important mariculture species are black tiger shrimp *Penaeus monodon* and Pacific white shrimp (*Litopenaeus vannamei),* shellfish (green mussel, oysters and cockle), seabass and grouper.

Feed and feeding practices vary depending on the farming system and species as well as the destination (domestic market or export) of the final product. In the past, chopped trash fish was the feed of choice. However, because of the low farm-gate value, higher transport and fuel costs and the declining supply of trash fish, farmers have switched over to poultry by-products or other industrial food wastes. Industrial and agricultural by-products are either used as single or mixed feeds. Industrially manufactured, nutritionally complete feeds are generally used in intensive culture systems, especially in cages. These feeds are expensive and not always cost effective. However they are preferred due to their superior nutritive and physical properties. Farm-made feeds are less stable in water and are nutritionally inconsistent. This is largely due to the highly variable quality and nutritive composition of the raw materials. Farmers have limited knowledge of feed preparation and have no control over the quality of the ingredients they use as feed. Although, the government promotes the use of commercial aquafeeds, farm-made feeds are still widely used throughout the country. Extension support with respect to raw material selection, storage, processing of raw materials, feed formulation and preparation of farm-made aquafeeds must be improved.

The use of organic fertilizers in aquaculture has declined because of the increasing competition from agriculture. Moreover, the price of chicken manure is increasing and not as freely available as in the past because of the outbreak of bird flu in 2003. This has seriously affected integrated chicken or duck/fish farming.

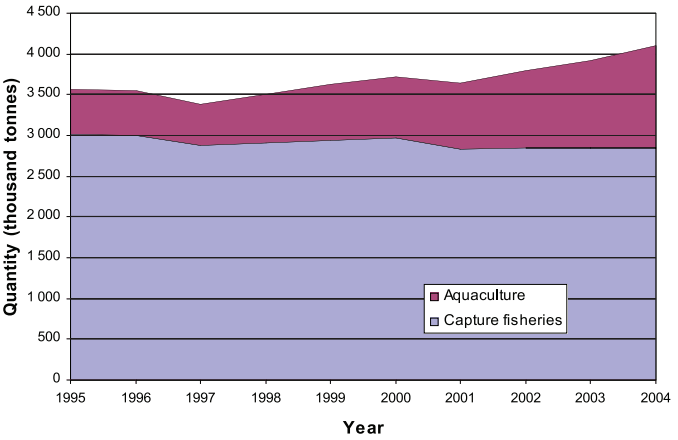
Aquaculture in Thailand, including the industrial aquafeed industry, is a regulated activity and HACCP is implemented to ensure the quality of inputs and outputs. At the farm level, two quality assurance guidelines have been developed and adopted, viz., "Good Aquaculture Practice" (GAP) and a "Code of Conduct" (CoC) for shrimp farming. GAP emphasizes product freshness, cleanliness, freedom from drugs and chemicals and freedom from disease. CoC guidelines have been developed based on the philosophy of sustainable and environmentally responsible shrimp culture, hygiene and food safety.

1. INTRODUCTION

Thailand is bound by the Gulf of Thailand in the east and the Andaman Sea in the west and has a coastline of 2 614 km, with many sheltered bays and lagoons. Inland water bodies include 66 rivers, 10 233 lakes and swamps and 685 reservoirs constituting a total water surface area of 566 400 ha (Tavaratmaneegul, 2001).

Fisheries continue to play an important role in the national economy of Thailand, which since 1997 has ranked among the top ten fish producing countries in the world. In 2004, the export of fishery products amounted to 1.66 million tonnes, valued at US$4 413 million, of which shrimp products accounted for US$1 683 million.

FIGURE 1
Capture fisheries and aquaculture production in Thailand during 1995-2004



Source: Fishery Information Technology Center (2006)

Aquaculture in Thailand has been practiced for more than 70 years and started with freshwater pond culture of snakeskin gourami (*Trichogaster pectoralis*). It continues to expand over the years, although the most rapid advances have been made in the last decade (Figure 1). Freshwater aquaculture continues to expand, while the area for coastal aquaculture has remained more or less the same (Table 1). For certain species, culture systems have changed from extensive to semi-intensive to intensive. Since 1998, inland aquaculture production has surpassed the inland wild catch (Table 2).

TABLE 1
Total area (ha) under inland and coastal aquaculture from 1999–2004

Year	Total	Freshwater	Coastal
1998	159 007	82 989	76 019
1999	168 580	91 036	77 544
2000	177 265	96 145	81 120
2001	177 494	100 553	76 941
2002	176 333	101 952	74 381
2003	193 921	111 902	82 019
2004	227 419	143 500	83 919

Source: Fishery Information Technology Center (2006)

TABLE 2
Capture fisheries and aquaculture production (thousand tonnes) in Thailand during 1992–2004

Year	Total production	Capture fisheries		Aquaculture	
		Marine	Inland	Coastal	Inland
1992	3 240	2 736	132	229	142
1993	3 385	2 753	175	296	162
1994	3 523	2 804	203	346	170
1995	3 573	2 827	192	358	196
1996	3 549	2 786	208	326	229
1997	3 384	2 680	205	300	200
1998	3 506	2 709	202	368	227
1999	3 626	2 725	207	442	253
2000	3 713	2 774	202	467	271
2001	3 648	2 632	203	535	280
2002	3 797	2 644	199	660	295
2003	3 914	2 651	198	703	361
2004	4 100	2 636	204	736	524

Source: Fishery Information Technology Center (2006)

2. GENERAL OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

Aquaculture practices in Thailand originated from traditional rice culture, from which wild fish were harvested as a by-product. This led to the proactive stocking of fish into ponds with improved fertilization regimens. The stocking density of fish in extensive culture systems is low at 500 fish/rai (1 rai = 0.16 ha) The most important extensive culture species are tilapia, common carp, rohu and Chinese carps. Some fish farms are integrated with poultry and/or pigs, and this is widely practiced in rural areas. The integrated culture of tilapia, sutchi catfish and chicken was very profitable. However, since the outbreak of bird flu in 2003/04, this practice is no longer well accepted as a farming system. Chicken farms have become bio-secure operations, such that any future outbreaks of the virus can be controlled.

Extensive aquaculture is still practiced in paddy fields, especially in Chachoengsao, Samut Prakan and Samut Sakhon provinces (Fishery Statistic Analysis and Research Group, 2005), though this practice is also decreasing, except in Samut Prakarn Province where snakeskin gourami is commonly grown in rice fields.

Semi-intensive polyculture is practiced in fertilized ponds in which fish are fed kitchen waste, slaughterhouse by-products or simple farm-made feeds consisting of rice bran, soybean oilseed cake and trash fish. Semi-intensive aquaculture is often integrated with poultry or pig farming. Nile tilapia and hybrid catfish are the two most common species cultured in these systems. The disadvantage of this practice is the low farm-gate price of fish in comparison to marine or freshwater carnivorous fish. Fish in these systems are mainly produced for local consumption using low-cost feeds. Formulated pellet feeds are generally not used in semi-intensive aquaculture. The farm gate value of tilapias cultured in ponds is US$0.63/kg. Stocking densities in semi-intensive systems vary between 50 000 and 62 500 fingerling/ha and production varies from 3 125–6 250 kg/ha. The pond size varies widely and ranges between 0.8 and 4.8 ha.

Intensive aquaculture is practiced in ponds and cages. The ponds are smaller and vary between 0.16–0.8 ha. The most commonly cultured species are hybrid catfish, Nile tilapia, hybrid tilapia/red tilapia (hybrid between Nile tilapia and Mozambique tilapia), snakehead and prawns. Although among tilapias, Nile tilapia is the species of choice, intensive culture of red tilapia is expanding because of its high market value (Figures 2 and 3). Feeds include poultry by-products, farm-made feeds or commercial

FIGURE 2
Culture of hybrid tilapia in cages in Mae Khong River, Nongkhai Province

FIGURE 3
Culture of hybrid tilapia in earthen ponds, Nakorn Rachasrima Province

pellets (floating or sinking). Stocking density of fish in intensive culture systems varies between 187 500–312 500 fingerlings/ha and reported yields vary from 9 375–50 000 kg/ha/crop for fish and 1 250–2 500 kg/ha/crop for prawns. The farm-gate value of cage-cultured fish is usually higher than pond-reared fish.

