FAO
FISHERIES AND
AQUACULTURE
TECHNICAL
PAPER

541

ISSN 2070-7010

Impact of rising feed ingredient prices on aquafeeds and aquaculture production

Cover photograph:
Harvest of Nile tilapia (*Oreochromis niloticus*) from a freshwater pond, Jamalpur, Bangladesh, 2008 (courtesy of FAO/Jayanta Saha).

Impact of rising feed ingredient prices on aquafeeds and aquaculture production

FAO
FISHERIES AND
AQUACULTURE
TECHNICAL
PAPER

541

Krishen J. Rana
Sunil Siriwardena
Institute of Aquaculture
University of Stirling
Stirling, United Kingdom of Great Britain and Northern Ireland

and

Mohammad R. Hasan
Aquaculture Management and Conservation Service
Fisheries and Aquaculture Management Division
FAO Fisheries and Aquaculture Department
Rome, Italy

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2009

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

The views expressed in this information product are those of the author and do not necessarily reflect the views of FAO.

ISBN 978-92-5-106422-1

All rights reserved. Reproduction and dissemination of material in this information product for educational or other non-commercial purposes are authorized without any prior written permission from the copyright holders provided the source is fully acknowledged. Reproduction of material in this information product for resale or other commercial purposes is prohibited without written permission of the copyright holders. Applications for such permission should be addressed to:
Chief
Electronic Publishing Policy and Support Branch
Communication Division
FAO
Viale delle Terme di Caracalla, 00153 Rome, Italy
or by e-mail to:
copyright@fao.org

© FAO 2009

Preparation of this document

This document was prepared as part of the FAO Aquaculture Management and Conservation Service's (FIMA) ongoing programme "Monitoring, Management and Conservation of Resources for Aquaculture Development". The activities under the study entitled "Impact of rising feed ingredient prices on aquafeeds and aquaculture production" were undertaken in response to the soaring increase in food (particularly cereal grain) prices all over the world during 2007–2008 and was partially funded by Norway Programme Cooperation Agreement 2008.

This technical paper was edited for technical content by Dr M.N. Kutty. For consistency and conformity, scientific and English common names of fish species were used from FishBase (www.fishbase.org/home.htm).

The authors acknowledge Ms Tina Farmer and Ms Françoise Schatto for their assistance in quality control and FAO house style and Mr José Luis Castilla for layout design. The publishing and distribution of the document were undertaken by FAO, Rome.

Finally, Mr Jiansan Jia, Chief of the Aquaculture Management and Conservation Service of the FAO Fisheries and Aquaculture Department, is acknowledged for providing the necessary support to initiate the study and to complete the publication.

Abstract

It is now widely recognized that the rising demand for aquatic products will have to be met by aquaculture. The future of aquaculture will depend on how well it meets this challenge. The contribution of aquaculture to total fishery products (excluding plants), globally, has steadily increased from 4 percent in 1970 to 36 percent in 2006 and is continuing to increase. The growing importance of aquaculture in overcoming production limits of capture fisheries can be judged from the fact that China's 2004 aquaculture production was about 70 percent of its total fisheries production. By 2020, global aquaculture is expected to contribute about 120–130 million tonnes of fish to meet projected demands. The types of species/species groups dominating fed aquaculture production and the recent focus to increase and intensify production of crustaceans, marine finfish, and diadromous fishes, reflects a tendency to increasing reliance on aquafeeds, for their production, and particularly commercial diets. It is, therefore, crucial that aquaculture is sustainable and that the resources required for promoting aquaculture are secured. Key resources required to meet this challenge are aquafeeds and the ingredients used in their production. These resources, together with high transportation costs as a result of costly energy, form the central part of this study.

Fed aquaculture relies on a basket of common input ingredients such as soybean, corn, fishmeal, fish oil, rice and wheat, for which it competes in the marketplace with the animal husbandry sector as well as with use for direct human consumption. Many of these key ingredients traditionally used in recipes for commercial or on-farm aquaculture feeds are internationally traded commodities. Therefore, aquafeed production is also subjected to any common global market shocks and volatility. Since 2005, the basket commodity price index (CPI) rose by about 50 percent and the prices of soybean meal, fishmeal, corn and wheat rose by 67, 55, 284, 225 and 180 percent, respectively. Similarly, the cost of major oils used in the aquafeed industry has increased by up to 250 percent. The aquaculture industry is, therefore, not immune to this global phenomenon and the major concern is how it will impact aquaculture. Specifically, smallholders and rural farmers may particularly be susceptible to these global changes and the fallout may further contribute to their poverty and vulnerability. Considering such developments, this technical review evaluates the underlying reasons for the recent dramatic rise in prices of these commodities used in aquafeed production and its consequences for the aquafeed industry and, in particular, on demand and expectations from aquaculture in securing current and future fish supplies.

This technical paper also discusses issues related to availability of and access to land and water resources, and the impact of other sectors using these resources on the direction of aquaculture both in terms of species produced and the production systems. In the light of probable increase in competition for land and water in many aquaculture producing countries in Asia, there will inevitably be increasing pressure to intensify aquaculture productivity through the use of more commercial feeds than farm-made feeds. Urbanization has influenced both the level and distribution of income and dietary habits which are driving upwards the demand for high-value fish species with significant implications for feed supplies. Due to the increasing prices of ingredients, aquafeed prices, especially the prices of compound aquafeeds, may increase further and a shortfall in the local supplies will compel importation of aquafeeds. Of the ingredients, fishmeal and fish oil are highly favoured for aquafeeds and aquafeed production is under increasing pressure due to limited supplies and increasing price of fishmeal and fish oil. This review also outlines initiatives that are searching for substitutes for fishmeal and fish oil so as to position the industry to meet the challenge of securing aquafeed for sustaining aquaculture.

To regulate the rising commodity prices would require governmental interventions. A brief overview of coping strategies to strengthen national capacity to address the issue of aquafeed supply and to mitigate rising prices of aquafeed ingredient is given. These strategies include policies, research and private sector and farmers' initiatives.

Rana, K.J.; Siriwardena, S.; Hasan, M.R.
Impact of rising feed ingredient prices on aquafeeds and aquaculture production.
FAO Fisheries and Aquaculture Technical Paper. No. 541. Rome, FAO. 2009. 63p.

Contents

Contributors

Mohammad R. Hasan, Aquaculture Management and Conservation Service, FAO Fisheries and Aquaculture Department, Rome 00153, Italy.
E-mail: Mohammad.Hasan@fao.org

Krishen J. Rana[1]**,** Institute of Aquaculture, University of Stirling, Stirling FK94LA, Scotland, United Kingdom.
E-mail: k.j.rana@stir.ac.uk

Sunil Siriwardena, Institute of Aquaculture, University of Stirling, Stirling FK94LA, Scotland, United Kingdom.
E-mail: s.n.siriwardena@stir.ac.uk

---

[1] Division of Aquaculture, University of Stellenbosch, Stellenbosch, South Africa.

Introduction

BACKGROUND

During 2007–2008, there was a soaring increase in food prices (particularly cereal grain) all over the world. This was especially severe in the world's poorest countries and was predicted to contribute to about a 56 percent rise in cereal import bills of those countries in 2007–2008. This sharp increase in food prices was due to a number of factors, including the reduced production of cereal crops worldwide and continued increases in oil prices resulting in higher freight cost. There was also the added concern that the use of certain grains in biofuel production would further aggravate this problem.

In aquaculture, feed accounts for over 50 percent of the production cost. Although considerable variation exists, cereal grains are the usual sources of carbohydrates in most of the aquafeeds and these cannot be economically supplemented with other sources. Fishmeal is the single most important source of protein in fish feed. The increased cost of energy (due primarily to soaring petroleum prices), El Niño effects, and increasing demand have resulted in a global increase in fishmeal price. The world price for fishmeal ranged between US$500 and US$700 per tonne during the period 2000–2005. In May 2008, the price of fishmeal was US$1 210 per tonne.

The average price of other feed ingredients commonly used in aquafeed rose by 20–92 percent during the period between June 2007 and June 2008. The increasing price of feed ingredients (fishmeal, fish oil and cereal) and increasing manufacturing and transportation costs were, therefore, likely to have had a compound effect on global production and the price of aquafeeds. It was reported that during late 2008, feed prices had increased by over 30 percent on average in many of the countries in Asia, while farmgate prices of aquaculture products had remained static, literally impinging on the economic viability of several thousands of small-scale producers that form the backbone of the aquaculture sector, particularly in Asia, the epicentre of aquaculture production. The aquaculture industry will not be immune to this global phenomenon, and specifically smallholders and rural farmers may be particularly susceptible to this global change and the fallout may further contribute to their poverty and vulnerability. This global phenomenon could eventually induce small-scale producers to change businesses and/or may result in loss of livelihood.

The impact of an increase in feed prices is bound to vary not only between countries and regions but also within different farming systems and for different fish species. For example, while an increase in fishmeal and fish oil may have a profound impact on the farming of salmonids in Europe, a price increase will not have a profound effect on tilapia, catfish and carp farming in most of the Asian and sub-Saharan African countries as the proportion of fishmeal and fish oil in diets is relatively low, typically 2–7 percent for fishmeal and 1 percent for fish oil, while soaring prices of other ingredients (e.g. cereal and cereal by-products) may likely have a major impact. A study (Rola and Hasan, 2007) carried out in Viet Nam and Thailand in 2006 showed that proportion of the break-even price with the actual price on catfish farms are 85 percent and 69 percent, respectively, while the respective feed costs are about 86 and 81 percent of total production costs. The higher the break-even price, in comparison to the market price, the more vulnerable is the producer implying that farmers in Viet Nam and Thailand cannot afford to absorb a decrease of the proportion exceeding 15 and 31 percent, respectively. This indicates that most of the catfish and tilapia farmers in these countries will not be able to absorb any further feed price increase. Under these circumstances, the immediate need is to assess the extent and magnitude of the impact of this global phenomenon on aquaculture to understand the situation, to study the medium- and long-term impact on aquaculture production, including food security and the overall biosecurity of the system, and to develop coping strategies to address the changing situation.

Activities

The study was carried out with special reference to the continents of Asia and Europe, considering that Asia contributes over 90 percent of global aquaculture production, while the aquafeed industry is the most well-developed in Europe. The activities under the study included both specific and overall impact analyses which were carried out through the collection, review and analysis of available published literature and information, as well as data collected in selected market studies.

The review had two major focuses: (a) a collection of data on the status in the costs and trends of and availability of feed ingredients and aquafeed; and (b) an analysis to examine how this change was reflected in aquaculture production, the prices of final aquaculture products and their consumption pattern in relation to the biosecurity and safety of aquaculture products for human consumption. The study includes the following specific topics to measure the overall impact of increased price of feed ingredients:

- assessment of status and trends of aquaculture feed: volume of production, prices of ingredients, and product quality with special reference to countries of south and southeast Asia and western Europe;
- assessment of aquaculture products/production: volume, quality, price, shift/change in production patterns (species diversification); and consumption in two regions, Asia and Europe;
- impact on biosecurity of aquaculture products resulting from a change in feeding patterns and unavailability of standard nutritional options; and
- comparison of the impacts in Asia and Europe, and development of management measures for adaptation to strengthen national capacity for emergency preparedness and recovery.

Abbreviations and acronyms

AFSD-BAI	Animal Standard Division, Bureau of Animal Industry (Philippines)
ARWR	Actual Renewable Water Resources
CF	Crude fibre
CL	Crude lipid
CP	Crude protein
CP Group	Charoen Pokphand Group Thailand
CPI	Commodity Price Index
CPSP	Fish protein soluble concentrates
DDGS	Corn Distillers Dried Grains with Solubles
DKK	Danish krone
DNA	Deoxyribonucleic acid
EAA	Essential amino acids
EE	Ether extracts
EU	European Union
€	Euro (€, European Union)
FAO	Food and Agriculture Organization of the United Nations
FM	Fishmeal
FIN	Fishmeal Information Network
Fed aquaculture	Aquaculture production that utilizes or has the potential to utilize aquafeeds of any type in contrast with the farming of filter-feeding invertebrates and aquatic plants that relies exclusively on natural productivity. Also defined as "farming of aquatic organisms utilizing aquafeeds in contrast to that deriving nutrition directly from nature"
HFM	Hydrolysed feather meal
IMF	International Monetary Fund
IMPACT model	International Model for Policy Analysis of Agricultural Commodities and Trade
INRA	Institut National de la Recherche Agronomique (French National Institute for Agricultural Research)
IFPRI	International Food Policy Research Institute
IRWR	Internal Renewable Water Resources
NE	North Europe
NFE	Nitrogen free extractives
NSPs	Non-starch polysaccharides
PBM	Poultry by-product meal
PDV	Productschap Dievoeder (Product Board Animal Feed, the Netherlands)
PEPPA	Perspectives of Plant Protein Use in Aquaculture
PHP	Philippine peso
ppb	Parts per billion
ppm	Parts per million
RAFOA	Research on Alternatives to Fish Oil in Aquaculture
RE	Rest of Europe

RMB	Currency of the People's Republic of China. The official ISO 4217 abbreviation is CNY (Yuan, ¥), although commonly abbreviated as RMB
RNA	Ribonucleic acid
SBM	Soybean meal
SPC	Soybean protein concentrate
SPI	Soy protein isolate
SSA	sub-Saharan Africa
UK	United Kingdom of Great Britain and Northern Ireland
UN	United Nations
USDA	United States Department of Agriculture
US$	US dollar (United States of America)
VAC	Integrated garden (V), fishpond (A) and livestock (C) system (VAC in Vietnamese is *vuon, ao, chuong*, which means garden, pond and livestock)
VASEP	Viet Nam Association of Seafood Exporters and Processors
VND	Dong (þ, Viet Nam)
WHO	World Health Organization

1. Assessment of aquaculture production with special reference to Asia and Europe

This section presents an overall assessment of aquaculture products and their production with special reference to the two regions, Asia and Europe. Production volume, product quality and price, production patterns (species diversification) as well as consumption patterns are discussed.

1.1 RECENT TRENDS IN AQUACULTURE PRODUCTION

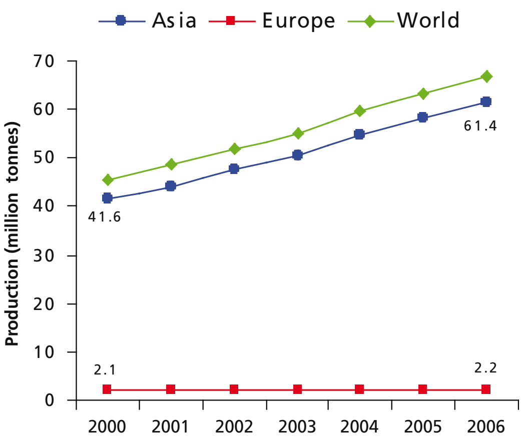
1.1.1 Regional contribution to global production and implications for the aquafeed supply

Approximately 220 species of aquatic animals and plants are currently cultured worldwide, in a vast range of production systems, ranging from low-input extensive systems to high-input intensive aquafarms in ponds, caged enclosures and tanks. In broad terms, aquaculture production systems used for producing these aquatic animals and plants can be divided into feed-dependent systems or fed aquaculture (e.g. finfish and crustaceans) or non-fed aquaculture systems where culture is predominately dependent on the natural environment for food, e.g. aquatic plants and molluscs.

In 2006, global aquaculture production reached 66.7 million tonnes, growing at an annual rate of 9 percent, while increasing its proportional contribution to total fisheries output. Excluding aquatic plants, aquaculture output in 1970 accounted for 3.9 percent of total fisheries production, by 2001 that proportion had increased to 29 percent and by 2006 to 36 percent (FAO, 2008a). Thus, aquaculture continues to make a significant contribution to total fisheries production over the last few decades. This increasing contribution, however, is largely an Asian phenomenon because Asia accounted for 61.43 million tonnes or 92 percent of total world aquaculture production in 2006, while Europe contributed 2.17 million tonnes or 2.2 percent (Figure 1). In terms of value, the Asian region's share was US$68.61 million or 80 percent of total value of world aquaculture production. The Asian contribution is significantly influenced and skewed by China. When China is excluded, the Asian contribution to total world aquaculture production drops dramatically to 24.2 percent in terms of quantity and 29 percent in terms of value. As is evident, currently, aquaculture production is overwhelmingly concentrated in one country, China. Considering the geographic spread and potential economic contribution of aquaculture in relation to aquafeeds, a better assessment may be made by excluding Chinese fish and aquatic plants to understand the progress made by the other 105 countries that have reported aquaculture production of over 1 000 tonnes in 2006.

FIGURE 1

Recent trends in aquaculture production (including aquatic plants)



Source: Adapted from FAO (2008a).