During the period 1992-2004, freshwater aquaculture production increased from 142 100 to 523 709 tonnes and in value from US$86.96 million to US$482.82 million. During the same period, the volume of coastal aquaculture production increased from 229 300 to 736 271 tonnes and in value from US$655.86 million to US$1 231.25 million (Fishery Information Technology Center, 2006).

2.1 Freshwater aquaculture

Over 20 species of freshwater fish are farmed in Thailand. The most important freshwater aquaculture species, with high export potential, are hybrid catfish *(Clarias gariepinus x C. macrocephalus*), Nile tilapia (*Oreochromis niloticus*), Java barb (*Barbonymus gonionotus*), snakeskin gourami (sepat siam in Thai) (*Trichogaster pectoralis*) and sutchi catfish (*Pangasius hypophthalmus*). Production of some of the more important freshwater fish from aquaculture and capture fisheries and their total value in 2004 are shown in Table 3.

The total area used for freshwater fish culture in 2004 was 143 501 ha (Table 4) with a reported production of 523 709 tonnes. Total production of freshwater fish by culture system and by species over the last five years (1999-2004) is shown in Tables 5, 6 and 7. In 2004, over 87 percent of total aquaculture production was from pond culture systems, while the outputs from paddy field, ditch and cage culture were 6.68, 1.08 and 5.17 percent, respectively (Table 5). Percent production of important freshwater species by intensity of aquaculture is shown in Table 8.

TABLE 3
Freshwater aquaculture production (tonnes) and inland capture fisheries and value (US$ million) in 2004

Species	Total production		Aquaculture	Capture fisheries
	Production	Value		
Nile tilapia (*Oreochromis niloticus*)	203 100	157	160 241	42 859
Common carp (*Cyprinus carpio*)	13 800	11	6 092	7 708
Java barb (*Barbonymus gonionotus*)	106 800	82	66 821	39 979
Snakeskin gourami/sepat siam (*Trichogaster pectoralis*)	37 800	38	35 294	2 506
Hybrid catfish (*Clarias macrocephalus x C. gariepinus*)	166 100	128	159 314	6 786
Snakehead murrel (*Channa striata*)	29 800	44	10 226	19 574
Sutchi catfish (*Pangasius hypophthalmus*)	33 700	21	30 626	3 074
Giant freshwater prawn (*Macrobrachium rosenbergii*)	33 000	97	32 583	417

Source: Fishery Information Technology Center (2006)

TABLE 4
Total area (ha) of productive fish farms and area under aquaculture during 1998–2004

Year	1998	1999	2000	2001	2002	2003	2004
Pond Culture	64 776	70 821	68 516	73 916	75 495	86 968	118 002
Paddy field	16 703	18 175	25 244	24 466	24 245	23 066	23 432
Ditch culture[1]	1 482	2 001	2 350	2 135	2 184	1 811	2 007
Cage culture	28	39	38	15	27	57	59
Total area	82 989	91 036	96 145	100 553	101 952	111 903	143 501

[1] Ditch is a man made waterway in plantations. Its width is normally less than 5 m. All ditches in plantation are connected to increase the space for cultured fish.

Source: Fishery Information Technology Center (2006)

TABLE 5
Total production (tonnes) of freshwater fish and yield (kg/ha) by culture system during 1998–2004

Year	Pond culture		Paddy field		Ditch culture		Cage culture		Total production
	Production	Yield	Production	Yield	Production	Yield	Production	Yield	
1998	206 738	3 190	13 151	790	5 406	3 650	1 629	58 510	226 923
1999	229 428	3 240	16 618	910	5 118	2 560	1 448	37 240	252 612
2000	240 907	3 520	19 936	790	6 707	2 850	3 462	90 910	271 012
2001	251 995	3 410	20 371	830	4 406	2 060	2 924	194 410	279 696
2002	266 461	3 530	20 602	850	4 113	1 880	3 325	123 700	294 501
2003	319 150	3 670	31 582	1 370	4 296	2 370	6 097	107 640	361 125
2004	455 981	3 864	34 967	1 492	5 659	2 820	27 102	459 359	523 709

Source: Fishery Information Technology Center (2006)

TABLE 6
Production (tonnes) of freshwater species during 2000–2004

Cultured species	2000	2001	2002	2003	2004
Nile tilapia (*Oreochromis niloticus)*	82 363	84 480	83 780	98 336	160 241
Mozambique tilapia (*O. mossambicus*)	26	30	27	19	149
Common carp (*Cyprinus carpio)*	5 539	4 773	5 046	4 457	6 092
Java barb (*Barbonymus gonionotus*)	46 276	42 152	44 242	49 066	66 821
Snakeskin gourami/sepat siam (*Trichogaster pectoralis)*	21 577	22 519	24 179	34 123	35 294
Chinese carps	438	202	202	200	286
Hybrid catfish (*Clarias macrocephalus x C. gariepinus)*	76 000	77 905	86 475	101 606	159 314
Snakehead murrel (*Channa striata*)	4 446	6 830	5 483	4 060	10 266
Giant snakehead (*C. micropeltes*)	81	87	95	145	193
Sutchi catfish (*Pangasius hypophthalmus*)	13 226	14 638	14 837	23 085	30 626
Marble goby (*Oxyeleotris marmorata*)	5	6	7	9.5	26
Giant gourami (*Osphronemus goramy*)	1 488	1 182	1 555	2 130	2 849
Rohu (*Labeo rohita*)	1 172	1 595	2 125	4 224	4 952
Bronze feather back (*Notopterus notopterus*)	5	4	5	66	1
Swamp eel (*Monopterus albus*)	38	38	25	43	50
Moon light gourami (*Trichogaster microlepis*)	169	154	165	290	538
Climbing perch (*Anabas testudineus*)	470	403	519	2 399	2 360
Small scale mud carp (*Cirrhinus microlepis*)	1 058	798	985	619	1 009
Giant freshwater prawn (*Macrobrachium rosenbergii*)	9 917	13 311	15 393	28 151	32 583
Frog (*Rana sp*.)	1 033	1 046	835	866	1 944
Soft-shelled turtle (*Trionyx cartilageneus*)	367	22 523	3 143	3 124	2 800
Others	5 313	5 012	5 373	4 095	5 332
Total production of cultured species	**271 012**	**279 696**	**294 501**	**361 125**	**523 709**

Source: Fishery Information Technology Center (2006)

TABLE 7
Aquaculture production (tonnes) by species and culture system in 2004

Species	Pond culture	Paddy field	Ditch culture	Cage culture
Nile tilapia (*Oreochromis niloticus)*	131 181	6 572	1 777	20 711
Common carp (*Cyprinus carpio*)	5 101	945	42	4
Java barb (*Barbonymus gonionotus*)	62 123	2 395	2 221	82
Snakeskin gourami/sepat siam (*Trichogaster pectoralis*)	13 905	21 353	35	1
Chinese carps	265	19	2	-
Hybrid catfish (*C. macrocephalus x C. gariepinus*)	153 658	316	783	4 557
Snakehead murrel (*Channa striata*)	8 250	1 953	22	1
Giant snakehead (*Channa micropeltes*)	183	0	0	10
Sutchi catfish (*Pangasius hypophthalmus*)	30 082	6	32	506
Giant freshwater prawn (*Macrobrachium rosenbergii*)	32 583	-	-	-
Marble goby (*Oxyeleotris marmorata*)	10	0	0	16
Giant gourami (*Osphronemus goramy*)	2 282	-	50	517
Rohu (*Labeo rohita*)	4 862	37	53	0
Swamp eel (*Monopterus albus*)	50	-	-	-
Moon light gourami (*Trichogaster microlepis*)	70	467	1	-
Climbing perch (*Anabas testudineus*)	1 164	868	327	1
Frog (*Rana sp*.)	1 931	1	-	12
Soft-shelled turtle (*Trionyx cartilageneus*)	2 797	-	3	0
Others	4 381	33	249	669
Total production	**455 981**	**34 967**	**5 659**	**27 102**
% of total production	**87.07**	**6.68**	**1.08**	**5.17**

Source: Fishery Information Technology Center (2006)

TABLE 8
Proportion (Percent) of total production by species and culture intensity in 2004

Species	Intensive system	Semi-intensive system	Extensive system
Nile tilapia	12.9	87.1	-
Common carp	-	84.4	15.5
Java barb	0.1	96.3	3.6
Sepat siam	-	99.9	0.1
Hybrid catfish	99.3	0.7	-
Snakehead	-	99.8	0.2
Sutchi catfish	99.9	-	0.1
Prawn	100.0	-	-

Source: Fishery Information Technology Center (2006)

2.2 Coastal aquaculture

In 2004, the production from coastal aquaculture (736 271 tonnes) accounted for approximately 58 percent of total aquaculture production (1 259 970 tonnes) (Table 2). The most important species are shrimps (*Penaeus sp*.), shellfish, mostly mussels, oysters and cockles, and fish such as Asian seabass/barramundi (*Lates calcarifer*) and grouper (*Epinephelus sp*.). Shrimp culture is the largest by volume and value.

2.2.1 Marine finfish farming

Seabass and groupers are the main cultured species in cages and earthen ponds. The production of marine finfish (Table 9) from cages (13 823 tonnes, 80.54 percent) exceeds that from ponds (3 339 tonnes, 19.46 percent) (Fishery Information Technology Center, 2006). Trash fish is used as a single feed and fed once a day in cages. Commercial pellet feeds for seabass are now available. However, trash fish is preferred as farmers are uncertain of profit margins using pelleted feeds. Moreover, the weaning of fingerlings of marine fishes on formulated feeds has not yet been perfected in Thailand.

Cage sizes for seabass and grouper culture vary from 20–50 m^3, with an average depth of 2 m. Seabass fingerlings are produced in hatcheries and stocked in cages at densities between 65–80 fish/m^3. Trash fish is used as food once a day at 3–5 percent of body weight (Sakaras, 1986). The grow-out period is 6–8 months, depending on the stocking size and the size at harvest varies from 600–800 g. Average feed conversion ratio is 7.5:1. Most seabass cages are family-owned businesses (Figures 4 and 5).

TABLE 9
Total production of marine finfish and the contribution from cages and ponds in 2004

Species	Total production (tonnes)	Cage culture (tonnes)	Pond culture (tonnes)
Seabass	13 588	10 615	2 973
Grouper	3 574	3 208	366
Total	**17 162**	**13 823**	**3 339**
% contribution		**80.54**	**19.46**

Source: Fishery Information Technology Center (2006)

FIGURE 4
Seabass reared in cages and fed on chopped trash fish once a day

Seabass and grouper production data, value and feed use are presented in Tables 10 and 11.

FIGURE 5
Seabass cages in Chachoengsao Province.
Cage-reared seabass are usually harvested when they reach marketable size of 600–800 g.

TABLE 10
Seabass and grouper production (tonnes) and feed consumption (tonnes)

Year	Seabass		Grouper		Total feed
	Production	Feed consumed[1]	Production	Feed consumed[1]	
1999	6 056	54 120	1 143	7 339	61 459
2000	7 752	70 040	1 312	8 299	78 339
2001	8 003	72 750	1 443	9 507	82 257
2002	11 032	97 300	1 170	7 794	112 894
2003	12 230	101 300	2 338	15 068	116 368
2004	13 588	108 700	3 574	23 231	131 931

[1] Trash fish consumption was calculated by using the average FCRs of 7.5 for seabass and 5.5:1 for grouper.

Source: Fishery Information Technology Center (2006)

TABLE 11
Total value (US$ million) of marine finfish culture

Year	1998	1999	2000	2001	2002	2003	2004
Grouper	9	8	9	10	7	12	30
Pond culture	1	2	2	1	1	2	3
Cage culture	8	6	7	9	6	10	27
Seabass	17	16	19	19	26	29	31
Pond culture	3	3	3	3	2	6	76
Cage culture	14	13	16	16	24	23	24
Total value	**26**	**24**	**28**	**29**	**33**	**41**	**61**

Source: Fishery Information Technology Center (2006)

2.2.2 Shrimp farming

Shrimp farming in Thailand started some 30 years ago with black tiger shrimp (*Penaeus monodon*) and banana shrimp (*P. merguiensis*). Shrimp were cultured in large rice fields of more than 4 ha using the traditional methods of tidal water exchange via a sluice gate and natural seed supply. Sluice gates were opened during the high tide to facilitate the entry of wild shrimp fry and nutrient rich water. Production from these extensive systems was unreliable and this gave rise to the current semi-intensive and intensive farming systems. Since the mid-1980s shrimp farming has spread to every coastal province in the country. In 2003, production from extensive systems was a mere 657 tonnes (0.02 percent of total shrimp production), while that from semi-intensive and intensive systems amounted to and accounted for 4 843 tonnes (1.07 percent) and 325 225 tonnes (98.34 percent), respectively.

The success of shrimp farming was supported by technological breakthroughs in shrimp hatchery and nursery technology and feed development. Total shrimp production has increased from 12 800 tonnes in 1982 to 360 289 tonnes in 2004 (Fishery Information Technology Center, 2006). The size of ponds under intensive farming conditions varies from 0.16–1.00 ha and these are stocked at densities ranging from 50–100 PLs/m^2, usually with black tiger shrimp. Shrimp are fed at least 4–5 times a day with high-quality commercial feeds and FCRs vary between 1.25–1.7:1, depending on the quality of feed and efficiency of feed management. A typical cost calculation for a shrimp farm is shown in Table 12. Shrimp ponds are normally aerated by paddle wheels or air/oxygen injectors are employed to maintain oxygen levels above 5 mg/l.

TABLE 12

Cost of shrimp production in 0.16 ha ponds (Thai baht)

Item	Fixed cost	Variable cost	Total cost
Shrimp PL (100 000 fry)	11 000		
Feed cost (40.7% of total cost)		52 210	
Energy cost (20% of total cost)		25 656	
Manpower (1 person)	12 000		
Maintenance		27 389	
Total cost	**23 000**	**105 255**	**128 255**

Stocking density 66 fry/m^2; survival rate = 45.14%; average production per 0.16 ha pond = 780 kg; US$1.00 = Thai baht 40.00

Source: Tookwinas (2001)

To address environmental problems culture systems have now evolved to zero discharge systems (Tunsutapanit *et al*., 1996), in which wastewater is treated and reused in the grow-out ponds. Regulations have also been introduced for shrimp farm registration and effluent regulation to mitigate against negative effects of shrimp farms on the coastal environment. The Department of Fisheries (DoF), Thailand has also introduced several programs to promote the production of quality shrimp to safeguard consumers and to prevent export rejections (Tookwinas and Keerativiriyaporn, 2004), namely the "Guideline for Good Aquaculture Practice" (GAP) and the Code of Conduct (CoC). GAP emphasizes the production of shrimp that are fresh, clean, drug residue free and not contaminated with disease and dirt. The CoC guidelines were developed on the philosophy of environmentally sustainable shrimp culture and the hygienic production of shrimp that are safe for consumers, in accordance with CODEX, ISO14001/(EMS) and the FAO Code of Conduct for Responsible Fisheries. These initiatives have been implemented to increase consumer confidence in the quality and safety of Thai shrimp, to promote environmentally responsible shrimp farming in Thailand and for the benefit and protection of farmers (Songsangjinda and Tatttanon, 2004).