When aquatic plants are excluded from production estimates for the Asian region and Asia excluding China, aquaculture production contributes 90 percent and 23.2 percent, respectively, in terms of quantity and 78 percent and 29.2 percent in terms of value, respectively, to the world total aquaculture production. Aquatic plant production is dominated by China. Seventy-three percent of total aquatic plant production in Asia is in China. There is no noticeable change in terms of quantity or value of aquaculture in Europe when plants are excluded.

In Asia, fed aquaculture accounted for 54 percent of the region's total aquaculture production, indicating that almost half of Asia's aquaculture production comes from non-fed aquaculture. However, the non-fed aquaculture production within Asia is not evenly distributed and is mainly centred in China. Fifty percent of China's total aquaculture production (including plants) is non-fed aquaculture production.

Asia's fed aquaculture, excluding China and including aquatic plants, amounts to 64.2 percent. If the recent trend in the slowing down of the annual growth of the non-fed aquaculture sector continues (see section below), while maintaining an increase in total aquaculture production, the demand for aquafeed in Asia will significantly increase. In contrast to the Asian situation, finfish and crustacean aquaculture production in Europe is 100 percent dependent on aquafeeds.

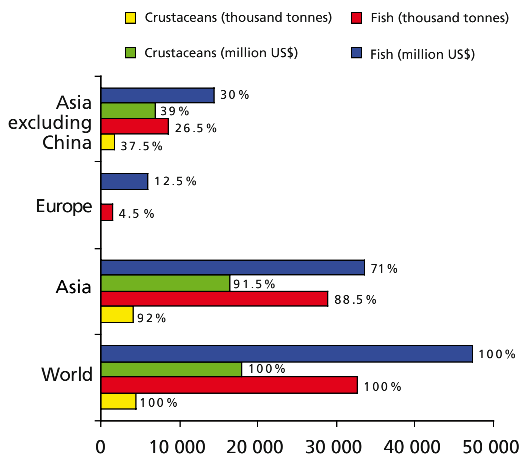
Asia's aquaculture production is also dominated by the use of aquafeeds. Asia is the largest global consumer of aquafeed ingredients. Aquaculture production, mainly of crustaceans and finfish, relies on farm-made or complete industrial diets. It is estimated that Asia contributed 88.5 percent of fish in terms of quantity and 71 percent in terms of value to total world fed aquaculture production (Figure 2). In contrast, Europe contributed 4.5 percent of fish in terms of quantity to total world fed aquaculture production. More importantly, Asia, excluding China, contributed 26.5 percent of fish in terms of quantity and 30 percent in terms of value to total world fed aquaculture production, indicating that the demand for aquafeed ingredients is also heavily skewed towards China.

In terms of crustacean fed aquaculture production, Asia contributed 91.5 percent of total world production (Figure 2). When China is excluded from the Asian equation, the contribution of the rest of Asia is 37.5 percent of total world crustacean production. Europe's contribution to world farmed crustacean production is negligible. Therefore, the impact of commodity volatility will be felt to a greater degree in Asia than in Europe.

Future pressure on the demand for feed ingredients will depend on the changing proportions of fed and non-fed aquaculture to total aquaculture production, the demand and the types of species used to meet the demand of aquatic products. The demand for feed ingredients will also depend on whether the trend will be to increase mass production of low-value species using aquafeeds or to increase production in high-value species, which generally requires high quality performance diets. Either way, the demand for all aquafeed ingredients will increase. Production of high-value species will put upward pressure on fishmeal and fish oil demand and prices, while production of low-value species will increase the demand and price for feed ingredients such as grains and oils of plant origin.

FIGURE 2

Contribution of Asia and Europe to world fed aquaculture by type of cultures



Source: Adapted from FAO (2008a).

1.1.2 Aquaculture growth in Asia and Europe

All aquaculture species groups have shown positive growth, but the acceleration in growth has varied between species groups. Crustacean production grew at an average annual rate of 24.5 percent, while that of finfish and molluscs grew at an average growth of 7.0 percent and 5.0 percent, respectively, over the period 2000–2006. However, in the last three reporting years, the annual growth of crustacean aquaculture production has declined and stabilized at 9–12 percent. All other species groups, namely, amphibian, other invertebrates and aquatic plants showed a slowing down in their percentage annual production growth during the same period (Table 1). Thus, crustaceans and finfish are the groups that showed promising growth. As these species groups represent fed aquaculture, this will put greater upward pressure for farm-made or complete commercial diets.

The growth of fed aquaculture production in the Asian region has continued to be strong especially for the marine sector, reflecting a trend over the last ten years. This growth results mainly from a continuous increase in production in China. Between 2000 and 2006, production of fed aquaculture in China increased by 6.8 million tonnes (7.1 percent annual average growth). In terms of tonnage, other Asian countries that showed large increases included Myanmar, Viet Nam, Thailand, Indonesia, India and the Philippines over the same period (Table 2). Both freshwater and marine fed aquaculture (including brackish water) production showed a steady growth in leading aquaculture producing countries in Asia except in Japan. Out of the ten leading aquaculture producing countries, which contributed 87.1 percent to regional total fed aquaculture in Asia in 2006, Myanmar (185 percent), Viet Nam (68.4 percent), China (29 percent), and Taiwan Province of China (8 percent) showed a significantly higher average percentage annual growths in terms of quantity in the marine sector (including brackishwater) than in the freshwater sector over the same period (Table 2). Overall, Myanmar and Viet Nam are emerging as countries with substantial aquaculture growth in both environments (Table 2).

Just as China is the centre of production in Asia, Norway is the centre of fed aquaculture production in Europe, with an average annual percentage growth of 7.3 percent from 2000 to 2006 (Table 3). In 2006, Norway contributed 48 percent

TABLE 1

Global aquaculture production – percentage growth rates of different species groups

Species groups	2000–2006	2000–2001	2001–2002	2002–2003	2003–2004	2004–2005	2005–2006
Amphibians	33	22	2	92	6	12	4
Crustaceans	24	17	12	36	12	9	12
Other invertebrates	48	17	-27	188	37	21	-4
Molluscs	5	6	6	4	4	3	5
Finfish	7	7	6	3	8	6	7
Aquatic plants	8	4	9	8	11	6	2

Source: FAO (2008a).

TABLE 2

Production of fed aquaculture in the top ten producing countries in Asia

Country	2000 production (thousand tonnes)			2006 production (thousand tonnes)			Average annual growth (%)		
	Total	Freshwater	Marine	Total	Freshwater	Marine	Total	Freshwater	Marine
China	15 881	15 077	804	22 650	20 445	2205	7.1	6.0	29.0
India	1 941	1 844	97	3 123	2973	150	10.2	10.2	9.2
Viet Nam	459	365	94	1 512	1034	478	38.3	30.6	68.4
Indonesia	789	363	426	1 293	664	629	10.7	13.8	8.0
Thailand	589	270	319	1 021	502	519	12.2	14.4	10.4
Bangladesh	657	570	87	892	785	107	6.0	6.0	4.0
Philippines	363	112	251	587	245	342	10.0	20.0	6.1
Myanmar	99	94	5	575	515	60	80.0	75.0	185.0
Japan	321	60	261	302	42	260	-1.0	-5.2	0.0
Taiwan Province of China	179	131	48	217	145	72	3.5	1.7	8.4

Source: FAO (2008a).

TABLE 3
Production of fed aquaculture in the top ten producing countries in Europe

Country	2000 production (thousand tonnes)			2006 production (thousand tonnes)			Average annual growth (%)		
	Total	Freshwater	Marine	Total	Freshwater	Marine	Total	Freshwater	Marine
Norway	490	–	490	705	–	705	7.3	–	7.3
United Kingdom	140	10	130	146	11	135	0.7	1.6	0.6
Russian Federation	74	74	–	105	105	–	7.1	7.1	–
Greece	71	3	68	85	4	81	3.3	5.5	3.2
Spain	49	34	15	59	26	33	3.5	-4.0	20.0
France	60	54	6	51	42	9	-2.5	-3.7	8.3
Italy	67	49	18	49	33	16	-4.4	-5.4	-1.8
Denmark	44	36	7	37	28	9	-2.6	-3.7	4.8
Poland	36	36	-	36	36	-	0.0	0.0	-
Germany	42	42	-	32	32	-	-3.2	-3.2	-

Source: FAO (2008a).

of total fed aquaculture production in Europe. The other countries in Europe that showed a sizeable contribution to total fed aquaculture tonnage in 2006 were the United Kingdom (10 percent), the Russian Federation (7 percent), Greece (6 percent) and Spain (4 percent).

Marine aquaculture of high-value species fed complete commercial diets is a predominant feature of European fed aquaculture. While registering a negative growth in freshwater sector, positive aquaculture growth rates in the marine sector during 2000–2006 were shown in Denmark, France and Spain (Table 3). Over the same period, Germany also registered negative growth in the freshwater sector (Table 3).

The overall trend in fed aquaculture in both the Asian and European regions is to focus on marine aquaculture (including brackishwater) of usually high-value species that require complete commercial or high performance diets.

1.2 PROJECTED GLOBAL AQUACULTURE PRODUCTION WITH CONTRIBUTIONS FROM ASIA AND EUROPE AND THE IMPLICATIONS FOR AQUAFEEDS

With stagnating global capture fisheries production, there is growing expectation for aquaculture to meet the shortfall of aquatic products and to cater to the growing demand of the increasing population. Predictions of the exact shortfall are imprecise: many forecasts have been developed based on a wide range of assumptions (Ye, 1999; Delgado *et al*., 2003; Wijkstrom, 2003; Dey, Rodriguez and Briones, 2004; Brugère and Ridler, 2004).

Delgado *et al*. (2003) with their International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT model) attempted to address the complexity inherent in creating a demand forecast by incorporating prices and their effects on consumer demand into the IMPACT model. Predictions were made using three main scenarios. Under the baseline scenario, which is the most plausible, "best guess" assumptions, global food-fish production was projected to reach 130 million tonnes by 2020 and aquaculture was expected to produce 41 percent (53.6 million tonnes) of this production. However, projected production at 2020 for all models (assuming a capture fisheries growth of 0.9 percent per year) has already been achieved (Table 4).

In their study for FAO, Brugère and Ridler (2004) adapted the studies of Delgado *et al*. (2003) for national predictions by considering government policy and production targets in national plans. Such national predictions were made for China, India, Indonesia, Thailand, Bangladesh, Chile, Viet Nam, the Philippines, Egypt, Brazil and Canada (Table 5).

The global actual average annual growth rate of 7.6 percent (from 2000 to 2006) (see footnote 2 in Table 4) and actual average annual growth rates of leading aquaculture producing countries in Asia (Table 5) suggest that all forecasted targets set for 2010 and 2020 by the forecast models in Table 4 are likely to be met.

TABLE 4

Forecast of global food-fish aquaculture production to total food-fish production

Forecast model	Forecast date/ per capita consumption (kg/year)	Food-fish demand by the forecasted date (million tonnes)	Food fish required from aquaculture to achieve the demand by forecasted date (million tonnes)		Actual aquaculture food-fish production in 2006 against production forecasts (%)[2]	
			Growing fisheries scenario	Stagnating fisheries scenario	Growing fisheries scenario	Stagnating fisheries scenario
IFPRI (Delgado *et al*., 2003) Baseline	2020/17.1	130.0	53.6 (1.8%)[1]	68.6 (3.5%)[1]	96.4	75.4
Ecological[3] collapse	2020/14.2	108.0	41.2 (0.4%)[1]	46.6 (1.4%)[1]	125.5	110.9
Faster[4] aquaculture development	2020/19.0	145.0	69.5 (3.2%)[1]	83.6 (4.6%)[1]	74.4	61.8
Wijkstrom (2003)	2010/17.8	121.1	51.1 (3.4%)[1]	59.7 (5.3%)[1]	101.2	86.6
	2050/30.4	270.9	177.9 (3.2%)[1]	209.5 (3.6%)[1]	29.0	24.7
Ye (1999)	2030/15.6	126.5	45.5 (0.6%)[1]	65.1 (2.0%)[1]	113.6	79.4
	2030/22.5	183.0	102.0 (3.5%)[1]	121.6 (4.2%)[1]	50.7	42.5

[1] Forecasted average annual growth rate of aquaculture food-fish production to forecasted date.

[2] Actual global food-fish aquaculture production in 2006 was 51.7 million tonnes and the average annual growth rate from 2000 to 2006 was 7.6 percent.

[3] One percent annual growth trends in production, excluding supply response to price change, for all capture fisheries commodities including fishmeal and oil.

[4] Aquaculture output aggregate commodities are increased by 50 percent relative to the baseline scenario.

Source: Columns 2, 3 and 4 correspond to references in column 1. Column 5 is authors' computation.

TABLE 5

Growth rates of food-fish aquaculture in leading aquaculture producing countries in Asia

Country	Actual annual growth rates (%)			Forecasted growth rates (%)[1]	Forecast date[1]
	1980–1990[1]	1990–2000[1]	2000–2006		
China	17.1	33.8	6.7	3.7	2001–2010
Bangladesh	7.9	12.8	6.0	4.1	2001–2010
				3.5	2001–2020
India	11.4	6.8	10.1	8.2	2000–2005
				8.5	2001–2010
Indonesia	9.9	5.1	11.0	11.1	2003–2009
Philippines	6.3	0.3	9.7	13.4	2001–2004
Thailand	10.2	9.0	14.6	1.8	1996–2010
Viet Nam	11.8	8.5	38.8	10.0	2001–2010

[1] *Source*: Brugère and Ridler (2004).

These targets together with historic trends in species contribution to annual production can be used to forecast estimates of production tonnage and to predict trends in intensification of aquaculture practices for the various species groups farmed. These scenarios can help to understand the future demand and pressure on quantity and types of feed ingredients that may be required to meet production targets. For this purpose, the food-fish aquaculture production outlook projected to 2020 by Brugère and Ridley (2004) based on country national plans was used.

Contribution by species group to the forecasted aquaculture production (excluding aquatic plants) in 2020 is given in Table 6. To estimate the contribution of species groups to forecasted aquaculture production (excluding aquatic plants) to 2020 in countries listed in Table 6, the 17-year (1990–2006) average annual percentage contributions of the species groups (for Bangladesh, the 12-year average) were applied to 2020 production predictions.

Similarly, the contributions by species group were estimated for Europe based on the projected aquaculture production (excluding aquatic plants) forecasted by Failler (2008) in the 11 leading aquaculture producing countries in Europe (Table 7), which accounted for 88.0 percent of the total European aquaculture production (excluding aquatic plants) in 2006.

TABLE 6

Projected contributions by species group to aquaculture production (excluding aquatic plants) by 2020 in selected leading aquaculture countries in Asia

Country	Projected aquaculture production by 2020 (million tonnes)	Species groups[1]	Annual average % contribution to total aquaculture production 1990–2006[2]	Projected species group contribution to 2020 target (thousand tonnes)[3]
Bangladesh	1.34	Carps and other cyprinids	69.2	927.3
		Freshwater crustaceans	1.3	17.4
		Other freshwater fishes	21.1	282.7
		Marine shrimps and other crustaceans	8.5	114.0
China at 3.5% growth	52.22	Carps and other cyprinids	54.0	28 199.0
		Freshwater crustaceans	1.2	626.6
		Catfishes	1.5	783.0
		Other freshwater fishes	3.4	1 775.5
		Marine/brackishwater fishes	1.4	731.1
		Marine shrimps and other crustaceans	2.0	1 044.4
China at 2.0% growth	40.75	Tilapias and other cichlids	2.4	1 253.3
		Molluscs	34.2	17 859.2
		Carps and other cyprinids	54.0	22 005.0
		Freshwater crustaceans	1.2	489.0
		Catfishes	1.5	611.0
		Other freshwater fishes	3.4	1 385.5
		Marine/brackishwater fishes	1.4	570.5
		Marine shrimps and other crustaceans	2.0	815.0
		Tilapias and other cichlids	2.4	978.0
India	10.74	Molluscs	34.2	13 936.5
		Carps, barbs and other cyprinids	78.2	8 398.7
		Freshwater crustaceans	0.6	64.4
		Catfishes	5.6	601.4
		Other freshwater fishes	11.4	1 224.4
		Marine shrimps and other crustaceans	4.3	462.0
Indonesia	7.35	Carpsbarbs and other cyprinids	26.3	1 933.1
		Catfishes	6.5	477.8
		Other freshwater fishes	6.6	485.0
		Miscellaneous marine/brackishwater fishes	1.7	125.0
		Miscellaneous diadromous fishes	25.2	1 852.2
		Marine shrimps and other crustaceans	22.0	1 617.0
		Tilapia and other cichlids	11.7	860.0
Philippines	6.30	Carps, barbs and other cyprinids	2.0	126.0
		Catfishes	0.7	44.0
		Other freshwater fishes	0.2	12.6
		Marine/brackishwater fish	0.3	18.9
		Miscellaneous diadromous fishes	49.7	3 131.1
		Marine shrimps and other crustaceans	14.8	932.4
		Tilapias and other cichlids	24.8	1 562.4
		Molluscs	7.6	–
Thailand	0.84	Carps, barbs and other cyprinids	6.7	56.0
		Freshwater crustaceans	1.9	16.0
		Catfishes	16.1	135.0
		Other freshwater fishes	0.5	4.0
		Miscellaneous marine/brackishwater fishes	0.2	1.7
		Miscellaneous diadromous fishes	0.8	6.7
		Marine shrimps and other crustaceans	39.9	335.0
		Tilapias and other cichlids	11.4	96.0
		Molluscs	22.5	189.0
Viet Nam	5.20	Freshwater crustaceans	2.7	140.4
		Catfishes	20.3	1 056.0
		Other freshwater fishes	50.8	2 642.0
		Marine shrimps and other crustaceans	19.5	1 014.0
		Molluscs	6.7	348.4

[1] Species group based on FAO classification; [2] For Bangladesh 12-year average was considered to include all species groups. For other countries 17-year average was used to include all species groups; [3] Based on the long-term average species group contributions.