The CoC guidelines are also a strategic development to comply with international requirements of the world shrimp market. These development programs have been effectively monitored through HACCP throughout the country (Tookwinas, 2002). Residues in cultured shrimp are also monitored before harvesting and certified for both export and local consumption.

The followings measures are taken for controlled and safe shrimp production in Thailand.

1. Registration of farms
2. Technical assistance for the controlled use of feeds/antibiotics
3. Monitoring of residues in farmed shrimp
4. Mobile control unit to monitor diseases and the use of antibiotics and feeds
5. Monitoring water quality of both inlet and outlet of farms
6. Inspection of farm hygiene and post-harvest handling practices
7. Training farmers on GAP, safe uses of chemotherapeutic agents and handling practices

3. REVIEW AND ANALYSIS OF AQUACULTURE FEEDS AND FEEDING

Thailand produces formulated feeds for herbivorous fish, carnivorous fish and shrimp. Commercial pellet feeds are commonly used in shrimp aquaculture, but are not well accepted by fish farmers who still largely rely on farm-made feeds. This is mainly due to the low value of most fish. However, recent fuel price increases have

affected the price of trash fish and other feed ingredients normally used in farm-made feeds. Hence, farmers are trying to develop new formulations and feed management practices to reduce the cost of production. For herbivorous fish, pond fertilization with animal manures is practiced to increase natural food production. However, the high competition for organic fertilizers from agriculture has reduced the availability of fertilizers for fish farming.

3.1 Feed and feed ingredients

In Thailand, feed ingredients and commercial feeds are expensive. Feed generally accounts for more than 60 percent of the total production cost, especially for freshwater fish. In the past, chopped trash fish was the principal feed ingredient of choice (Jantrarotai and Jantrarotai, 1994; Sitasit, 1994; Thongrod, Jintasataporn and Boonyaratpalin, 2004). However, because of the low farm gate value of fish and the escalating price of trash fish farmers have changed to poultry by-products or other

TABLE 13
Nutritional value of some feed ingredients used in aquafeed in Thailand

Ingredients	Nutritional value (% dry matter)						
	Moisture	Crude protein	Crude lipid	Ash	Crude fibre	NFE*	Source of information
Feed ingredients of animal origin							
Fishmeal (Thai origin) 50% crude protein (CP)	10.0	49.1	-	-	-	-	1
Fishmeal 55% CP	8.0	55.0	8.0	26.0	1.0	2.2	1
Fishmeal 60% CP	8.0	60.0	10.0	19.0	-	3.0	1
Squid by-product	8.1	74.8	8.8	3.4	-	4.9	3
Shrimp head meal	10.0	41.8	4.3	34.0	9.9	-	1
Mackerel viscera	69.0	16.0	12.0	-	-	-	3
Chicken by-product meal	6.5	57.5	15.0	15.6	2.3	3.1	3
Chicken head	38.8	26.9	26.4	7.6	0.3	-	3
Chicken viscera	73.7	13.9	11.2	1.2	-	-	3
Poultry feather meal	10.0	83.5	2.5	2.5	1.5	-	1
Meat and bone meal	7.4	49.1	10.3	29.9	2.6	0.7	3
Blood meal	10.4	81.5	1.0	4.8	0.7	1.6	3
Feed ingredients of plant origin							
Rice hull	10.0	12.2	11.8	13.1	12.3	40.6	3
Defatted rice hull	9.0	13.9	1.0	15.0	13.0	48.1	1
Rice bran	12.0	8.0	0.9	0.7	1.0	77.4	1
Soybean meal, full fat	5.9	36.2	19.8	4.6	5.5	28.0	2
Soybean meal, defatted	11.8	44.6	1.5	5.8	6.1	30.3	2
Soybean protein concentrate	9.3	61.3	0.4	5.5	5.6	17.9	2
Soybean hull (grade 1)	10.0	42.0	4.7	5.7	6.7	30.9	3
Soybean hull (grade 2)	10.0	44.0	1.0	6.0	7.0	32.0	1
Soybean hull (grade 3)	10.0	48.5	1.0	6.0	3.5	31.0	1
Spirulina meal	6.0	66.4	0.4	6.4	9.4	11.5	2
Mung bean hull	10.8	18.4	1.7	3.4	17.8	47.8	2
Palm oil kernel	10.0	18.5	1.5	3.6	14.2	52.2	1
Peanut hull	7.0	48.0	5.8	5.1	7.0	27.1	3
Cassava	13.5	2.2	0.5	5.0	3.0	75.8	3
Cassava leaf	12.0	19.0	5.6	7.0	26.0	30.4	1
Corn grain	12.2	9.6	3.9	1.5	2.0	70.8	1
Corn meal	11.2	9.4	0.2	1.2	0.8	77.2	3
Coconut by-product	10.0	21.0	6.0	7.0	12.0	44.0	1
Lupin leaf	10.0	20.2	3.5	8.8	18.0	39.5	1
Distiller waste	10.0	26.0	6.0	4.0	12.0	42.0	1
Green fodders							
Duckweed	91.9	1.7	0.5	0.9	0.9	4.0	3
Water lettuce (*Pistia stratiotes*)	91.9	1.2	0.4	-	1.8	2.9	3
Alligator weed (*Alternanthera* sp.)	77.5	3.2	0.8	-	2.6	11.6	3
Water hyacinth (*Eichhornia* sp.)	94.9	1.0	0.2	-	0.9	1.8	1

*Nitrogen-free extract

Source: [1] Kasetsart University (1999); [2] Boonyaratpalin *et al.* (2003); [3] Sitasit *et al.* (1982)

industrial food wastes. Many ingredients are used for farm-made feeds and commercial feeds. Except for soybean meal, these ingredients are locally available. Soybean meal is imported from the United States of America and China and is used mainly for the production of nutritionally complete commercial feeds. The nutritional value of selected feed ingredients commonly used in Thailand is presented in Table 13. For marine fish farming, trash fish is still used as a single feed for both the nursery stage and for grow-out. The DoF is presently promoting the replacement of trash fish with commercial feeds for the rearing of marine fish species.

3.2 Freshwater fish feeding practices

3.2.1 Herbivorous fish

Most herbivorous fish are cultured in extensive or semi-intensive systems, except for tilapia. Aquaculture of herbivorous fish in extensive culture system primarily depends upon natural food produced by fertilization with organic manure, inorganic fertilizer or a combination of both. Commonly used pond fertilization practices are presented in Table 14.

Chicken manure is expensive and is now often unavailable for fish farming. This is due to the bird flu (Highly Pathogenic Avian Influenza) disease outbreak in 2003. This has negatively affected integrated fish farming. Chicken manure is currently only available from large industrial farms in Thailand and these are bio-secure systems.

Feeds such as rice bran are evenly distributed over the pond or put in feeding bags. Under semi-intensive and intensive farming conditions compound feeds that consist of aquatic plants, rice bran, broken rice, trash fish or poultry by-product are provided in feeding bags. The mixtures are also cooked and processed into wet dough, extruded through a meat mincer and fed in a moist form or sun dried.

TABLE 14
Pond fertilization practices in Thailand

Type of fertilizer	Rate of application
Lime ($Ca(OH)_2$)	200 g/m^2
Organic fertilizer - chicken, duck or buffalo manure	125–250 g/m^2
Crop waste, rice straw	5 truck container/ha
Inorganic fertilizer - urea	2–3 g/m^2

Source: farmer interview

Tilapia cage culture

Tilapia cage-culture systems are described by Sihapitakgiat *et al* (2000). Cage volumes vary from 25–40 m^3 with an average depth of 2 m. Tilapia fingerlings are stocked into the cages at between 25–100 g. The rearing period varies from 3–5 months, depending on size. Fish are fed with floating catfish pellets twice per day. A feeding schedule for tilapia is illustrated in Table 15.

TABLE 15
Feeding schedule for tilapia cage culture

Stocking size	Rearing period	Feed no.	Protein content (%)	Average weight (g) at harvest	FCR
25 g	1 month	1	32		
	2–3 months	2	30		
	4–5 months	3	25	800–1 200	1.24–1.5
40 g	57 days	3	25	200	
	130 days	3	25	625	
100 g	3 month	3	25	600	

Source: farmer interview

The average weight of tilapia at harvest varies between 800 g and 1.2 kg and FCRs range from 1.24–1.5:1, depending on feed quality. The farm-gate value of tilapia depends on fish size and type of culture (Table 16). The price of cage-cultured tilapia is double that of fish reared in ponds. FCRs in pond culture are between 1.7–1.8:1. The difference in FCR is a consequence of the protein levels, which under pond farming conditions are lower than that of the feeds fed to fish in cages.

TABLE 16
Farm-gate price of tilapia reared in cages and in ponds

Size of fish (g)	Cage culture (US$/kg)	Pond culture (US$/kg)
Less than 600 g	0.75	0.38
600–800	0.95	0.63
800–1200	1.00–1.05	0.75

Source: farmer interview

Climbing perch (Anabas sp.) culture

Pond culture of climbing perch (*Anabas* spp.) is becoming increasingly popular. It is easy to manage in small ponds, ranging between 400–1 600 m^2. Advantages of climbing perch culture include a short culture period of three months, high production and high value. Fry are stocked at 1 cm in length at about 20 fingerlings/m^2. They are fed with catfish feed for three months and reach 70–150 g with a total production of 700–800 kg/400 m^2 pond. Feed conversion ratio varies between 1.4–1.5:1 and the farm-gate price depends on size, ranging from US$0.63 for 75 g fish to US$1.75/kg for 170 g fish. It is likely that aquaculture of climbing perch will increase substantially in the near future.

3.2.2 Carnivorous and omnivorous fish

The most important carnivorous and omnivorous freshwater fish are hybrid clariid catfish, snakehead and sutchi catfish. Culture systems vary according to the intensity of inputs and stocking density and the type of culture system adopted (e.g. monoculture, polyculture or integrated fish culture) depends on the chosen species. Omnivorous species like tilapia, Java barb, common carp, Chinese carp and mrigal are polycultured, while carnivorous species like clariid catfish, snakehead, sutchi catfish, freshwater prawns and sand goby are generally chosen for monoculture (Dey, Paraguguas and Alam, 2001).

Catfish grow-out ponds are between 300–2 000 m^2 and 1–1.5 m deep. Fingerlings of 2–3 cm are stocked at 40–100 fish/m^2, depending upon availability and price, as well as the intended production practice (Jantrarotai and Jantrarotai, 1994). Juvenile fish are fed mainly on formulated pellet, whereafter farmers switch to cheaper farm-made feeds. These consist of trash fish, cooked broken rice and rice bran or of chicken viscera, chicken head and bones and rice ban (Kosutarak, 1999). The composition of typical farm-made feeds is shown in Table 17. Thongutai (1969) reported superior growth of fish fed with farm-made feeds containing trash fish and rice bran (9:1) in comparison to those fed on pelleted feed only, in which fishmeal and soybean meal were used as protein sources. Na-nakorn (1995) recommended that fresh feed should be used as a supplement

TABLE 17
Typical formulation of a farm-made hybrid clariid catfish feed (perecent as fed basis)

Formula	Ingredients (%)					Nutritional value (%)		Cost of feed (baht/kg)
	Distillers waste	Chicken bone	Chicken head	Chicken viscera	By-product from soy sauce	Crude protein (%)	Crude lipid (%)	
1	12	-	-	80	8	17.4	6.1	2.13
2	8	-	4	80	8	17.6	6.8	2.21
3	8	-	8	76	8	18.0	7.6	2.34
4	8	-	12	72	8	18.4	8.4	2.47
5	8	-	16	68	8	18.8	9.3	2.60
6	16	-	-	76	8	17.6	6.2	2.18
7	12	-	4	76	8	17.8	6.9	2.26
8	12	-	8	72	8	18.2	7.7	2.39
9	12	-	12	68	8	18.6	8.5	2.52
10	12	-	16	64	8	19.0	9.3	2.65
11	20	-	-	72	8	17.8	6.2	2.23
12	8	12	-	72	8	17.6	6.1	2.35
13	8	16	-	68	8	17.7	6.2	2.44
14	8	20	-	64	8	17.8	6.2	2.53
15	12	12	-	68	8	17.8	6.2	2.40
16	12	16	-	64	8	17.9	6.2	2.49
17	12	20	-	60	8	18.0	6.3	2.58
18	-	20	-	72	8	17.4	6.0	2.43
19	-	-	20	72	8	18.8	9.9	2.63
20	-	16	12	64	8	18.5	8.4	2.73

Source: Surasak farm, Nakhon Ratchasima Province

to floating pellets. A formulated pellet feed for catfish (NIFI 12), containing 56 percent fishmeal, 12 percent dehulled peanut meal, 12 percent rice bran, 14 percent starch, 4 percent fish oil, 1 percent vitamin and mineral premix and 0.4 percent binder is available on the market (Sitasit, 1985). The average FCR obtained on formulated pellets ranges from 1.5–2:1. The rearing period is between 3 and 6 months depending on the intended harvest size, which ranges between 100 and 300g and production levels of between 10–14 tonnes/rai are normally achieved. A catfish feeding schedule has been developed by the DoF that farmers have adapted according to their experiences. Generally the fish are fed twice a day on a ration that decreases from around 40 percent biomass per day to between 3 and 4 percent of biomass at the end of the growing period. Summary information including total production, feed cost and farm gate value is presented in Table 18.

TABLE 18
Rearing costs of hybrid clariid catfish in a 0.8 ha pond

Total production	5 000 kg
Survival rate	80%
Average fish size	250 g
Farm-gate price	US$0.7/kg
Total farm gate value	US$3 500
Total feed cost	US$2 045
Profit	US$1 456

Source: farmer interview

TABLE 19
Feed and feeding practices for a typical 1 rai sutchi catfish pond stocked with 10 000 fingerlings

Age	Feeding duration	Type of feed	Amount of feed
1–15 days	2 weeks	Floating pellet	5–10 kg in total (2 weeks)
	2 weeks	Chicken bone	50 kg/day
2 months	1 month	Chicken bone	50 kg/day
		Commercial feed	5 kg every other day
3 months	1 month	Chicken bone	100 kg/day
		Commercial feed	5 kg every other day
4 months	1 month	Chicken bone	150 kg every other day
		Commercial feed	5 kg every other day
5 months	1 month	Chicken bone	200 kg every other day
		Commercial feed	5 kg every other day
6 months	1 month	Chicken bone	200 kg every other day
		Commercial feed	5 kg every other day

Source: farmers' interview

TABLE 20
Feed use and cost for a 1 rai sutchi catfish pond stocked with 10 000 fingerlings

Feeding duration	Chicken bone		Commercial feed	
	Amount (kg)	Price (US$)	Amount (kg)	Price (US$)
1st month	1 500	150	5–10	2.5–4.5
2nd month	3 000	300	75	33.75
3rd month	3 000	300	75	33.75
4th month	2 250	225	75	33.75
5th month	3 000	300	75	33.75
6th month	3 000	300	75	33.75
Total	**15 750**	**1 575**	**450**	**171–173.25**

Source: farmers' interview

Sutchi catfish (Pangasius hypophthalmus) farming

Sutchi catfish culture is widely practiced in central Thailand. The fingerlings (3 cm average length) are stocked in 0.16 ha (1 rai), 2 m deep earthen ponds, at a density of 6.25 fingerlings/m^2. Feed type and feeding practices and feed use and costs are described in Tables 19 and 20, respectively. The average FCR obtained on poultry by-product is 3.33:1, average size at harvest after 6 months is 1.5–2 kg and total production is about 5 tonnes/rai. The average farm-gate price in 2005 was US$0.55/kg. Ponds are often fertilized with pig manure at 1 200 l (wet weight) per week.