Source: Brugère and Ridley (2004).

TABLE 7

Projected contributions by species group to aquaculture production by 2020 in selected leading aquaculture countries in Europe

Country	Species groups	17-year average % contribution to total aquaculture production[1]	Projected aquaculture production by 2020 (tonnes)	Projected species group contribution to 2020 (thousand tonnes)[2]
Denmark	River eels	3.7	53 347	1 974
	Salmons, trouts, smelts	96.3		51 373
France	Carps and other cyprinids	3.2	307 497	9840
	Molluscs	77.8		239 233
	Flounders, halibuts, soles	0.2		615
	Marine/brackishwater fishes	1.3		3 998
	Miscellaneous freshwater fishes	0.4		1 230
	Salmons, trouts, smelts	17.0		5 227
Germany	Carps, barbs and other cyprinids	21.1	71 026	14 987
	Molluscs	29.0		20 598
	Miscellaneous freshwater fishes	9.2		6 534
	Salmons, trouts, smelts	40.6		28 837
Greece	Carps, barbs and other cyprinids	0.8	79 486	636
	Molluscs	31.8		25 277
	Marine/brackishwater fish	58.4		46 420
	Miscellaneous freshwater fishes	0.5		397
	River eels	0.8		636
	Salmons, trouts, smelts	7.6		6 041
Ireland	Molluscs	62.1	55 881	34 702
	Salmons, trouts, smelts	37.9		21 179
Italy	Carps, barbs and other cyprinids	0.3	279 363	838
	Molluscs	67.4		188 291
	Marine/brackishwater fishes	6.5		18 159
	Miscellaneous freshwater fishes	1.2		3 352
	River eels	1.5		4 190
	Salmons, trouts, smelts	22.7		63 415
	Sturgeons, paddlefishes	0.4		1 117
Netherlands	Molluscs	93.6	138 534	129 668
	Miscellaneous freshwater fishes	2.6		3 602
	River eels	3.6		4 987
	Salmons, trouts, smelts	0.2		277
Norway	Cods, hakes, haddocks	0.4	617 967	2 472
	Marine/brackishwater fishes	0.2		1 236
	Molluscs	0.3		1 854
	Salmons, trouts, smelts	99.1		612 405
Poland	Carps, barbs and other cyprinids	66.0	28 328	18 697
	Miscellaneous freshwater fishes	2.5		708
	Salmons, trouts, smelts	31.5		8 923
Spain	Carps, barbs, cyprinids	0.1	361 017	361
	Molluscs	84.1		303 615
	Flounders, halibuts, soles	1.1		3971
	Marine/ brackishwater fishes	3.4		12 275
	River eels	0.1		361
	Salmons, trouts, smelts	11.0		39 712
	Shrimps, prawns	0.1		361
	Tunas, bonitos, billfishes	0.2		722
United Kingdom	Molluscs	9.7	168 241	16 319
	Salmons, trouts, smelts	90.3		151 922

[1] For Norway, Poland and Germany, the 12-year average was considered to include all currently cultured species groups. For other countries, the 17-year average was used to include all species groups; [2] Based on the long-term average species group contribution.

Source: Failler (2008).

1.3 EMERGING TRENDS IN AQUACULTURE PRACTICES AND THE IMPLICATIONS FOR FEED DEMAND

1.3.1 Trends in the use of species groups in aquaculture practices

The detailed nature of aquaculture activities is hard to typify due to the great diversity of farming practices both among and within countries in Asia and Europe. At a glance, two species groups dominate aquaculture production in the two regions, carps in Asia and salmonids in Europe, and this will continue if current trends in growth continue. In addition to salmonids, marine (coastal) finfish make a significant contribution in terms of value in Europe. In Asia, carps, including barbels, and other cyprinids accounted for 62 and 55 percent of total Asian and world fed aquaculture production. In Europe, salmon and trout contributed 50 and 74 percent, respectively, to European total aquaculture, all fish farmed with commercial feeds.

This species group dominance in fed aquaculture in both regions and the recent focus on crustaceans, marine finfish, and other diadromous fishes point towards a tendency of increasing reliance on commercial aquafeeds for their production. Although carps are considered low-value species and are mainly fed farm-made aquafeeds (usually single ingredient feeds), their bulk production will place a heavy demand on feed ingredients, especially grains which will have to be procured on globally traded markets. Between 2000 and 2006, the production of marine shrimps and prawns, and freshwater crustaceans in Asia increased by 183 and 121 percent, respectively (Table 8), and in Europe, diadromous fish and coastal fish (including marine fish) production increased by 18 and 35 percent, respectively (Table 9), where feed demand is expected to be high.

It is worth noting that in the freshwater sector, the production of a number of carnivorous species has grown substantially since 2000. For example, production of pangas catfishes increased by 66.6 percent, amur catfish by 1 005 percent and snakeheads by 23 425 percent. Asian mariculture is generally dominated by high-value species such as penaeid shrimps and seabreams. Of the penaeid shrimps, whiteleg shrimp production has made significant advances in recent years to move into seventh place (Table 10). The production of other high-value species such as the oriental river prawn, giant tiger prawn, mandarin fish, Japanese amberjack and Japanese eel has also increased significantly. Thus, there is a notable move away from bulk production of low-value species and a focus on production of high-value species to meet growing demand of the local increasingly affluent populations and consequently greater pressure on sources of high-quality protein and oil. There are a number of high-value species worth highlighting as emerging species (Table 11). Since 2000, there was rapid growth in the production of high-value carnivorous species such as whiteleg shrimp, freshwater swamp eel, mandarin fish, channel catfish, red swamp craw fish, Chinese river crab and marine finfish.

TABLE 8

Production by main species group in Asia and its contribution to total fed aquaculture production

Species groups	Production (thousand tonnes)		Average annual percentage growth	% contribution to total Asian fed aquaculture production in 2006	% contribution to total world fed aquaculture production in 2006
	2000	2006			
Carps, barbs and other cyprinids	15 077	20 155 (34%)[1]	6	62 (33)[2]	55 (30)[2]
Miscellaneous freshwater fishes	2 358	4 420 (87%)	15	13 (7)	7 (12)
Marine shrimps and prawns	996	2 813 (183%)	30	9 (5)	8 (4)
Tilapias and other cichlids	993	1 836 (85%)	14	6 (3)	5 (3)
Freshwater crustaceans	475	1 048 (121%)	20	3 (2)	3 (2)
Miscellaneous coastal fishes	160	725 (353%)	59	2 (1)	2 (1)
Miscellaneous diadromous fishes	488	615 (26%)	4	2 (1)	2 (1)

[1] Percentage production increase; [2] Data in parenthesis includes plants.

Source: FAO (2008a).

TABLE 9

Production by main species group in Europe and its contribution to total and fed aquaculture production

Production groups	Production 2000 (tonnes)	Production 2006 (tonnes)	Average annual percentage growth	% contribution to total aquaculture production in Europe in 2006	% contribution to total fed aquaculture production in Europe in 2006
Salmons, trouts, smelts	926 459	1 091 505 (18%)[1]	3.0	50.0	74
Carps, barbs and other cyprinids	197 405	185 946 (-6%)	-1.0	9 .0	13
Brackishwater fishes	113 000	15 000 (35%)	5.0	6.0	9

[1] Percentage production increase.

Source: FAO (2008a).

TABLE 10

Production of top 20 fed-aquaculture species and species group in Asia (thousand tonnes)

Rank order of species and species group by production in 2006	2000	2006	Average annual growth 2000–2006 (%)	% contribution to the total world fed aquaculture production in 2006	Unit value 2006 (US$/tonne)
Silver carp	3 394	4 312	4.5	13.1	838
Grass carp	3 315	4 003	3.5	12.1	1 191
Common carp	2 461	2 978	3.5	9.0	864
Bighead carp	1 628	2 393	7.8	7.2	887
Crucian carp	1 379	2 097	8.7	6.3	727
Other freshwater fishes	1 881	2 040	1.4	6.2	1 404
Whiteleg shrimp	2	1 815	15 108	5.5	3 574
Nile tilapia	854	1 629	15.1	4.9	1 014
Rohu	734	1 332	13.6	4.0	1 173
Catla	602	1 331	20.2	4.0	994
Giant tiger prawn	623	648	0.7	2.0	4 738
White amur bream	512	594	2.7	1.8	837
Milkfish	468	585	4.2	1.8	1 104
Pangas catfishes	100	500	66.6	1.5	1 496
Chinese river crab	232	475	17.4	1.4	5 192
Mrigal	552	360	-5.8	1.1	844
Black carp	171	351	17.6	1.0	1 712
Other marine fishes	443	314	-4.8	0.9	1 045
Amur catfish	5	310	1 005	0.9	955
Snakehead	0.22	304	23 425	0.9	836

Source: FAO (2008a).

In Viet Nam, high-priced freshwater pangas catfish and marine crustaceans increased their combined contribution of 36.5 percent (pangas catfish – 21.8 percent, marine crustaceans – 14.7 percent) in 2000 to 49.5 percent (pangas catfish – 29.7 percent, giant tiger prawn – 9.9 percent, whiteleg shrimp – 9.9 percent) in 2006 to total fed aquaculture production, while of other freshwater fish the contribution decreased from 57.8 to 46.8 percent over the same period (Figure 3). Percentage contributions of the main species to aquaculture production in Thailand are presented in Figure 4. Of the main contributing species in Thailand, production of high-priced crustaceans and carnivorous catfish increased from 15.1 percent in 2000 to 65 percent of the total fed aquaculture production, while the contribution of other freshwater fish remained static at around 28 percent over the same period (Figure 4). The contribution of high-priced crustacean to total fed aquaculture production in Indonesia almost doubled from 11.5 percent in 2000 to 22.4 percent in 2006 (Figure 5). Thus, marine crustaceans and carnivorous catfish have been recent major cultured species throughout the subregion. Another species worth mentioning is the Nile tilapia, which increased its share from 5.2 percent in 2000 to 14.0 percent in 2006 in Indonesia, while in Thailand it maintained its contribution to total fed aquaculture production at between 14 and 15 percent over the same period.

TABLE 11

Changes in production trends of key traditional and emerging species in main Asian aquaculture producing countries

Country	Percentage average annual change in production from 2000 to 2006													
	Traditional species									Emerging species				
	Silver carp	Grass carp	Common carp	Bighead carp	Crucian carp	Other freshwater fish	Nile tilapia	Rohu	Catla	Whiteleg shrimp	Mandarin fish	Freshwater swamp eel	Catfish	Red swamp crawfish	Salmonids
Bangladesh	6.5 (120 816)					3.8 (133 495)		7.3 (120 446)	7.5 (104 435)						
China	2.5 (3 227 944)	4.2 (3 162 634)	3.7 (2 119 762)	7.8 (1 613 972)	8.7 (1 375 378)	-7.6 (1 377 534)	12.8 (629 182)			153.7[1] (100 000)	17.9 (98 859	8.9[4] (125 336)	45.8[4a] (45 552), 13.7[4b] (54 819), 12.0[4c] (177 406), 7.5[4d] (212 103)	25.5[9] (51 593)	45.0[1]
India	407.3 (14 215)							13.8 (516 542)	22.8 (497 200)						
Indonesia			6.2 (180 202)			0.03 (40 492)	56.8 (40 836)			27.7[2] (53 217)			24.0[5] (31 629)		
Iran	25.0 (17 000)	80.2 (2 000)	29.4 (7 000)	26.4 (1 500)											69.0
Myanmar			11.0[1] (30 000)			35.5[3] (73 854)		19.0 (93 948)					317.0[6] (500)		
Philippines							17.8 (76 036)								
Thailand							14.3 (82 363)			119.4[3] (60 000)			15.4[7] (76 000), 14.0[7a] (21 577)		
Viet Nam						27.8 (265 015)				233.3[3] (10 000)			58.3[8] (100 000		
Taiwan Province of China										58.0 (2 310)					

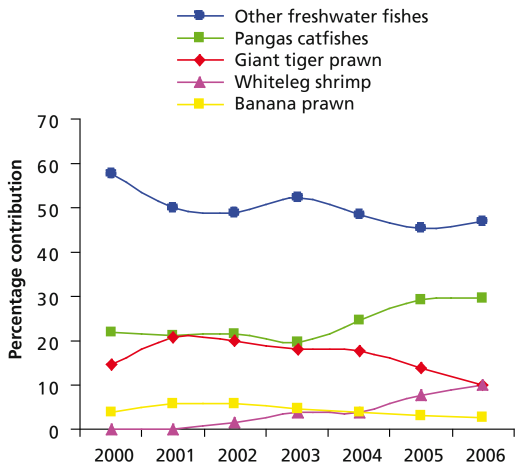
[1] % annual change in production (2001–2006); [2] % annual change in production (2004–2006), [3] % annual change in production (2002–2006); [4]% annual change in production (2003–2006), [4a]channel catfish % annual change in production (2003–2006), [4b] yellow catfish % annual change in production (2003–2006); [4c] snakehead % annual change in production (2003–2006); [4d] amur catfish % annual change in production (2003–2006); [5] torpedo–shaped catfish; [6] pangas catfish % annual change in production (2002–2006), [7] hybrid catfish; [7a]snakeskin gourami; [8] pangas catfish, [9] red swamp crawfish % annual change in production. (2003–2006).

Base year production figures (tonnes) are given in parenthesis.

Source: FAO (2008a).

FIGURE 3

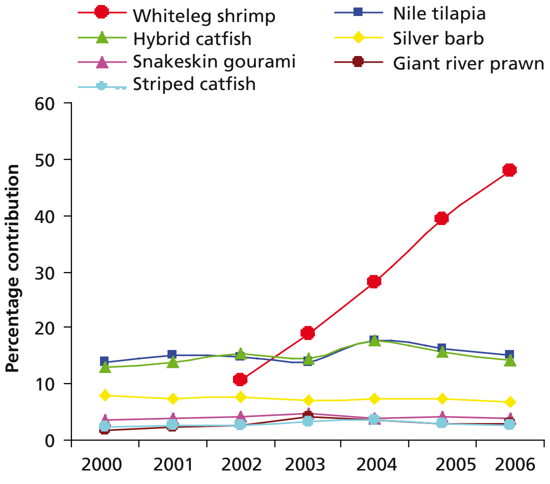
Percentage contribution of main species to aquaculture production in Viet Nam



Source: Adapted from FAO (2008a).

FIGURE 4

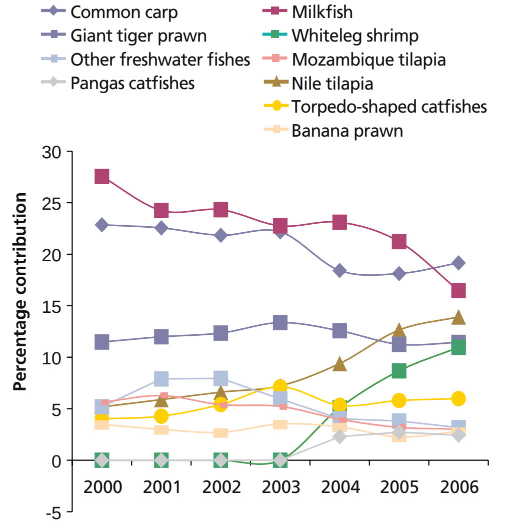
Percentage contribution of main species to aquaculture production in Thailand



Source: Adapted from FAO (2008a).

FIGURE 5

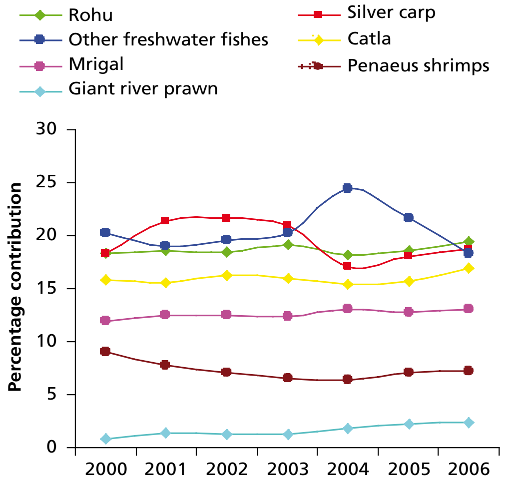
Percentage contribution of main species to aquaculture production in Indonesia



Source: Adapted from FAO (2008a).

FIGURE 6

Percentage contribution of main species to aquaculture production in Bangladesh

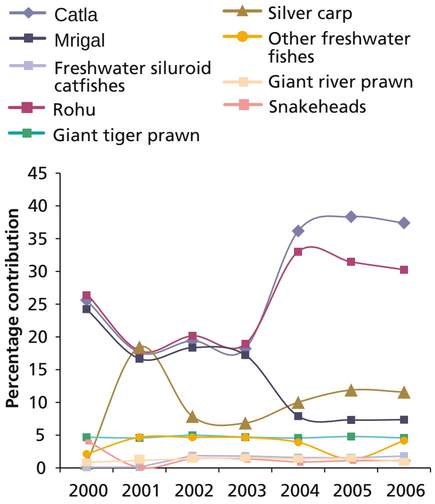


Source: Adapted from FAO (2008a).

Indian carps (rohu, catla and mrigal) provide the mainstay of aquaculture production in Bangladesh and India. Bangladesh maintained a contribution between 46 and 49 percent (Figure 6) to the total fed aquaculture production over the period 2000–2006 while India's contribution over the same period was around 75 percent (Figure 7). Recent years have also witnessed a rapid increase in the production of silver carp (a 25–fold increase 2000-2006) in India. Crustacean contribution to total fed aquaculture production declined in the leading aquaculture producing countries in the subregion in recent years except in Myanmar. In contrast to Bangladesh (59 143 tonnes in 2000 to 64 700 tonnes in 2006) and India (90 975 tonnes in 2000 to 130 155 tonnes in 2006), rapid growth in high-priced crustacean production was seen in Myanmar which recorded a 12–fold increase in production from 2000 to 2006 (from 4 964 to 60 000 tonnes) and made a 5.0 to 10.4 percent contribution to total fed aquaculture production over the same period (Figure 8). Thus, the potential demand for performance diets in

FIGURE 7

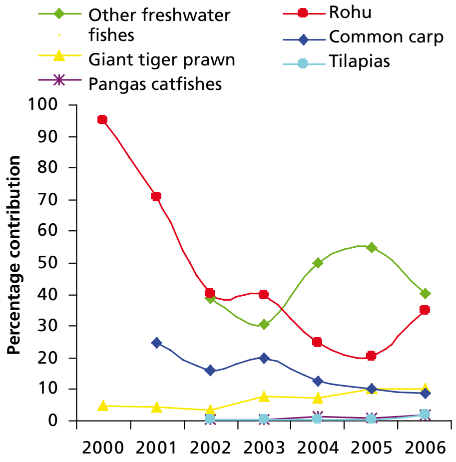
Percentage contribution of main species to aquaculture production in India



Source: Adapted from FAO (2008a).

FIGURE 8

Percentage contribution of main species to aquaculture production in Myanmar



Source: Adapted from FAO (2008a).

future in the subregion is localized and may not be as high as in the Southeast Asian subregion. However, the trend in switching from extensive to semi-intensive carp culture will increase the demand for feed ingredients.

1.3.2 Trends in intensification of aquaculture practices

Aquafeeds usually account for 50–70 percent of production costs. Therefore, for most farming operations, the price of fish influences the expenditures for inputs such as feeds and feed ingredients. In general, low-value freshwater species are cultured in extensive or semi-intensive systems that need great volumes of water and land area, and inputs may be limited to fertilizers and single-ingredient farm-made aquafeeds. Accordingly, productivity is lower than that of higher value-species cultured in intensive systems using commercially formulated aquafeeds. Land and water resources, however, are already in short supply in many leading aquaculture producing countries in Asia due to land tenure structures, urbanization and industrialization, and competing demand for land and water for irrigation, compounded by increasing human population.

Current world aquaculture production, particularly low-value species, is heavily dependent on land-based production systems. In China, production in ponds accounted for 77 percent of the total inland aquaculture production (Ye, 1996). In the last decade, pond culture contributed 70–90 percent of total freshwater aquaculture production in Thailand (WorldFish Center, 2004a). FAO (2000) reported that about 78 percent of Indonesian farming households cultivate fish in small ponds of less than 500 m^2, and aquaculture is the main source of income for 66 percent of the households that cultivate fish in the paddies and ponds (WorldFish Center, 2004b). The most important farming system in Viet Nam is pond polyculture commonly stocked with Chinese carps (silver carp, grass carp and bighead) in the northern region and river catfish, common carp and Indian major carps (rohu, mrigal) in the southern region (WorldFish Center, 2004c). In recent years, red tilapia is cultured in ponds by using an intensive monoculture system. In addition, an integrated VAC system (V: garden, A: fish pond, C: livestock) is also common in Viet Nam. Thus, it can be estimated that overall 70–80 percent of freshwater aquaculture production in leading aquaculture producing countries comes from ponds and, therefore, land-based aquaculture will play an important role in future world aquaculture production. The availability of and continued access to land as well as fish prices, however, will dictate the pace of intensification.

To illustrate the challenges of meeting the projected aquaculture production in 2020 in two leading aquaculture producing countries, China and India, an increase in pond area would be on the order of 75 and 310 percent, respectively, in 2006 (Table 12).

Similarly, procurement of water, particularly freshwater, required to expand aquaculture would be a challenge due to competing demands for freshwater by other sectors (as shown in Table 13) and increasingly limited water availability for development.

Margat (1996) estimated that fisheries (including aquaculture) as an economic sector uses water without significant consumption and, hence, water is not lost from the hydrosphere. Although in hydrological terms water consumption in aquaculture is low, in physical and qualitative terms, aquaculture may make water unavailable for

TABLE 12

Additional pond area required to meet the 2020 aquaculture production target in leading aquaculture producing countries in Asia

Country	Production of low-value species in 2006 (tonnes)	Average freshwater fish production (tonne/ha/year)	Approximate pond area under culture (ha)	Forecasted production (tonnes) of low-value species in 2020	Approximate increase in required new pond area (ha)	Reference[1]
Bangladesh	642 554	2.8–3.0 (semi-intensive)	221 570	927 300	319 760 (44%)	Barman and Karim (2007)
China	16 641 016	7.5–15/1.5 to 2 years (semi-intensive); 15–22/ 2 years (intensive)	2 971 610	29 139 000	5 203 393 (75%)	Weimin and Mengqing (2007)
India	2 704 883	4–6; 10–15 (semi-intensive)	541 000	8 398 700	1 679 740 (310%)	Ayyappan and Ahamad Ali (2007)
Indonesia	451 936	2.82	160 261	2 793 100 2 578 100	914 422 (470%)	FAO (2000)
Philippines	168 136	3–4 (catfish); 1.3–7 (semi-intensive tilapia); 7–15 (intensive tilapia)	40 515	1 297 800	312 723 (672%)	Sumagaysay-Chavoso (2007)
Thailand	196 198	3–6 (tilapia and catfish) 9–50 (intensive tilapia)		128 000		Thongrod (2007)

[1] References cite average fish production and approximate pond area under culture; production figures in column 2 are from FAO (2008a); forecasted production figures in column 5 are authors' computations based on values from Table 6; figures in column 6 are authors' computations.

TABLE 13

Water consumption for irrigation and industrial and domestic uses in selected leading aquaculture producing countries in Asia

Country	Irrigation (million m^3)		Industry (million m^3)		Domestic (million m^3)	
	1995	2025[1]	1995	2025[1]	1995	2025[1]
China	244 200 (85.0%)	230 900 (71.8%)	13 100 (4.6%)	31 100 (9.7%)	30 000 (10.4%)	59 400 (18.5%)
India	321 300 (91.9%)	331 700 (85.4%)	7 200 (2.1%)	15 700 (4.0%)	21 000 (6.0%)	40 900 (10.5%)
Indonesia	29 500 (73.7%)	30 300 (59.5%)	3 600 (9.0%)	7 100 (14.0%)	6 900 (17.2%)	13 500 (26.5%)
Philippines	15 900 (79.5%)	17 100 (62.4%)	2 800 (14.0%)	7 300 (26.6%)	1 300 (6.5%)	3 000 (10.9%)
Bangladesh	18 000 (87.8%)	19 200 (78.7%)	200 (1.0%)	500 (2.0%)	2 300 (11.2%)	4 700 (19.3%)
Thailand	24 100 (89.0%)	24 700 (78.4%)	1 100 (4.0%)	2 500 (8.0%)	1900 (7.0%)	4 300 (13.6%)
Japan	16 700 (56.4%)	14 800 (51.5%)	9 500 (32.1%)	10 300 (36.0%)	3 400 (11.5%)	3 600 (12.5%)
Viet Nam	10 200 (70.3%)	13 100 (69%)	2 500 (17.3%)	1 400 (7.4%)	1 800 (12.4%)	4 500 (23.6%)

[1] Forecast to 2025 is based on "business as usual" scenario; percentage of water consumption of total water use is given in parenthesis.

Source: Adapted from Rosegrant *et al.* (2002).

other uses. Therefore, we anticipate that aquaculture will compete with other economic users of freshwater as pressure on the national renewable water resources increases.

As a rough estimate, if the critical ratio of water withdrawal exceeds a quarter of actual renewable water resources of a country, water can be considered a limiting factor to development and, reciprocally, the pressure on water resources can have a direct impact on all sectors, from agriculture to environment and fisheries (FAO, 1997). Moreover, a high dependency ratio, meaning the proportion of water in a country that is received from external sources (see Box 1), indicates the vulnerability of a country to the effects of extraction, impoundment and pollution. A high dependency ratio will inevitably have important implications for water-sharing policies, cooperation and conflicts, while a low dependency ratio for a water-scarce nation means it has to make careful decisions on improving future internal efficiencies in water usage. The high percentage of the water withdrawal indicator (critical ratio) among the leading

BOX 1

Schematic representation of renewable water resources

Internal renewable water resources (IRWR) are generated from the endogenous precipitation (precipitation within the country) (Figure a).

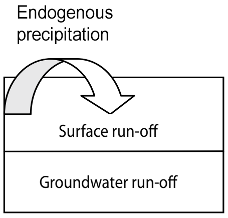


Figure a

The external renewable water resources (ERWR) are the water that enters from the upstream countries through rivers and aquifers (shared lakes, border rivers, transboundary flow) (Figure b).

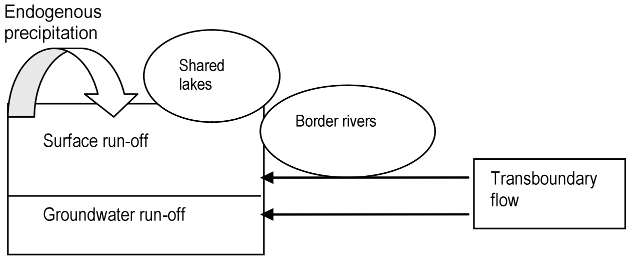


Figure b

The actual renewable water resources (ARWR) of a country is defined as the sum of IRWR and ERWR, taking into consideration the quantity of flow reserved to upstream and downstream countries through formal or informal agreements and treaties and possible reduction of external flow due to upstream water abstraction (Figure c).

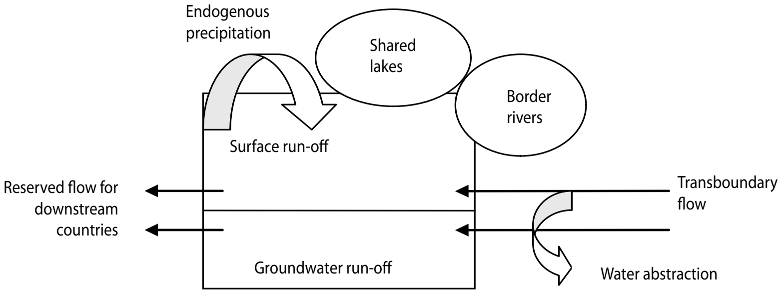


Figure c

TABLE 14
Some possible indicators for sustainable water resources development in leading aquaculture producing countries in Asia

Country	Some possible indicators for sustainable water resources development			
	Internal renewable water resources (IRWR) (million m^3)	Actual renewable water resources (ARWR) (million m^3)	% water withdrawal from ARWR	Dependency ratio
China	2 812 000	2 829 600	22.3	0.6
India	1261000	1 896 700	34.0	33.5
Indonesia	2 838 000	2 838 000	3.0	00
Philippines	479 000	479 000	6.0	00
Bangladesh	105 000	1 210 600	6.5	91.3
Thailand	210 000	409 900	21.2	48.8
Japan	430 000	430 000	20.6	00
Taiwan Province of China	67 000	67 000	-	00
Viet Nam	366 500	891 200	8.0	58.9

Source: Adapted from WRI (2008).

aquaculture countries in Asia, points to a possible water limiting factor for aquaculture development in China, India, Thailand and Japan and the high dependency ratio indicator for Bangladesh and Viet Nam may suggest increased competition from other sectors and countries with which they share this resource (Table 14).

In the light of probable increased competition for land and water throughout many aquaculture producing countries in Asia, there will inevitably be increasing pressure to improve productivity through intensification. This trend is already evident. The production of low-value (in marketing term) herbivore and omnivore species is changing rapidly from extensive to semi-intensive systems using low-cost farm-made aquafeeds. This is illustrated by the recent trend in global aquafeed production and number of farms dependent on aquafeeds. In 2003, global aquafeed production was estimated at approximately 19.5 million tonnes, but it is anticipated that it would increase to over 37.0 million tonnes by the end of this decade (Barlow, 2000). According to an estimate based on the aquafeed production of the seven leading aquaculture producing countries (Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam), this trend was also evident from the increase in the use of industrial aquafeeds from 10.3 million tonnes in 2003 to an estimated 22.2 million tonnes in 2013 in Asia alone (De Silva and Hasan, 2007).

It is also predicted that the usage of farm-made aquafeeds may go up over the next ten years, to 30.7 million tonnes in 2013 from 19.3 million tonnes, representing a growth of 60 percent from the 2003 level (De Silva and Hasan, 2007). In a recent analysis based on case studies in six leading Asian aquaculture producing countries, 50–70 percent of farms, with the exception of China, were dependent on farm-made aquafeeds. China's dependency was only 25 percent. The number of semi-intensive farms depending on complete commercial feeds is highest in India (74 percent) followed by China (46 percent) (Rola and Hasan, 2007). China and India together accounted for 90 percent of the world's carp and other cyprinid production, and 92 percent of Asia's carp and other cyprinid production, indicating a trend towards the mainstay of low-value species but semi-intensive farming using commercial complete feeds as opposed to feeds made on-farm. These developments suggest a trend towards increasing intensification of production and consequently increasing dependency on formulated complete diets.

1.4 FISH CONSUMPTION PATTERNS IN ASIA AND EUROPE AND THE IMPLICATIONS FOR THE USE OF FEED IN AQUACULTURE

During the 1990s, global apparent consumption of fish increased. The global average apparent per capita consumption increased from about 9 kg per year in the early 1960s to 16.3 kg in 1999 (WHO, 2002). The global per capita availability of fish and fishery products has, therefore, nearly doubled in 40 years, outpacing population growth. This

TABLE 15
Per capita fish consumption (kg/person/year) in Asia and Europe

Country	1985	1990	1995	2000	2003	Average growth (%)
Bangladesh	7.0 (6.0)	7.0 (6.0)	8.0 (7.0)	11.0 (10.0)	11.0 (9.0)	57 (83)
China	7.0 (2.0)	11.0 (4.0)	20.0 (7.0)	25.0 (10.0)	25.0 (10.0)	257 (400)
India	3.0 (1.0)	3.0 (1.0)	4.0 (2.0)	4.0 (2.0)	4.0 (2.0)	33 (100)
Indonesia	13.0 (3.0)	14.0 (3.0)	17.0 (4.0)	20.0 (4.0)	20.0 (4.0)	54 (33)
Japan	69.0 (4.0)	71.0 (5.0)	71.0 (5.0)	67.0 (5.0)	66.0 (5.0)	-4 (25)
Myanmar	14.0 (1.0)	15.0 (1.0)	14.0 (2.0)	18.0 (2.0)	18.0 (3.0)	29 (200)
Philippines	33.0 (5.0)	36.0 (5.0)	32.0 (4.0)	29.0 (4.0)	28.0 (5.0)	-15 (0)
Thailand	20.0 (3.0)	20.0 (4.0)	33.0 (6.0)	30.0 (7.0)	30.0 (7.0)	50 (133)
Viet Nam	12.0 (3.0)	13.0 (3.0)	16.0 (5.0)	19.0 (7.0)	17.0 (6.0)	42 (100)
Asia	10.0 (2.0)	12.0 (3.0)	16.0 (4.0)	17.0 (6.0)	17.0 (6.0)	70 (200)
South Asia	3.0 (1.0)	4.0 (2.0)	4.0 (2.0)	5.0 (3.0)	5.0 (3.0)	67 (200)
East and Southeast Asia	21.0 (3.0)	22.0 (3.0)	24.0 (4.0)	25.0 (4.0)	25.0 (5.0)	19 (67)
Europe	18.0 (1.0)	20.0 (1.0)	19.0 (2.0)	19.0 (2.0)	20.0 (2.0)	11 (100)
Western Europe	21.0 (1.0)	24.0 (1.0)	25.0 (2.0)	25.0 (2.0)	26.0 (2.0)	24 (100)
Eastern Europe	8.0 (1.0)	6.0 (1.0)	6.0 (1.0)	7.0 (1.0)	8.0 (1.0)	0 (0)
World	12.0 (2.0)	13.0 (2.0)	15.0 (3.0)	16.0 (4.0)	16.0 (4.0)	33 (100)

The number in parenthesis within the table denote freshwater fish consumption.