TABLE 21
Ingredient composition and nutrient content of feed commonly used for larvae of clariid catfish[1] and tilapia fry (percent as fed basis)

Ingredients	Catfish larvae	Catfish larvae	Catfish / tilapia larvae	Tilapia larvae
Cassava starch	-	15	15	15
Rice bran	-	3	10	30
Wheat gluten	25	0	0	0
Fishmeal	50	72	65	47
Fish oil	7	7	7	5
Di-calcium phosphate	1	1	1	1
Premix[2]	2	2	2	2
Binder[3]	15	-	-	-
Total	100	100	100	100
Calculated nutritional composition				
Crude protein	45.0	40.0	37.5	30.0
Crude lipid	10.9	12.5	12.0	10.0
Ash	12.1	18.3	17.6	16.3
Crude fibre	0.7	1.6	2.2	3.8
NFE	24.9	19.6	22.2	31.6
Energy (kcal/kg)	3 000	3 000	3 000	2 800
Feed cost (baht/kg)	39.96	19.15	18.13	15.1

[1] Both walking catfish and hybrid catfish
[2] Vitamin and mineral premix for freshwater fish are commercially produced and sold in the market
[3] Binder included primarily cassava starch and rice flour.

Source: Thongrod, Jintasataporn and Boonyaratpalin (2004)

4. FEED MANAGEMENT STRATEGIES

In both semi-intensive and intensive farming, feed is the most important and expensive input. The production and supply of poultry by-products has been constrained by the changes that the industry has had to make after the outbreak of bird flu in 2003. This has also influenced aquaculture as the demand for poultry offal is increasing in response to the declining availability and increasing price of trash fish in many parts of the country.

The major problems surrounding the use of farm-made feeds are associated with the quality and supply of primary ingredients. Farmers find it extremely difficult to control the quality of the feeds they produce, which results in unpredictable production and environmental pollution. Farm-made feeds consist of trash fish or poultry offal or both, cooked broken rice, rice bran, soybean meal, agricultural by-products and vitamin and mineral premixes. Most farmers now use poultry by-products as the primary ingredient, which in most instances has to be delivered on a daily basis, as they do not have appropriate cold storage facilities. Farmers can also choose from a number of different fishmeal based formulations developed by the DoF and other research institutions. Some of these are shown in Tables 21, 22 and 23. Catfish fingerling feeds are often fortified with mackerel viscera, which acts as an attractant resulting in improved FCRs. Feed bags

TABLE 22
Farm-made practical feed formulation for clariid catfish[1] (percent as fed basis)

Ingredients	Ingredient composition/ fish size		
	Fingerling (1st 3 months)	Grow-out 1 (2nd 3 months)	Grow-out 2 (3rd 3 months)
Dried cassava meal	26	22	22
Coconut by-product	-	-	20
Rice bran	-	15	-
Soybean meal	41	32	32
Fishmeal	25	20	20
Lupin leaf	-	5	-
Fish oil	5	3	3
Di-calcium phosphate	1	1	1
Vitamin and mineral premix	2	2	2
Total	**100**	**100**	**100**
Nutritional composition			
Protein	32.00	28.00	28.00
Lipid	8.02	6.28	6.66
Ash	11.69	11.93	10.73
Fibre	3.62	5.44	5.28
Gross energy (kcal/kg)	2 800	2 700	2 600
Feed cost (Baht/kg)	11.86	10.18	9.78

[1] Both walking catfish and hybrid catfish

Source: Thongrod, Jintasataporn and Boonyaratpalin (2004)

TABLE 23
Farm made practical feed formula for tilapia and other herbivorous fish (percent as fed basis)

Ingredients	Ingredient composition/ fish size			
	Fingerling to 2-4 months	Grow-out (cage)	Grow-out 1 (pond)	Grow-out 2 (pond)
Dried cassava meal	23	23	35	22
Coconut meal	-	-	-	30
Rice bran	15	20	15	-
Soybean meal	30	25	25	25
Fishmeal	25	25	20	20
Lupin leaf	-	-	-	-
Fish oil	4	4	2	-
Di-calcium phosphate	1	1	1	1
Vitamin and mineral premix	2	2	2	2
Total	**100**	**100**	**100**	**100**
Nutritional composition				
Crude protein	31.00	30.00	26.80	29.86
Crude lipid	7.44	7.53	5.01	4.11
Ash	12.57	12.76	11.40	10.67
Crude fibre	4.25	4.40	4.20	6.05
NFE	35.80	36.30	42.88	40.22
Gross energy (kcal/kg)	2 700	2 700	2 500	2 500
Feed cost (Baht/kg)	11.30	10.65	9.36	8.50

Source: Thongrod, Jintasataporn and Boonyaratpalin (2004)

are also used to reduce wastage, particularly in tilapia culture. Two recommended feed formulations for seabass and marine shrimp are shown in Tables 24 and 25, respectively.

TABLE 24
Recommended feed formulae for seabass (*Lates calcarifer*) (percent as fed basis)

Ingredients	Percentage composition	
	Formula 1	Formula 2
Thai fishmeal	63.0	70.0
Rice bran	-	9.0
Shrimp head meal	6.8	-
Soybean meal	11.9	-
Alpha starch/wheat gluten	6.0	12.4
Tuna oil	4.5	1.5
Soybean oil	4.5	3.0
Trace mineral premix	2.0	2.0
Vitamin premix	1.0	2.0
Vitamin C	0.1	0.1
Sodium monophosphate	0.2	-
Total	**100.0**	**100.0**
Proximate composition (%)		
Moisture	7.40	6.48
Crude protein	44.23	41.8
Crude lipid	13.91	9.64
Ash	18.57	16.66
Crude fibre	2.19	0.87
NFE	13.71	24.56

Source: Boonyaratpalin (1991)

TABLE 25
Recommended feed formulae for grow out of black tiger shrimp (*Penaeus monodon*) (percent as fed basis)

Ingredients	Percentage composition	
	Formula 1	Formula 2
Thai fishmeal	28.0	33.0
Shrimp head meal	10.0	10.0
Squid visceral meal	4.0	4.0
Soybean meal	20.0	16.0
Wheat gluten	5.0	7.0
Wheat flour	20.0	-
Tuna oil	2.5	0.5
Vitamin Premix	2.0	2.0
Trace Mineral Premix	2.0	2.5
Vitamin C	0.48	0.1
BHT	0.02	-
Lecithin	1.0	-
Binder	-	1.5
Rice bran	5.0	23.4
Total	**100.0**	**100.0**
Calculated proximate composition (%)		
Moisture	10.49	9.24
Crude protein	37.02	43.29
Crude lipid	7.53	5.77
Ash	10.47	14.39
Crude fibre	2.46	4.38
NFE	32.04	22.93

Source: Manual for feed preparation, Department of Fisheries, adopted from Boonyaratpalin and New (1994)