Source: Adapted from Laurenti (2007).

development was heavily dominated by events in China, which emerged as the world's largest fish producer during this period (Popkin, 2001). In fact, excluding China, the apparent consumption per person in the rest of the world actually declined from 14.4 kg in 1990 to 13.1 kg in 1999. However, it is important to note that such global figures mask the very wide differences among countries in the amount of fish used for food consumption (FAO, 2003) (Table 15).

In both Asia and Europe, the low proportion of freshwater fish in per capita fish consumption indicates the preference for marine (including brackishwater) fish. East and Southeast Asia, where aquaculture is growing fast, this trend is quite evident when fish consumption is compared with South Asia. A majority of the cultured marine species are high-value and depend on high-quality complete diets.

Driving forces that influence consumer behaviour and lead to an increase in the demand for various types of fish and meat are urbanization, lifestyle and dietary habits (Popkin, 1999). The forces that influence fish consumption, however, may vary between developing and developed countries. Delgado (1999) pointed out that in developing countries, increasing income and urbanization would be the leading factors for the increasing demand for fish and meat by 2020 (Delgado *et al.*, 2003). Lubchenco (2003) claimed that the increasing demand in developed countries is driven by increased consumer awareness of the health and nutritional benefits of seafood, increased standardization and availability of products and cheaper prices. The relationships between income and urbanization and fish consumption are clearly important factors to be taken into consideration in the calculation of future fish demand and type of fish as there is a trend in urbanization globally.

The increase in population between 2005 and 2030 is expected to be 1.7 billion. This increase will be primarily accounted for by the growth in the urban areas of less developed regions, which is expected to reach 3.9 billion from 2.3 billion in 2005 (UN, 2007). Unlike developing regions, developed regions had already attained high levels of urbanization by 1950 (Table 16). It is projected that similar levels of urbanization will take place in the developing world. Between 2000 and 2030, Asia's urban population will increase from 1.36 billion to 2.64 billion, that of Africa from 294 million to 742 million, and that of Latin America and the Caribbean from 394 million to 609 million. As a result of these shifts, developing countries will have 80 percent of the world's urban population in 2030 (UN, 2007). By then, Africa and Asia will host almost

TABLE 16
Proportions of urban and rural populations in the regions of the world

Area/region	Percentage urban			Percentage rural		
	1950	2000	2030	1950	2000	2030
Africa						
Eastern Africa	5.3	20.7	33.7	94.7	79.3	66.3
Central Africa	13.9	37.4	54.9	86.1	62.6	45.1
Northern Africa	24.8	48.9	64.1	75.2	51.1	35.9
Southern Africa	37.6	53.9	68.6	62.4	46.1	31.4
Western Africa	10.4	39.3	57.4	89.6	60.7	42.6
Asia						
Eastern Asia	16.5	40.4	62.5	83.5	59.6	37.5
South-central Asia	16.5	29.4	42.9	83.5	70.6	57.1
Southeast Asia	15.4	39.6	61.2	84.6	60.4	38.8
Western Asia	28.6	63.6	72.1	71.4	36.4	27.9
Europe						
Eastern Europe	39.2	68.3	73.7	60.8	31.7	26.3
Northern Europe	69.0	83.4	87.4	31.0	16.6	12.6
Southern Europe	45.1	65.4	74.3	54.9	34.6	25.7
Western Europe	62.3	76.2	82.6	37.7	23.8	17.4
Latin America & Caribbean						
Caribbean	36.0	62.1	72.6	64.0	37.9	27.4
Central America	39.3	68.8	77.6	60.7	31.2	22.4
South America	43.8	79.4	88.1	46.2	20.6	21.9
North America	63.9	79.1	86.7	36.4	20.9	23.3
Oceania						
Australia/New Zealand	76.2	86.9	91.5	23.8	13.1	8.5
Melanesia	5.4	19.2	27.6	94.6	81.8	72.4
Micronesia	31.6	65.7	76.6	68.4	34.3	23.4
Polynesia	23.7	41.1	53.2	76.3	58.9	56.8

Source: UN (2007).

seven out of every ten urban inhabitants in the world. With urbanization, people are increasingly drawn towards urban settlements and as both the level and distribution of income changes, the pattern of fish demand will change, with important implications for the demand for fish, and, in turn, implications for the type of feed used.

As Huang, Rozelle and Rosegrant (1997) suggest, increased urbanization may account for an increased demand for fish of 10 percent in China. Consumers are as diverse in their consumption preferences as the fish products they consume. The increasing demand in developed countries, where urbanization is high, has been mostly for high-value fish species. Thus, the demand for high-value species, which consume high-quality feeds, may increase in developing countries as urbanization increases. Although growth in all aquaculture sectors is increasing (see Section 1.2), it can already be seen that exceptionally high growth rates have occurred in the production of high-value and carnivorous species such as freshwater swamp eel, mandarin fish, channel catfish, red swamp crawfish and freshwater swamp eel.

The increasing supply of high-value species is associated with decreasing market price of high-value species. The decrease in market price of high-value species may be attributed to the promotion of intensive practices in recent years to increase production, development of complete commercial performance diets and the competitive market environment. For example, the rapidly increasing production of whiteleg shrimp has led to price depression in the international markets (FAO, 2006). Similarly, farm-gate value for 15–20 g size whiteleg shrimp has steadily decreased from US$5/kg in 2000 to about US$3.00–3.50/kg in 2005. The market prices of European seabass and gilthead seabream imported to Italy from Greece dropped from €7/kg in 1999 to €4.6/kg in 2007 and €6/kg in 1999 to €3.8/kg in 2007, respectively (Fish Site, 2007).

2. Status of and trends in aquafeeds with special reference to Asia and western Europe

2.1 IMPACTS OF RECENT MARKET VOLATILITY ON AQUAFEEDS IN WESTERN EUROPE AND ASIA

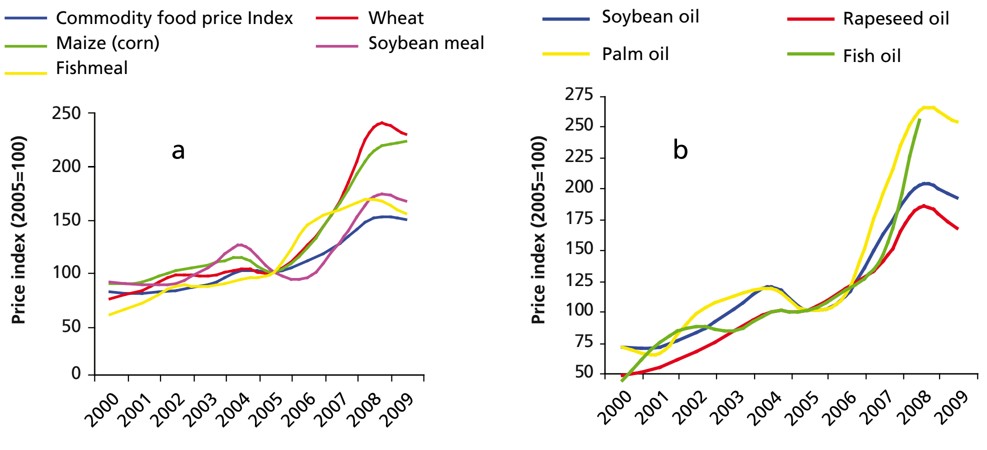
The aquafeed industry is reliant on a basket of common input ingredients such as soybean, corn, fish oil, rice and wheat for which it competes in the marketplace with other animal protein production sectors such as those raising beef, poultry and pork as well as those producing food for direct human consumption. Many of these key ingredients traditionally used in recipes for commercial and on-farm aquaculture feeds are internationally traded commodities and, therefore, aquafeed production is also subject to any global market shocks and volatility. Since 2005, the basket commodity price index (CPI) rose by about 50 percent (Figure 9). During the same period, the price of soybean meal, fishmeal, corn and wheat rose by 67, 55, 124 and 130 percent, respectively (Figure 9a). Similarly, the cost of major oils used in the feed industry increased by up to 250 percent (Figure 9b). The price of these ingredients has increased dramatically since the millennium but the rate of price increase has occurred in two phases; a steady gradual increase in prices until around 2004 followed by a dramatic exponential rise and then slight fall in the latter half of 2008 (Figure 9). The major drivers impacting on the prices of ingredients commonly used in aquafeeds are outlined below.

2.1.1 Trends in fuel costs and impacts on aquafeed production and use

The escalation in demand for commodity feed ingredients coincided with the dramatic increase in fuel prices since 2004, peaking at over US$130/barrel in July 2008 (Figure 10). Since 2005, the price index for crude oil soared to 250 percent but slipped back to around US$ 50/barrel by the end of 2008, before rising again

FIGURE 9

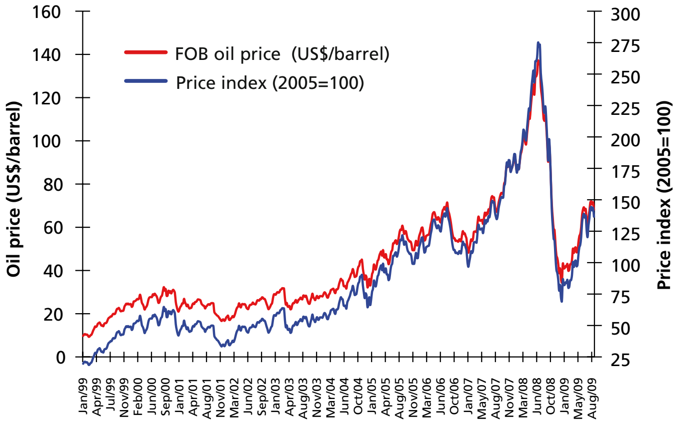
Price index (2005=100) of key (a) food commodities and grains and fishmeal and (b) plant and fish oils, used for animal feeds and human consumption



Source: Adapted from International Monetary Fund (2009).

FIGURE 10

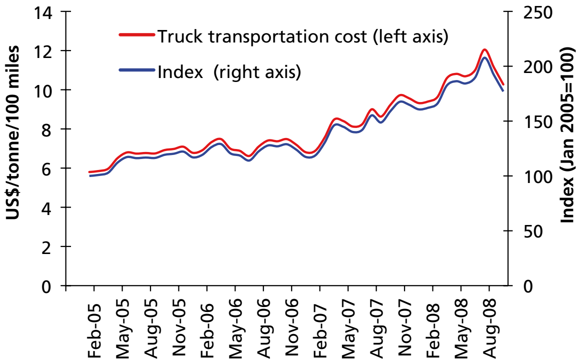
Escalation of crude oil prices



Source: Adapted from Energy Information Administration (2009).

FIGURE 11

Monthly truck transportation cost of soybean in Brazil



Source: Adapted from USDA (2009).

to $70/barrel. This rise in fuel costs impacted heavily on transportation and production costs of those industries relying on feed ingredients and other commodities, leading to an increase in the landed cost of those ingredients. The key commodities used in aquafeed production are corn, soybean, fishmeal and oil, all of which are largely sourced from the Americas, notably Brazil, the United States of America, Chile and Argentina, and have to be shipped to major markets. In Brazil, where production areas can be over 1 000 miles from sea ports, trucks are predominantly used to transport soybean. The cost of this transportation, illustrated in Figure 11, has also escalated owing to rising fuel prices. The cost of land transportation has doubled from US$6/100 miles in January 2005 to over US$12/100 miles in July 2008 (Figure 11). Similarly, fuel prices further impacted on the landed costs of feed ingredients due to increased sea freight costs. Thus, total transportation costs increased substantially.

In Brazil, for example, the total cost for transporting 1 tonne of soybean increased by 35 percent in just two years, from US$127 in 2005 to US$171 in 2007. Rising demand and production costs increased the farm value of soybean by 42 percent. Rising oil prices impacted on the costs of fertilizers, equipment and operations. Triple super phosphate and urea prices, for example, rose from US$202 to US$909/tonne and US$223 to US$509/tonne from 2006 to 2008 (July), respectively. Overall, the landed cost of soybean from Brazil increased by 39 percent in just two years (Table 17). Trucks are predominantly used to transport soybean in Brazil. The cost of this transportation has escalated owing to rising fuel prices and is illustrated in Figure 11. Since January 2005, the cost of land transport increased by 23 percent (Figure 11).

In addition to fuel hikes, the sharp rise in sea freight was compounded by the concurrent increasing demand mainly by China for dry and container cargo ships for transportation of coal, iron ore and grain. The Baltic Exchange Dry Index, an internationally recognized measure of sea freight cost, rose from 5 000 in January 2005 to over 11 000 in July 2008.

2.1.2 Diversification of human eating habits and new uses of traditional commodities and the implications for aquafeed

The price shocks were an unusual confluence of several primary and secondary factors, which disrupted the global demand and supply balance of the commodities used for feed ingredients. The impact has been greatest since 2000. Over the last

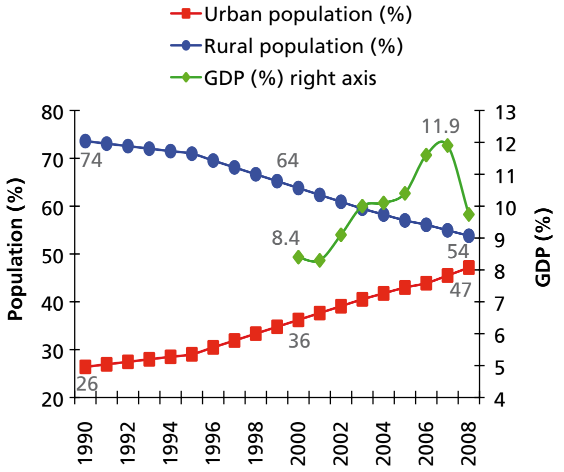
TABLE 17
Cost of transporting soybeans from Brazil (Santos) to Hamburg, Germany

	2005	2006	2007	Percent change since 2005
	US$/tonne			
Truck	79	79	98	23
Ocean	48	47	73	56
Total transportation	127	126	171	35
Farm value	164	165	234	42
Landed cost	291	291	405	39
Transport % of landed cost	44	43	43	-2

Source: USDA (2009).

decade, the strong increase in economic growth, especially in developing countries, together with the increase in population size, have raised the demand for food. While the economic growth of developed countries declined from 3.6 to 2.2 percent per year between 2000 and 2007, the economies of developing countries, especially Asian countries, grew at a staggering rate of 7 to 10 percent per year in the same period (International Monetary Fund, 2009). The increase in disposable income and prosperity was also accompanied by a notable shift in the dietary preferences of consumers in these countries as they diversified their diets to include more meat, fish and milk products, which consequently increased the demand for grains, the principal ingredient used in animal feeds. The poorer conversion ratios of feed to meat of around 2–8:1 compared with that of feed to fish of around 1–2:1 amplified the demand for the common aquafeed ingredients. Moreover, these changes occurred in the most populous countries in the world, notably in China, which had the greatest impact by skewing the global distribution of grain commodities. The impact of China, therefore, is discussed here as a special case.

FIGURE 12
Demographics and economic growth of Chinese population



Source: Adapted from National Bureau of Statistics of China (2009).

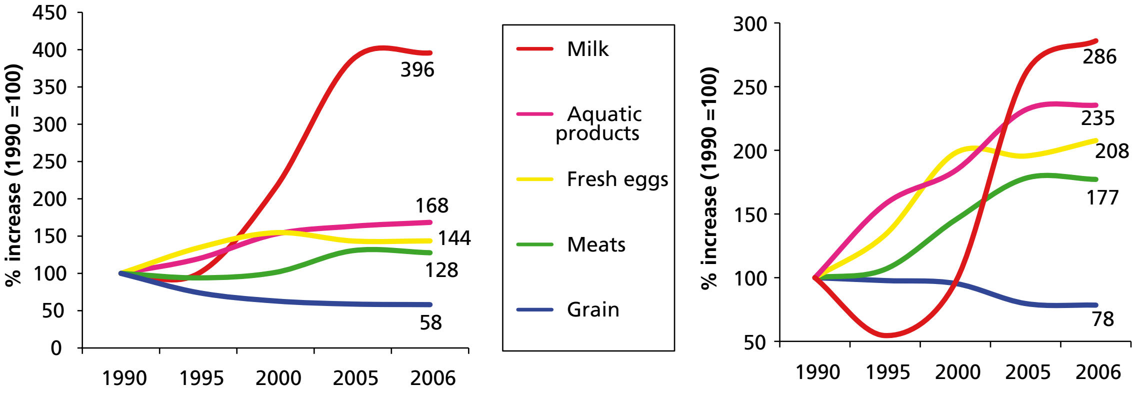
The demands placed by China on world commodity supplies used in aquafeeds were also fuelled by internal demographic and structural changes (Figure 12). Growth of the urban population averaged 4.3 percent per year from 1990 to 2006 and was expected to reach 6 percent per year by 2008. Urban population, which was 36 percent of total population in 2000, reached 44 percent in 2006 and 47 percent in 2008 (Figure 12). There was a concomitant decline in rural population by 20 percent, from 74 percent in 1990 to 54 percent in 2008 (Figure 12). These changes should be seen also in the context of differential per capita income and purchasing patterns between the rural and urban populations.

The per capita income of a person in an urban area is significantly greater than that of a person in a rural area and has risen at a significantly higher rate. Between 2000 and 2006, urban per capita annual income increased by 90 percent, from RMB6 280 to RMB11 760, compared with an increase of rural per capita annual income of 60 percent, from RMB2 253 to RMB3 600. Such an increase in affluence facilitated shifts in dietary lifestyle, with huge increases in the consumption of meat and milk products accompanied by a decline in grain consumption (Figure 13). In urban populations, consumption of milk, aquatic products, eggs and meat increased by 296, 68, 44 and 28

FIGURE 13

Increase in per capita annual purchases of major commodities in urban (left) and rural (right) households

(1990 =100. Kg values in 1990 for milk, aquatic products, eggs, meats and grain in urban area were 4.6, 7.7, 7.3, 25.2 and 131, respectively, and in rural area were 1.1, 2.1, 2.4, 12.6, 262)



Source: Adapted from National Bureau of Statistics of China (2009).

percent, respectively, from 1990 to 2006, while in the same period in rural areas increase of consumption of these same items were 186, 135, 108 and 77 percent, respectively (Figure 13). To meet this demand, animal production absorbed a significant tonnage of grains. Furthermore, the demand for oils (soybean, rapeseed and palm oil) also increased dramatically. Against this backdrop of sharply rising demand in China as well as in other populous developing economies such as India, the demand for all ingredients used in aquafeeds exerted significant upward pressure on prices. The rate of supply, however, did not keep pace with demand and key reasons for these are mentioned later.

2.1.3 The impact of climate change on the supply of aquafeed ingredients

Plant ingredients used in aquafeeds

The uncertainly concerning the availability of traditional fishmeal and fish oil and rising prices have required major industrial aquafeed manufactures to identify and evaluate alternate protein and oil sources and considerable progress has been made in recent years on substitution of fish protein and oil with proteins and oils of plant origin.

Grain crop yields, as with other arable crops, when negatively affected by variable and adverse weather conditions, increase uncertainty about grain supplies and prices. Therefore, the reliability of grain supplies for aquafeeds in the future will be influenced by short-term weather patterns and long-term predicted global warming directly through its impact on crop yields, crop pests and diseases, and soil fertility and condition. Supply will be also influenced by climate change indirectly through its impacts on economic growth, income distribution and agricultural demand (Schmidhuber and Tubiello, 2007).

During the last few years, unpredictable weather resulted in a critical shortfall of major grain and oilseed ingredients used for on-farm aquafeeds as well as for complete commercial diets. Unfavourable weather reduced crop yield and production in some countries in 2006. The crop yields in the Russian Federation and Ukraine were markedly lower due to drought. Australia encountered two years (2006 and 2007) of severe drought and South Africa also experienced drought. Consequently, the reduced world production and supply of grains and oilseeds contributed to a further decline in the global stock-to-use ratio for aggregate grains and oilseeds, and also to rising prices. In September 2006, maize prices began a significant rise to a new high.

Adverse weather patterns continued into 2007 negatively affecting yields and global grain supplies on most continents and in a great number of key countries supplying global markets with aquafeed ingredients such as rapeseed, soybean and grains. Northern Europe encountered a dry spring and floods during harvesting time, while southeast Europe suffered a drought. The droughts of 2006 in Ukraine and the Russian Federation continued into 2007. Turkey also experienced drought in 2007, which reduced yields in rain-fed production areas. In the Americas, a late heavy freeze over several consecutive days destroyed large tracts of hard red winter wheat and in the United States of America reduced yields over large areas, while in Canada, a hot and dry summer growing season resulted in lower yields for wheat, barley and rapeseed. In South America, a late freeze followed by a drought in Argentina reduced corn and barley yields (see Box 2). Droughts in northwest Africa and Australia in 2007 also affected major growing areas. The accumulative result of bad weather in 2007 resulted in the second consecutive drop in global average yields for grains and oilseeds, causing a further decline in the global stocks-to-use ratio and creating uncertainty among importers about the future availability of supplies. This placed an upward pressure on prices of plant proteins and oils used as aquafeed ingredients.

In 2009, a La Niña weather event affected crop production in the Southern Hemisphere, bringing rains to the main arable areas of Australia, serious drought to Argentine wheat production areas, reducing production by 48 percent, and sufficient rain for cereal crops in South Africa. This weather event, which was characterized by low surface-water temperatures in the Equatorial Pacific, was expected to continue well into March and April 2009. The predictably of rainfall can also affect supplies of grains. In Australia, in 2009, intermittent rain during the growing season and heavy rains during harvesting time reduced crop yields and available supplies of wheat.

It is now widely acknowledged that global weather patterns are unstable and that the frequencies of adverse climatic conditions are likely to increase. Climate change, which is being driven by global warming caused mainly by carbon emissions from industrialized countries, will continue to influence temperature and precipitation patterns around the world. This, in turn, will place severe upward pressure on water supplies in water-stressed regions of the world and may result in shifts in geophysical growing areas for the major protein crops and oil-plant crops yields of which are used in aquafeed production.

The effects of changing weather patterns are complex and several models have been developed to predict the degree of impact of such climate change on agricultural output. All models use varying assumptions (for a comprehensive review see Cline, 2007). The key assumption is that carbon concentrations in the atmosphere will increase as a result of greenhouse gas emissions from the current (2007) 365 ppm to above a threshold of around 585 ppm, reaching 735 ppm by 2080. This would foster increased production through increased photosynthetic activity, a phenomenon referred to as carbon fertilization, and hence increased yields (Cline, 2007). This positive effect, however, is reduced and reversed when the atmospheric temperature rises above 12–14°C. By combining information on carbon fertilization with information on changes in average annual temperatures and precipitations, Cline (2007) predicted the potential impact of these changes on national agricultural output.

At the regional level, assuming carbon fertilization occurs at the predicted rate, agricultural output in industrialized nations will rise by a predicted 7.7 percent, whereas that of developing countries will decline by 9 percent. Similarly, in sub-Saharan Africa (SSA), Asia and Latin America, the output is predicted to fall by 17, 7, and 13 percent, respectively. Thus, SSA and Latin America are the two developing regions most vulnerable to global warming. Countries such as Brazil and Argentina in Latin America, the United States of America and Canada, the Russian Federation, China, India, Malaysia, Indonesia and Australia are major producers and global

BOX 2

Impact of climate volatility on supplies and prices of aquafeed ingredients export and import regions

The price of grain commodities is also notably influenced by the futures trading market and forward buying of grains, a strategy to mitigate against price volatility. Such price forecasting, however, is also influenced by predictions of future yields and supplies. Another factor that is closely tracked for price forecasting is rainfall volumes and patterns, and droughts.

Due to unprecedented droughts in 2008–2009 in Brazil, Argentina and Paraguay, these countries are likely to reduce outputs and this would coincide with the recent credit crunch that forced farmers to reduce fertilizer purchases, which will likely result in reduced yields. The soybean and corn crops in Brazil and Argentina, the two largest soybean and corn exporters after the United States of America, suffered drought during critical stages of growth. According to weather station reports some areas were subjected to the worst droughts since 1971. It is estimated that in Argentina the soybean crop will be lower than last year's crop by 17 25 percent and Brazilian corn and soybean output may fall by 10 million tonnes.

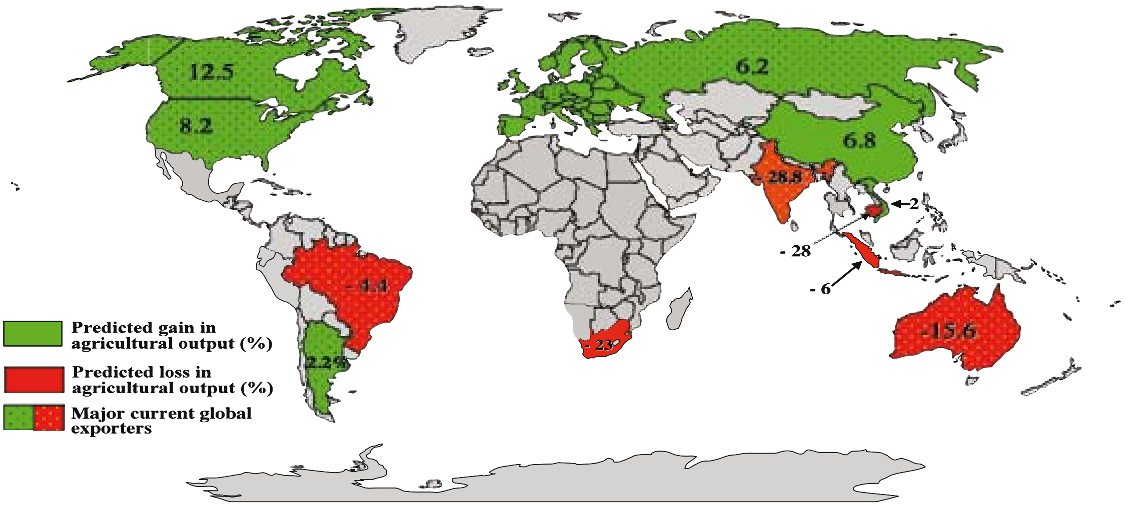
Droughts in the spring of 2009 in several parts of Europe, in particular eastern Europe, reduced outputs of wheat, putting greater reliance on imports to fulfil demands. Poor rainfall is likely to reduce EU total grain output by 4.5 million tonnes.

Reduced output of grains used in aquafeeds is also predicted for China and this is attributed to climate change. In 2006, the Government of China predicted a 37 percent reduction in corn, wheat and rice outputs in the next 20–50 years due to greenhouse effects. In 2007, the state meteorological administration predicted that China would need an additional 10 million ha by 2030 to compensate for impacts of global warming at a time when availability of farmland is diminishing due to urbanization. Rising temperatures are expected to negatively impact on rainfall amounts and distribution, and exasperate water supply as a result of increased evaporation. The evaporation rate from the currently stressed Yellow River is predicted to increase by 15 percent. In 2009, widespread drought across key soybean growing areas was also expected to reduce production by 3.2 percent.

Source: Adapted from: www.efeedlink.com

FIGURE 14

Impact of climate change on predicted agricultural output in 2080 showing main producing and exporting countries



Source: Adapted from Cline (2007).

suppliers of key protein and oils used in aquafeeds. These predicted changes, which show intraregional variation (Figure 14), show production gains for high-latitude countries and production losses for lower-latitude countries, mainly developing nations. To mitigate against such probable losses, countries can limit their losses due to climate change by switching to agricultural imports rather than growing the products imported (Cline, 2007).

Under the present scenario of global warming, the current dependency on imported aquafeed ingredients, such as soybean, maize, rice, wheat, palm oil and rapeseed, is likely to remain and will most likely increase because climate change and pressure on local land resources will reduce the probability of self-sufficiency. Moreover, because the main suppliers of soybean, maize and wheat are the United States of America, Brazil and Argentina and the main consumer markets are in Europe and Asia, these supplies will always be vulnerable to price swings due to fuel and transport price volatility (see section 2.1.1) and it is highly unlikely that prices of such commodities will reduce to pre-2000 levels for the foreseeable future.

2.1.4 Other factors affecting supplies and prices of key grain ingredients for aquafeed production

Grain production was limited due to (i) a gradual decline in acreage under grain cultivation; (ii) uncertainties about water availability for agriculture; (iii) a reduction in state research on crop yields; (iv) adverse weather conditions resulting in destruction of infrastructure for fishmeal processing plants; and (v) disease resulting in crop loss. The demand for ingredients for aquafeeds increased gradually until around 2004, and even though farm yields increased, supply could not keep pace with demand.

While the production of grains increased, although well below demand levels, the supply of fishmeal and fish oil from main producing countries such as Scandinavia, Peru and Chile into the world market diminished, putting greater upward pressure on prices of fishmeal and fish oil. Overall, the proportion of fish catch reduced for fishmeal is declining in favour of fish use for direct human consumption. In addition, lower fishing quotas for capelin, mackerel and blue whiting in Scandinavia contributed to a decline in exports from 504 000 tonnes in 2005 to 429 000 in 2008. Similarly, in South America, exports declined from 1.96 million tonnes to 1.51 million tonnes over the same period.

The price increases and availability of grain have compelled aquafeed manufactures to mitigate against these uncertainties to secure ingredients. In Europe, where aqua farming practices are predominately intensive and in Asia, where many commercially important species are farmed intensively, it is helpful to understand the structure of the commercial aquafeed industry and the sector segment it serves.

The prices were further aggravated by a series of concomitant short-term shocks. Since 2004, however, as world stocks of grains used in aquafeeds began to decline, countries like China that have huge foreign currency reserves began to import and stockpile fishmeal and other proteins and oils to secure supplies and this in turn exasperated the prices of these commodities on the world market.

In addition to high base prices on the global market, competition between the aquaculture sector and the animal husbandry sector (cattle, poultry and pigs) for key ingredients such as fishmeal caused added upward pressure on grain prices. In 2002, the aquaculture sector used 46 percent of the fishmeal on the world market, while the pigs and poultry sectors used 24 percent and 22 percent, respectively (FIN, 2007). It is expected that aquaculture will use 56 percent of the fishmeal on the world market by 2010.

2.2 TYPOLOGY OF COMPOUNDED AQUAFEED PRODUCTION IN WESTERN EUROPE AND ASIA

2.2.1 Major players of compounded aquafeed production

Profile of the aquafeed industry in Europe

Unlike in Asia, the farming of finfish in western Europe is exclusively intensive and dependent upon and driven by the use of compounded industrial feeds. Atlantic salmon, rainbow trout, seabass and seabream are the four species that dominate in European aquaculture. In 2006, production of these species totalled over a million tonnes and accounted for 81 percent of total finfish production in Europe. Moreover, salmon accounted for 54 percent (783 000 tonnes) of European finfish production. Feed manufactures, therefore, strategically monitor such developments to position themselves in geographic hotspots of production and historically around centres where key raw ingredients are produced, e.g. fishmeal and oil.

The feed industry in Europe has closely followed the market development of Atlantic salmon (and to a lesser extent rainbow trout), which is predominantly concentrated in Norway, Scotland, and to a lesser extent in the Faroe Islands and Ireland. These four northern European countries collectively accounted for 890 000 tonnes of salmonids in 2006 and over a million tonnes in 2007 (FAO, 2008b).

The aquafeed industry in Europe serving these markets is highly consolidated with three companies, Skretting, Ewos and BioMar, dominating the salmonid feed market (Table 18). In 2007, these companies manufactured over 96 percent or 1.3 million tonnes of the industrial feed used for salmon and trout production in northern Europe. In 2007, over 2.1 million tonnes of feed was used in Europe (Table 18). Details on the impact that rising prices of ingredient has had on the industry is difficult to determine because of company confidentiality. A seven and 13 percent increase in revenue for 2004 and 2006, respectively, were attributed to higher feed prices, was largely attributed to higher ingredient costs as raw materials account for 75 percent of feed production costs (Nutreco Annual Reports, 2004, 2006 and 2007; BioMar Annual Report, 2007).