TABLE 26
Nutritional value (%) of feeds under legislative control in Thailand

Feed	Form of feed	Size of feed particle	Crude protein (min)	Crude lipid (min)	Crude fibre (max)	Moisture (max)	Cost (US$/ kg)
Marine shrimp feed							
- Zoea – Mysis stage	Powder	<100 µm	>40	>6	<3	<10	Vary
	Flake	Not defined					
- Mysis stage	Powder	100–250 µm	>40	>6	<3	<10	Vary
	Flake	Not defined					
- Post larvae 1–5 (P1– P5)	Powder	200–500 µm	>40	>6	<3	<10	Vary
	Flake	Not defined					
- Post larvae 5–15 (P 5–P 15)	Flake	Not defined	>40	>6	<3	<10	0.92
	Crumble	Ø<0.5–0.71 mm					
- Juvenile (1.2–2.5 cm)	Pellet	Ø<0.5–0.71mm	>38	>5	<3	<11	0.92
- Juvenile (2.5–3.5 cm)	Pellet	Ø<0.71–1.68mm	>38	>5	<3	<11	0.91
- Juvenile (1–3 g)	Pellet	Ø<1.68–2.38mm	>38	>5	<3	<11	0.90
- Fingerling (3–12 g)	Pellet	Ø1.6–2.38 mm	>36	>4	<4	<12	0.89
- Medium shrimp (12–30 g)	Pellet	Ø1.8–2.4 mm	>35	>4	<4	<12	0.77
- Large shrimp (> 30 g)	Pellet	Ø2.2–2.6 mm	>35	>3	<4	<12	0.76
Supplementary shrimp feed	Pellet	Not defined	>32	>3	<4	<12	
Freshwater prawn feed							
- Juvenile - 1 month old	Crumble	Not defined	>37	>5	<3	<10	0.53
- 1– 3 months old	Pellet	Not defined	>30	>4	<5	<12	0.52
- 3 month - harvest size	Pellet	Not defined	>25	>3	<6	<12	0.51
- Large prawn	Pellet	Not defined	>25	>3	<6	<12	0.44
Herbivore fish feed							
- Fingerling	Pellet	Not defined	>28	>3	<8	<12	0.33
- 150–250 g fish	Pellet	Not defined	>25	>3	<8	<12	0.32
- >250 g fish	Pellet	Not defined	>20	>3	<12	<12	0.32
Catfish feed							
- Fingerling 4–15 days old	Powder	Not defined	>35	>5	<6	<12	1.23
- From 16–30 days old	Pellet		>35	>4	<6	<12	0.53
- From 30–45 days old	Pellet		>30	>4	<6	<12	0.51
- Medium size (<3 months)	Pellet		>28	>3	<8	<12	0.51
- Large size from 3 months – harvest			>24	>3	<8	<12	0.48
Carnivorous fish: snakehead							
- Fry	Powder		>40	>3	<4	<12	
- Fingerling	Crumble/pellet		>37	>4	<4	<12	
- Medium size	Pellet		>35	>4	<5	<12	
- Large fish			>30	>4	<6	<12	
Marine fish feed:							
- Fry	Powder	Sinking feed	>42	>5	<4	<12	
- Fingerling	Crumble/Pellet	Sinking feed	>40	>5	<4	<12	
- >50 g fish	Pellet		>38	>5	<4	<12	0.89
- >300 g fish			>35	>5	<5	<12	0.86
Frog Feed- 100 g frog	Pellet		>35	>4	<7	<12	0.61

Source: Thai Animal Feed Manufacturing Association (2004).

5. REVIEW OF THE DEVELOPMENT OF THE AQUAFEED INDUSTRY

Aquaculture in Thailand has expanded rapidly since 1986 and this has increased the demand for high-quality formulated feeds. At present there are about 60 feed mills in the country. Of these 34 produce only shrimp feed and 12 produce only fish feed, while the others produce both fish and shrimp feeds. In addition there are several companies that manufacture feed additives and premixes.

5.1 Feed quality control

The rapid increase in the demand for and production of aquafeeds has caused shortages of ingredients and this has resulted in inconsistent feed quality. Poorly formulated feeds and/or improper manufacturing processes have resulted in low digestibility and poor

water stability. Legal quality controls for marine shrimp, freshwater prawn, catfish and herbivorous fish feeds that requires the industry to manufacture feeds according to certain quality standards and to register and license their feeds were introduced in 1991 (Agriculture and Cooperatives Ministry Regulation 1991). Similarly, all imported feeds have to be registered and licensed by the Department of Livestock Development. Further details of the regulations are provided by Sitasit (1995) and the Aquafeed Quality Control and Development Division (2002). The nutritional value of feeds has to be clearly indicated and feeds are regularly sampled and tested. Feed factories may not produce medicated feeds. Similarly, wholesalers and retailers of aquafeeds must also be registered and licensed. In 1999 the legislation was amended to include commercial feeds for carnivorous marine and freshwater fish, soft-shell turtles and frogs. The average shelf life of commercial feeds is three months; hence the manufacture and expiration date must be stated. Factories are inspected regularly to maintain standards as laid down by law. The nutritional value of feeds under legislative control in Thailand and the current prices of feeds are given in Table 26.

5.2 Aquafeed production and import and export of feed ingredients

There is a high degree of competition among feed manufacturers in Thailand. This has been to the advantage of farmers who, as a consequence, have access to high-quality feeds at a competitive price. Estimated total production of compounded feed for livestock and aquaculture and utilization of major feed ingredients during 2000-2004 are shown in Table 27. Aquafeed production and consumption have increased substantially over the years (Table 28). In 2001, Aquafeed consumption was 660 000 tonnes, which increased to 1.07 million tonnes in 2005. Table 28 also illustrates the

TABLE 27
Estimated total feed production (animal and aquafeed) and ingredient utilization during 2000–2004 (in thousand tonnes)

	2000	2001	2002	2003	2004
Total feed production	9 311.1	9 734.2	10 515.3	10 720.0	9 858.5
Fishmeal	493.2	465.3	482.4	582.5	611.4
Corn	4 186.0	4 164.0	4 263	4 151.0	4 000.0
Full fat SBM	249.2	325.7	329.7	348.1	
Defatted SBM	1 722.0	1 961.0	2 064.0	2 632.0	2 281.8
Broken rice	455.7	735.0	381.8	398.6	981.0

Source: Thai Animal Feed Manufacturing Association (2004)

TABLE 28
Aquafeed production and ingredient use during 2001–2005

	Shrimp/fish	Production (tonnes)	Feed consumption (tonnes)	Fishmeal		Soybean meal		Corn	
				% in feed	Amount (tonnes)	% in feed	Amount (tonnes)	% in feed	Amount (tonnes)
2001	Shrimp	240 000	480 000	35	168 000	12	57 600	0	
	Fish	279 700	180 000	20	36 000	22	39 600	35	63 000
Total		**519 700**	**660 000**		**204 000**		**972 200**		**63 000**
2002	Shrimp	315 000	630 000	35	220 500	12	75 600	0	0
	Fish	294 500	217 350	20	43 470	30	65 205	30	65 205
Total		**609 500**	**847 350**		**263 970**		**140 805**		**65 205**
2003	Shrimp	280 000	560 000	35	196 000	12	67 200	0	0
	Fish	321 000	262 500	20	52 500	30	78 750	30	78 750
Total		601 000	822 500		248 500		145 950		78 750
2004	Shrimp	260 000	520 000	35	182 000	12	62 400	0	0
	Fish		262 500	20	52 500	30	78 750	30	78 750
Total			**782 500**		**234 500**		**141 150**		**78 750**
2005	Shrimp	400 000	672 000		107 200		121 600		0
	Fish	-	402 000	20	80 400	30	120 600	30	120 600
Total			1 074 000		187 600		242 200		120 600

Source: Thai Animal Feed Manufacturing Association (2004)

TABLE 29
Average price of local and imported feed ingredients during the last 2 years (baht/kg)

Local ingredients	2004	2005	Imported	2004	2005
Cassava	3	4	Wheat bran	4.28	4.49
Corn	6	6	Wheat gluten	47.11	42.06
Rice bran	5	5	Soybean grain	12.96	11.89
Broken rice	8	8	Wheat flour	15.85	13.88
Defatted soybean	14	12	Defatted soybean	14.61	11.51
Shrimp head meal	16	16			
Fishmeal	23	22	Fishmeal	31.58	32.79
Squid oil	44	40	Squid oil	44.35	40.40
Squid liver meal	73	61	Squid liver powder	26.72	29.70
			Fish oil	35.08	37.92

Source: Thai Animal Feed Manufacturing Association (2004)

type and volume of some of the ingredients used in aquafeed production. Feedmillers in Thailand are faced with high ingredient import tariffs, which range between 5-20 percent for the most important ingredients. There are no restrictions regarding import volumes and time frames for fishmeal, although only fishmeal with a protein content of 60 percent and above may be imported. A tariff of 15 percent is imposed on fishmeal imported from outside the ASEAN alliance, and 5 percent on fishmeal imported from ASEAN. However, there are rather severe import restrictions on corn. While tariff rates on corn imports have been liberalized, the benefit of this reduction has been offset by the requirement that corn should only be imported between March and June. Corn is subjected to a tariff-rate quota: in-quota corn imports (54 440 tonnes) are subjected to a 20 percent tariff rate, while out-of-quota corn imports are subject to a 73.8 percent tariff. There are unlimited import quotas for soybean, for which the import duty is five percent. However, Thailand requires that importers purchase a certain amount of domestically produced soybean product before being granted a license to import product. The price of some imported ingredients, such as squid and squid liver meal, is cheaper than the domestic product, because soybean meal is added to reduce the moisture content, while the local product is pure. The average prices of local and imported aquafeed ingredients are shown in Table 29.