TABLE 18
Key feed manufacturers and estimated industrial aquafeed production and market share

	Market share in 2007 (%)	Feed tonnage in 2006	Feed tonnage in 2007
North Europe (NE)[1]			
BioMar	23	300 000	316 250
Ewos	30	412 500	412 500
Skretting	43	500 000	591 250
Others	4	37 500	55 000
Total (tonnes)		**1 250 000**	**1 375 000**
NE (% of total)		**65**	**65**
Rest of Europe (RE)[2]			
BioMar	18	128 250	137 000
Skretting	18	128 250	130 500
Provmi	9	60 750	65 250
Persus	7	47 250	50 750
Didaq	6	40 500	43 500
Aller Aqua	5	33 750	36 250
Feedus	4	27 000	29 000
Others	33	209 250	239 250
Total (tonnes)		**675 000**	**725 000**
RE (% of total)		**35**	**35**
Total aquafeeds in NE + RE (tonnes)		**1 925 000**	**2 100 000**

[1] NE = Norway, Scotland, Ireland and Faroe Islands

[2] RE = >1000 tonnes: Denmark, Finland, France, Greece, Italy, Poland, Spain, Sweden, Germany, the Russian Federation, Turkey, Czech Republic, Croatia, Switzerland, the Netherlands

Source: Estimates extrapolated from BioMar Annual Report (2008).

Profile of the aquafeed industry in Asia

Unlike aquaculture in Europe, the species that dominate aquaculture in Asia are very diverse, with over 200 species being reportedly farmed in a range of culture systems using extensive to intensive practices. The trend in the mainstay of national aquaculture output from Asia, however, is similar to Europe and only a few species comprise reported aquaculture output at the national level (Table 19). In most major producing countries, over 70 percent of production is of just two or three species or species groups

TABLE 19

Main species that contribute at least 80% of national total aquaculture production in leading Asian countries in 2006

Country	Species/species groups[1,2]	No. species/ species groups	Contribution (%)	Main species tonnage (thousand tonnes)	National total aquaculture production (thousand tonnes)
Japan	*Japanese amberjack* (51) *Silver sea bream* (24) *Japanese eel* (7)	3	82	292.5	301.5
Myanmar	Freshwater fishes (40) Indian carps (35) *Penaeus shrimps* (10)	3	85	558	575
Bangladesh	Indian carps (49) Silver carp (19) Freshwater fishes (18) *Penaeus shrimps* (7)	3	93	866	893
Viet Nam	Freshwater fishes (47) *Pangas catfishes* (30) *Penaeus shrimps* (20)	3	97	1 466	1 512
India	Indian carps (75) Chinese carps (12) *Penaeus shrimps* (5)	3	92	3 029	3 123
Philippines	Milkfish (54) Nile tilapia (27) Other tilapias (7) *Penaeus shrimps* (7)	4	95	569	587
Thailand	*Penaeus shrimps* (48) Nile tilapia (15) Catfish, hybrid (14) Silver barb (7)	4	84	991	1 021
Taiwan Province of China	Tilapias (34) Milkfish (26) *Japanese eel* (11) *Penaeus shrimps* (5) Giant river prawn (5) *Groupers* (4)	6	85	210	217
Indonesia	Common carp (19) Milkfish (17) Nile tilapia (14) *Penaeus shrimps* (22) Torpedo-shaped catfishes (6) Freshwater fish (3)	6	81	1 254	1 293
China	Chinese carps (44) Common carp (11) Crucian carp (9) Nile tilapia (5) *Penaeus shrimps* (5) Freshwater fish (3) White amur bream (3)	7	80	21 970	22 650
Total production				**31 205.5 (97)**	**32 172.5**

[1] Values given in parenthesis are percentages of total national reported production.

[2] Species/groups in italics above are known to be farmed predominantly with commercial feeds.

Source: Adapted from FAO (2008b).

(Table 3). In 2006, around 97 percent (31 million tonnes) of production was of only a dozen species/species groups.

Mass production of these species in Asia is dependent on aquafeeds and some species are dependent almost exclusively on commercial aquafeeds and are under semi-intensive to intensive conditions. These species are highlighted in italics in Table19.

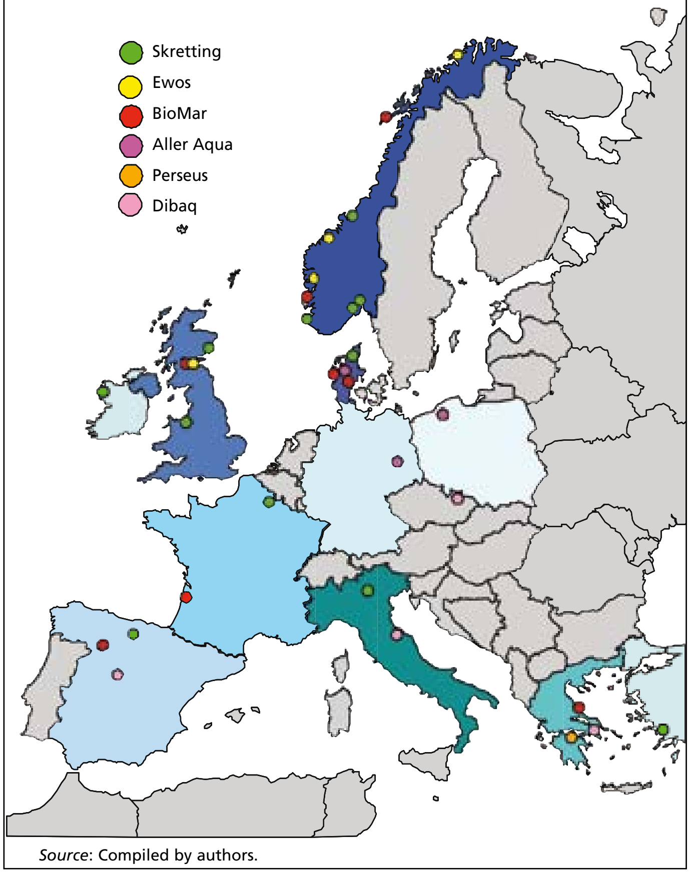
Although the current discussion about the use of animal proteins as aquafeed ingredients still largely focuses on the finite fishmeal and fish oil resources, the sustainability of aquaculture is more likely to be linked with the use of vegetable proteins and oils, and carbohydrate raw materials for aquafeeds, particularly because a significantly large proportion of production is of non-carnivorous aquatic species. In the coming years, developing countries are more likely than developed countries to be adversely impacted, if vegetable ingredients for aquaculture are not produced and sourced locally. The rising prices of key vegetable ingredients used in the aquafeeds on the international market are illustrated in Figure 9. In view of current trends, the local competition for these vegetable-based aquafeeds/ingredients will also increase as populations and disposable income in developing countries increase, as is evident in China (Figure 13) where the demand for meat and milk products, which require substantial volumes of grains to produce, continues to rise.

2.2.2 Production and distribution channels of aquafeed

Distribution of aquafeed in Europe

The major feed manufacturers are concentrated in main fish farming areas and historically near the suppliers (Norway and Denmark) of fishmeal. In Europe aquafeed needs are serviced by five main feed manufacturing companies with plants in Norway, Denmark, the United Kingdom, Ireland, Spain, France, Germany, Poland, the Czech Republic, Greece and Turkey (Figure 15). Of the three largest feed manufacturing companies, Skretting and Ewos focus on providing salmon aquafeeds for the much consolidated salmon and trout industries, while BioMar has a portfolio of aquafeeds for a more diverse number of species. These three companies account for around 90 percent of feed production in Europe.

FIGURE 15
Distribution of key aquafeed manufactures in Europe



Source: Compiled by authors.

Skretting is the largest aquafeed manufacturer, with Europe accounting for 64 percent of its global fish-feed revenue in 2008. Factories in Norway, Scotland and Ireland deliver to their respective markets. Skretting's three production plants in Norway, with a production capacity of 500 000 tonnes in 2008, mainly deliver to the Norwegian market.

Ewos, with aquafeed production plants in Norway (three plants producing 415 000 tonnes in 2008) and one plant in Scotland, is the second largest feed producer in Europe and has a European market share of around

25 percent. The markets of the four plants are highly concentrated in Scotland and Norway with feed plants delivering nationally.

BioMar group is the third largest supplier of fish feed to the European aquaculture industry, with 18 percent of the European market share, supplying 410 000 tonnes of feed in 2007 in Europe for salmon and trout in Norway and the United Kingdom and for freshwater trout (308 000 tonnes), seabass and seabream in continental Europe (102 000 tonnes). Feed factories in Norway and Scotland supply the 200 farming companies and 15 consolidated companies in Scotland, as well as Ireland and the Faroe Islands. The industry in Scotland and Norway is also highly consolidated, increasing the buying and bargaining power of these companies. Approximately 61 percent of the combined volume of the two BioMar factories in Norway and 95 percent of the volume of the one BioMar factory in the United Kingdom supply the five largest customers of BioMar (BioMar Annual Report, 2008).

BioMar has three feed production factories in continental Europe: Denmark, France and Greece. The five largest customers supplied by these three factories account for about 25 percent, 42 percent and 81 percent of volume of these factories, respectively.

BioMar's most important markets in the region are Denmark, Finland, France, Greece, Italy, Poland, Spain, Sweden and Germany. Its plants also deliver feeds to other European countries such as Bosnia and Herzegovina, Bulgaria, Estonia, Croatia, Latvia, Lithuania, Macedonia, Morocco, Romania, the Russian Federation, Switzerland, Serbia, Slovakia, Slovenia, the Czech Republic, Turkey and Austria.

Aller Aqua, which specializes in quality trout and freshwater fish feeds, has three centres of production located in Denmark, Germany and Poland, each serving specific regions in Europe. From Denmark, Aller Aqua delivers to the Russian Federation, Italy, Ireland, Sweden and Norway, while its centre in Germany supplies Germany, Turkey, Spain and Portugal. Operations in Poland focus on Poland and Eastern Europe.

Dibaq, a Spanish company, has four main production centres in Spain, Italy, the Czech Republic and Greece, each focusing on distributing to specific subregions. The centre in Spain supplies feeds to Spain, France, Portugal, Bulgaria, Romania and Morocco. The centre in Italy supplies Italy, Croatia, Serbia and Malta; the Czech Republic supplies the Czech Republic, Germany, Poland and Slovakia; the centre in Greece focuses on the home market.

2.2.3 Recent trends in the prices of compound feeds

Prices of aquafeed for indicator species in Asia and western Europe

The trends in the use of aquafeeds, both farm-made and manufactured commercial feeds, are discussed in Section 2.3. Moreover, current use of aquafeed in terms of quantities and predictions for future requirements are given in Table 20. Some feed and ingredient prices are given in Tables 21 and 22. As a result of the intensification of fish farming and the introduction of new species in aquaculture there tends to be more dependency on commercially manufactured compound feeds. Manufactured compound aquafeed prices vary from a few hundred dollars to over US$1 000/tonne depending on the species being fed. Aquafeeds for high-value and carnivorous species are in the higher price range. Farmers may be constrained from using commercial compound aquafeeds when prices of certain high-value species (see Section 1.4) fall and other freshwater fish species fetch low prices in the process of intensifying culture practices. Moreover, aquafeed prices, especially that of commercial compound aquafeeds, may increase from their current level due to increasing prices of ingredients (Table 23) and shortfalls in local supplies. This situation compels the users to import feeds. Commercial feed prices of shrimp in Indonesia increased by US$50/tonne during 2005 because of escalating prices of ingredients (Nur, 2007). Weimin and Mengqing (2007) estimated that in China there will be a shortfall of 43.2 million tonnes of cereals and 25.2 million tonnes of protein sources to meet the estimated demand of aquafeeds by

TABLE 20

Estimated aquafeed (commercial and farm-made) use in Asia during 2003–2005 and projected requirement in 2013 (million tonnes)

Country	Quantity used	Projected requirement
China	18.68	33.69
India	6.40	8.62
Indonesia	0.77	1.36
Philippines	0.59	1.49
Thailand	1.58	3.73
Viet Nam	1.50	4.00

Source: De Silva and Hasan (2007).

TABLE 21

Species-specific commercial feed prices in Asia during 2003–2005 (US$/tonne)

Species	Country				
	China	India	Thailand	Philippines	Viet Nam
Nile tilapia larvae/fry	400	–	377–450	469	–
Nile tilapia fingerlings/ growout	250–300	–		418–429	–
Grass carp	300	–	320–330	–	–
Common carp/crucian carp	250–300	–	–	–	–
Indian carps	–	90	–	–	–
Shrimp starter	850–950	978–1 067	–	931–1 022	–
Shrimp growout	450–800	844–956	–	876–967	–
Freshwater prawn juvenile	500–1 000	800–1 067	530	–	–
Freshwater prawn growout	350–600	444–800	440–520	–	–
Chinese river crab juvenile	400–500	–	–	–	–
Catfish larvae/fry	–	–	480–1 000	432	350
Catfish growout	–	–	1 333	400–407	250
Milkfish fry/starter	–	–	–	415–1 051	–
Milkfish growout	–	–	–	373–465	–
Grouper fry/starter	–	–	–	912–949	–
Grouper growout/ adult	–	–	–	849–876	–
Mud crab	–	–	–	806	–

Source: Hasan *et al.* (2007).

2015. This indicates that China will remain a net importer of ingredients to meet its aquafeed demand, contributing to high prices of ingredients on the world market. It has been reported that the feed manufacturing industry suffered from a perennial shortage of key ingredients such as fishmeal and soybean meal (AFSD–BAI, 2005). Depreciation of local currencies against the United States dollar will further increase the import cost of feed ingredients. For example, 70-90 percent of the feed cost of tilapia (US$236–309/tonne) in the Philippines in 2003 was attributed to imported feed ingredients (Sumagaysay-Chavoso, 2007). About 10 000 tonnes of fishmeal is imported into Thailand annually; there is a shortfall of soybean production of 1.68 million tonnes to meet the demands of the feed industry (Thongrod, 2007).

2.2.4 Volatility in commodity prices and underlying reasons

Fishmeal and fish oil

Fishmeal is a meal produced after cooking, pressing, drying and milling both whole fish derived from capture fisheries and food-fish trimming from fish processing plants. Fishmeal production also results in the production of fish oils. Approximately 90 percent of the fish species used to make fishmeal and oil is "presently unmarketable in large quantities as human food" (Bose *et al.*, 1991). In Europe, these species mainly include capelin, blue whiting, sandeel, sprat, herring and Norway pout and in South America, they include anchovy, jack mackerel and sardine. Because the supply of

TABLE 22

Prices of ingredients in Asia during 2003–2005 (US$/tonne)

Ingredients	India	Philippines	Viet Nam	Indonesia	Thailand	Malaysia
Animal by-products						
Fishmeal (imported)	733	855–1 000	736	710	740	661
Fishmeal (local)	466	236–536	536	545	666	500
Fish meat protein						
Shrimp meal	311	300				
Squid meal		11 212				
Fish soluble	622					
Grains						
Corn starch		409				
Sorghum	111					
Maize	133					
Broken rice	156					
Wheat flour	233	148–218	324	342	331	346
Finger millet	78					
Grain by–products						
Copra meal	144	58–236				
Sunflower meal	111					
Cotton seed cake	167					
Soybean meal	298	345–527	348	300	348	324
Rapeseed meal	144					
Rice polish	122					
Rice bran	71	55–175				
Corn bran		58				
Corn gluten meal	278					
Wheat bran	111					
Wheat gluten	1 022					
Groundnut cake	211					
Oils and fats						
Fish oil	711	509				
Cod liver oil		2 273				
Soybean oil		727				
Soy lecithin	844					
Premixes						
Vitamin and mineral		2 182–8 335				
Additives						
Phosphates		509				
Yeast	578					

Source: Hasan *et al.* (2007).