About 10 000 tonnes of fishmeal is imported per year from three countries: Peru (76.2 percent), Denmark (9.5 percent) and Chile (4.2 percent). To protect the local industry, the government only allows importation of high-protein fishmeal (>60 percent). This fishmeal is mainly used for shrimp feed production. Soybean production in Thailand is low (269 300 tonnes in 2003) in comparison to the requirement of 1.95 million tonnes. Corn production (4.2 million tonnes in 2003) approximately matches the current requirements of the animal feed industry.

6. PROBLEMS AND CONSTRAINTS

Trash fish based farm-made feed is considered as one of the most suitable feeds for many fish species. However, the price of trash fish has increased to such an extent that its use as a primary feed ingredient is declining rapidly. This is mainly due to competition from fishmeal manufacturers for the by-catch, fuel price hikes and a decline in by-catch landings. Consequently, farmers now use slaughterhouse by-products (mainly chicken offal – intestines, heads, feet, bones) as the primary ingredient for farm-made feeds. The outbreak of bird flu in 2003 was a disaster and has constrained the use of farm-made feeds. It is estimated that there were over 333 500 fish farms in 2003 (Fishery Information Technology Center, 2005), many of which previously relied on trash fish and latterly on chicken offal. This has placed an enormous strain on the sub-sector and competition for fresh trash fish and slaughterhouse by-products has become intense.

There are no standard farm-made feed formulations. In general, the composition of the feed depends on the availability and price of local raw materials. Hence, the

nutritional values of the feeds are highly variable, resulting in unpredictable production. Moreover, most farmers cannot store adequate quantities and have to purchase small quantities. Improper storage results in spoilage, poor fish growth and water pollution. In view of escalating costs this has become a major constraint for many farmers.

Farm-made feeds are generally made using simple equipment such as meat mincers and most often fed in a moist form. This causes water pollution and increases the risk of disease in comparison to manufactured commercial pellets. Farmers with adequate cash flow can afford to acquire additional equipment such as a hammer mill, mixer and cookers and are thus able to improve feed quality.

Feed management practices are largely inadequate. Many farmers simply dump the mixed raw materials into the fish pond once a day. This leads to feed losses, water quality problems and reduces the profitability of the enterprise.

The increasing price of organic manure is becoming problematic for fish farmers. Price escalation is related mainly to competition for chicken manure from agriculture and reduced availability because of bird flu. Poor farmers and those in rural areas are most affected, while those with a good cash flow can afford to purchase adequate quantities.

In Thailand, industrially manufactured feed is used mainly for shrimp farming and in intensive fish- cage and pond-culture systems, and especially for those fish that are primarily destined for export. If manufactured feeds are to be used to feed fish destined for local consumption, then it is incumbent upon feed manufacturers to invest in research on the nutritional requirements of all life-history stages of these species, such that low-cost feeds can be produced. It is anticipated that the demand for imported feed ingredients such as fishmeal, soybean meal and corn meal will increase. Although rice bran and broken rice are locally available there is likely to be shortage. The use of manufactured feeds is also constrained by farmer perceptions that the feeds are too expensive. Hence there is a need to educate farmers to calculate production costs and profit margins. This would go a long way towards assisting the farmers to adopt best feeding practices.

7. CONCLUSIONS AND RECOMMENDATIONS

Feed and feeding constraints in inland aquaculture vary depending on the farming systems (semi-intensive or intensive), type of feed used (farm-made feeds or commercial feeds) and species as well as whether the fish are produced for local consumption or for export. Feed manufacturers are still increasing production volumes, suggesting that the demand for aquafeeds is increasing. It is predicted that manufactured feeds will be the only viable option to ensure the sustainable development of freshwater and coastal aquaculture in the future, especially for products destined for export.

There is a need for government to set up extension projects to compare complete feeds with farm-made feeds. Simultaneously feed manufacturers must pay greater attention to the use of alternative and cheaper ingredients. The use of formulated feeds would also reduce the use of organic manures.

Farm-made feeds are less stable in water and inconsistent in nutritional value in comparison to commercial feeds and this leads variable fish production. Farmers have little knowledge of feed preparation and processing technology and of raw material quality control. While the government promotes the use of commercial feeds, farm made-feeds are still indispensable in some areas, especially where fish are produced primarily for domestic consumption. Hence, there is a need for government to provide extension support to farmers on the selection, storage and processing of raw materials and on the formulation and preparation of farm-made feeds. Such support should be adequately backed up by on-farm action with respect to sourcing and testing of new raw materials, formulation and feed processing, and research on the development of low-cost equipment to produce farm-made aquafeeds. In this regard, government and

the feed industry should make better use of farmer associations and feed distributors to disseminate information and new technologies. In addition, there is a need for training workshops, demonstration ponds and study tours, particularly for rural small-scale farmers.

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APPENDIX

Inland aquaculture systems in Thailand

A.1. Characteristics of inland aquaculture systems and practices in Thailand

System	Aquaculture species	Average size of pond (ha)	Stocking density (nos./ ha)	Feed and feeding	Rearing period (days/months)	Harvest size (g/kg)	Production (kg/ha)
Extensive							
Paddy field culture	Sepat siam	>1		Fertilization / natural food			1 250 kg/ ha
Polyculture	Tilapia and sutchi catfish	1	21 000-28 000	Vegetable waste and fertilization			
Semi-intensive							
Polyculture in pond	Tilapia and hybrid catfish	0.8	50 000 -62 500	Chicken by-product	6-8 months	Nile tilapia 500 g, Hybrid catfish 250 g	3 125 – 6 250 kg/0.8 ha
	Nile tilapia and sutchi catfish	0.3	5 000 + 5 000	Chicken by-product	6-8 months	Tilapia 0.5- 1 kg; sutchi catfish 1.5-2 kg	5 000 kg /0.3 ha
Intensive culture							
Pond	Tilapia, Java barb, catfish and common carp			Fertilization / commercial feed / kitchen waste / poultry by-product			
Cage	Climbing perch	400 m^2	8 000/cage	Commercial catfish feed	3 months	70-150 g	700-800 kg/400 m^2
	Tilapia 25-40 g	25-40 m^3		Commercial feed	3-5 months	800g – 1.2 kg	
	Tilapia 40g each	12.4 m^3	60/m^3	Floating pellet	57 – 130 days	200 – 625 g	43.6 kg/m^3
	Sutchi catfish			Commercial feed			
	All male tilapia	28.8 m^3	2 000/cage	Herbivorous fish feed (30% CP)	4.5 months	700 g	1500 kg/cage
	All male tilapia (25 g)	62.5 m^3 (5x5x2.5 m)	1 500/cage	Herbivorous fish feed	4 months	350- 500 g	600-650 kg/cage

Stocking density is expressed in number per ha unless otherwise indicated.