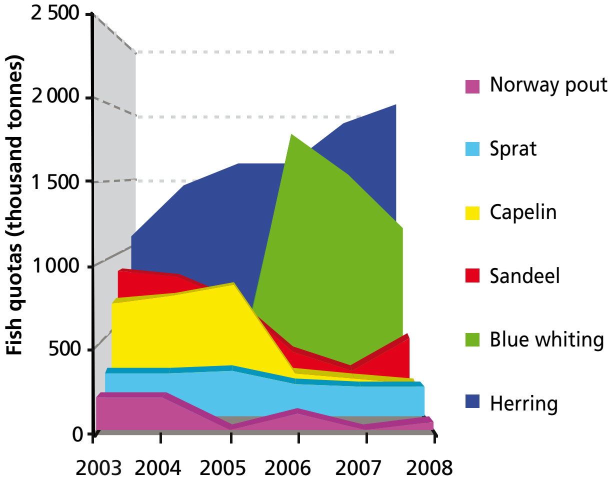
TABLE 23

Global prices of ingredients used in aquafeeds (US$/tonne)

Nutrient source	2000	2001	2002	2003	2004	2005	2006	2007	2008
Protein									
Fishmeal	452	530	646	650	693	744	1 074	1 186	1 184
Soybean	187	181	184	215	257	206	194	264	383
Soybean meal	183	169	189	233	277	233	218	317	479
Groundnut	786	753	655	856	910	769	829	1 178	1 633
Lipid									
Soybean oil	352	347	410	500	591	496	552	780	1 220
Palm oil	261	238	357	410	435	368	417	719	948
Sunflower oil	379	436	606	650	743	1 145	713	673	1 734
Rapeseed oil						721	851	1 158	1 550
Carbohydrate									
Wheat	114	127	149	146	157	152	192	255	346
Maize	88	90	99	105	112	98	122	163	236
Rice	204	173	192	200	246	288	303	332	729

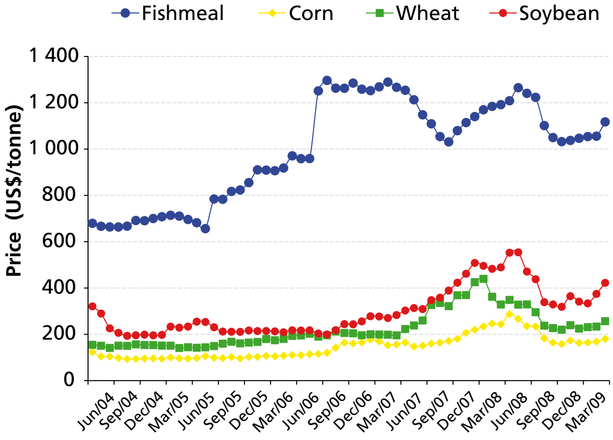
Source: Adapted from Index Mundi (2009).

FIGURE 16
Allowable quotas for fish used for reduction to fishmeal and fish oil in Europe



Source: Adapted from FIN (2008).

FIGURE 17
Commodity prices of main protein sources used in aquafeeds



Source: Data adapted form Index Mundi (2009).

fishmeal and fish oil ultimately depends on capture fisheries, their supply is primarily governed by allowable quotas for these species and is subject to seasonal variation.

Peru and Chile in South America and Norway, Iceland and Denmark in Europe are the major countries in the world where fish are used for fishmeal and oil production. Therefore, the global fishmeal supply is affected by fish landings in these countries. These landings in turn are shaped by allowable quotas and yields, particularly of fish oil, which depend on the seasons and species composition of total landings.

The decline in landings in Europe (Figure 16) and in South America have resulted in a sharp decline in fish supply. Overall, since 2003, global fishmeal supplies from the major producing countries in 2008 declined by 780 000 tonnes. This decline was sharpest in Europe. In Scandinavia, fishmeal availability declined from 504 000 tonnes in 2005 to 428 000 tonnes in 2008, while in South America fishmeal production declined from 2 million tonnes to 1.5 million tonnes in the same period. This production decline of suppliers combined with a sharp increase in imports by China led to escalating prices, which peaked at around US$1 300/tonne in mid-2006 (Figure 17).

Prices have slipped to some extent since then, but still are around the US$1 000 mark, about US$400 above 2003 prices. Currently, in 2009, prices are being checked by the global economic downturn and reduced demand for fishmeal from China, in particular.

The supply of fish oil also principally reflects the catch quotas for fish species used for reduction to fishmeal. The quantity or yield of oil recovered is influenced by seasonality and species composition used. Fish oil production also declined in line with fishmeal production but the proportional decline was greater owing to varying oil yields. Supplies in 2008 declined by around 40 percent from around 650 000 tonnes in 2004 to 399 000 tonnes in 2008.

Following record prices of nearly US$1 800/tonne in mid-June 2008, prices have sharply declined and fish oil is selling at less than half the price of US$850/tonne (Figure 18). The global economic downturn has also depressed the fish oil industry in 2008–2009. In addition, aquafeed producers are substituting more rapeseed oil for fish oil in their feed recipes, as the price of rapeseed began to fall. The high catch of mackerel in Iceland in late 2008 and the good yields of oil in the November 2008 fishing season in Peru, which increased inventories of fish oil, at a time of global economic downturn will most probably check price increase for fish oil.

2.2.5 Alternative proteins and oils used in aquafeeds

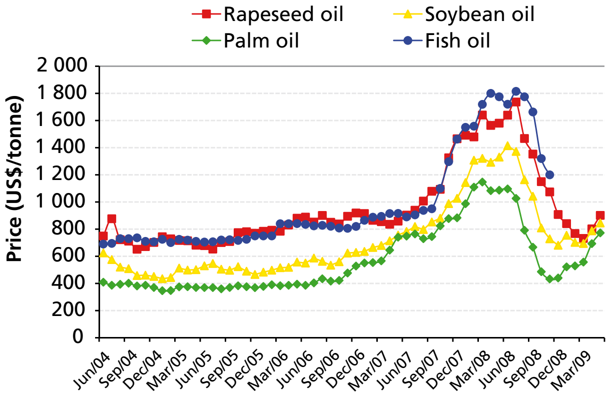
Significant progress has been made to reduce dependency on fishmeal and fish oil through the substitution of these marine raw ingredients with proteins and oils of land origin. As was the case for fishmeal and fish oil, the price increases of vegetable protein and oil mirrored those of marine ingredients, with sharp increases recorded in 2005 for soybean, corn and wheat (Figure 17), and rapeseed, palm and soybean oils (Figure 18).

The price of corn, which has escalated from around US$100/tonne in 2004, peaked at around US$300 in June 2008 before falling to around US$180 in May 2009. The corn gluten, a protein concentrate (from the EU), used in high performance aquafeeds, however, increased from US$500/tonne in 2005 to over US$800/tonnes in November 2008. Similarly, soybean prices increased from US$200–250/tonne in 2005 and peaked at US$550 in June 2008 before declining to US$330 in March 2009. The price of protein concentrate, however, is significantly higher, escalating from around US$450/tonne in the mid-2005 to a peak of US$950/tonne in June 2008 before dropping to US$800/tonne by the end of 2008.

The use of oils of plant origin as a substitute for fish oil has significantly increased and the prices of these substitutes have also risen sharply (Figure 19). Prices of palm, soybean and rapeseed oil have gradually increased between 2004 and 2006, followed by a sharp increase in prices between 2007 and 2008 (Figure 18). Rapeseed oil, which is the main substitute for fish oil in Europe, for example, increased from an average of US$720/tonne in 2005 to a peak of US$1 700/tonne in July 2008. Similarly, the price of palm oil used in Asia increased from US$375/tonne in 2005 to US$1 100/tonne in June 2008. Although prices have slipped since then, resurgence in demand in 2009 is forcing prices upwards again (Figure 18).

FIGURE 18

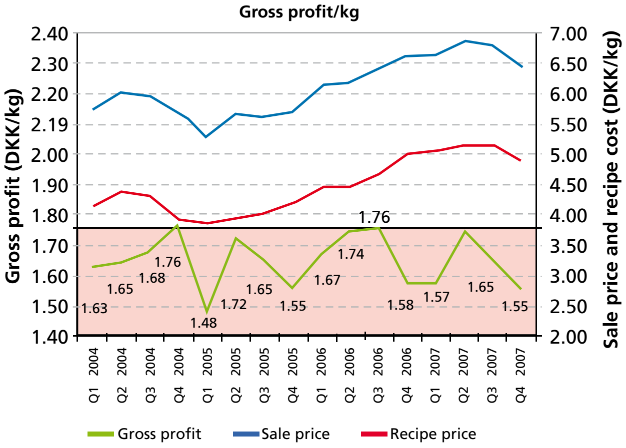
Commodity prices of main oil sources used in aquafeeds



Source: Adapted form Index Mundi (2009).

FIGURE 19

Actual relationship between the rising cost of salmon feed production and cost of feed to farmers



DKK = Danish Krone

Source: Adapted from BioMar (2008).

Impact of commodity prices on aquafeed costs and on farmers

Rising commodity, energy and fuel costs have resulted in significant increases in the prices of manufactured and on-farm aquafeeds in Europe and Asia.

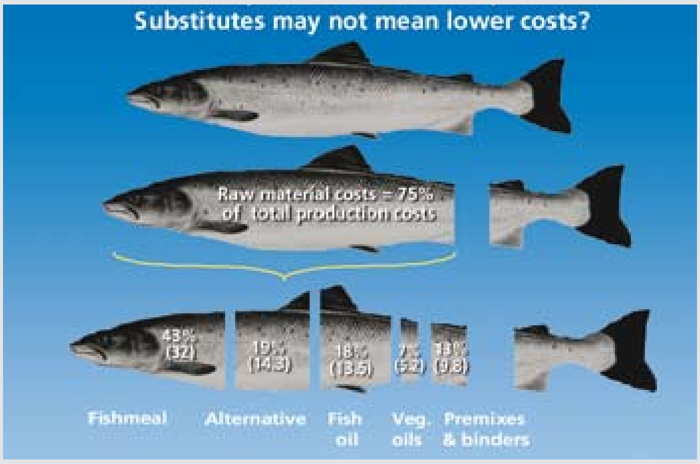
For salmon, the cost of raw materials accounts for 75 percent of production costs of formulated feeds and, therefore, the overall costs and escalation of commodity prices will have a notable impact on feed prices (see Box 3).

In Europe, BioMar, the third largest salmonid diet manufacturer, passed on increased costs to farmers to secure profit margins. Between 2005 and 2007, the kilogram recipe

BOX 3

Contribution of major groups of raw materials to production costs in 2007

Even though inclusion level of fishmeal is 25 percent, it accounts for 43 percent of raw material costs and 32 percent of total production costs. Alternative proteins (e.g. soybean, wheat and corn gluten), which can account for 45 percent of volume, accounts for 19 percent of raw material costs. The proportional costs of vegetable oils are higher than that of fish oil, while pigments/binders, which are less than 1 percent of diet, accounts for 13 percent of costs.



Source: Adapted from BioMar (2008).

costs of salmon diets increased by 25 percent (Figure 19). To secure the required gross profit margin of around 25 percent, the sale price (per kg diet) increased by a similar fraction (Figure 19). As these price increases are due to the increased price of traded commodities, such increases are likely to apply to other major feed manufacturers in Europe as well.

The higher aquafeed costs have also affected farmers in Asia. In China, since early 2006, the price of shrimp feed has increased by US$143/tonne (RMB1 000) to US$1 060/tonne (RMB7 400) after several rounds of price increases due to a large increase in the price of feed ingredients. However, considering the downturn of shrimp farming in 2008 and the limited capacity of shrimp farmers to bear further price increases, the shrimp feed price was only raised by RMB300 (US$43) per tonne. The difference between the production cost and price is borne by feed manufactures.

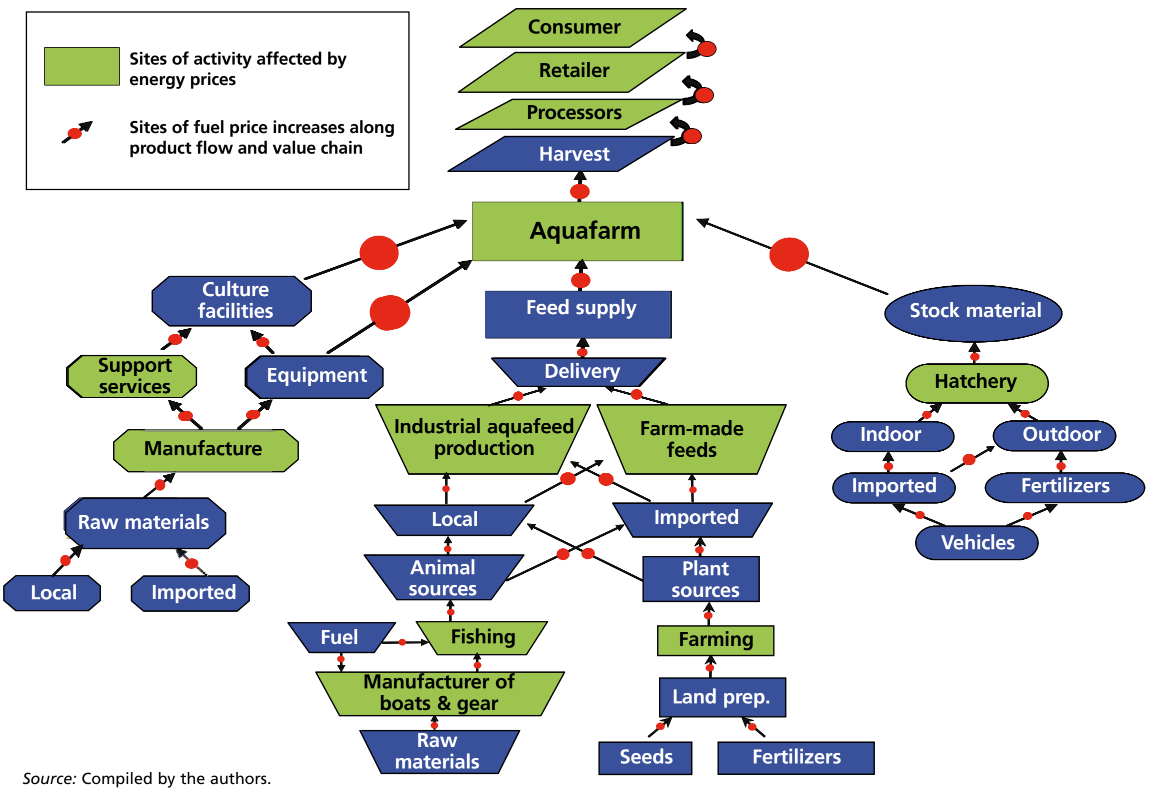
In Viet Nam, farmers and feed producers in the Mekong (Cuu Long) delta region are facing serious losses as the price of fish feed continues to rocket. In 2009, the prices of basic ingredients increased by 30 percent, raising the cost of feed by VND13 000–13 500/kg.

Rapeseed meal is a major raw material used in China as a protein substitute for fishmeal in aquafeeds and with its greater use in feeds, prices steadily increased. In 2003, prices were around RMB1 000/tonne. By April, 2009 prices almost doubled to RMB1 940/tonne.

2.2.6 Impact of rising fuel and energy costs on the cost of aquafeed ingredients

A schematic representation of the nodal points of impacts along the product chain affected by fuels price hikes is shown in Figure 20. The sharp increases in fuel prices have impacted significantly on the cost of securing the bulk ingredients used in aquafeeds and also affected the entire production chain. The high cost of fuel has impacted on fishing vessels that land fish for production and on transport of land-based

FIGURE 20
Nodal points of impact along the product chain affected by fuels price hikes



Source: Compiled by the authors.

ingredients used in aquafeeds. In addition, the higher fuel and energy costs have also reduced the profit margins of fish farmers, leading to farm closures and consolidation of the sector, especially in Europe.

In Europe, the cost of fuel for fishing vessels has escalated dramatically. According to the EU Fisheries Commissioner, Joe Borg, the price of marine diesel has shot up 240 percent across Europe since 2004 (New Europe, 2008). Further, the European Association of Fish Producers reported a 320 percent increase in fuel prices over the last five years, and a 40 percent increase in fuel prices since January 2008. Similarly, in Latin America, the cost of fuel has skyrocketed. In Mexico, where fuel accounts for 60 percent of a vessel's total operating costs, the cost of diesel fuel doubled from US$0.26 in 2006 to US$0.56 in 2008 (WW4 Report, 2008). Asian fishers, who supply a significant quantity of the trash fish used in aquafeeds, were also equally affected. In the Philippines, marine fuel prices increased by 50 percent between 2007 and 2008 from PHP40 to 60 (GMA News, 2008). In Viet Nam, the prices of diesel and kerosene went up by US$0.12 and UD$0.36 to UD$0.95 and UD$1.20, respectively (Asean Affairs, 2008), while in Indonesia, the government reduced subsidies and increased fuel prices by 29 percent overnight (Asia-Pacific News, 2008).

2.3 TYPES AND COMPOSITION OF AQUAFEEDS USED

In general, feeds and feeding practices vary according to the farming system, species under culture and stocking intensities. Traditional extensive farming systems, in which fish growth and production are dependent on consumption of natural food organisms in water, use no feed or fertilizer. In some cases, these systems use chemical fertilizers and/or organic manures, which may also be added to stimulate and enhance natural productivity of pond water. In more intensively stocked farming systems, fertilizers and supplementary or complete feeds are used.

Feeds range from single component feeds available on-farm such as grass or rice bran to farm-made formulated feeds and commercial feeds. Feeds also can be simple farm-made moist or dry aquafeeds or formulated commercially made aquafeeds. However, there is no clear definition for what is farm-made and non-farm made aquafeed and non-farm made aquafeeds. FAO suggests that farm-made feeds be defined as feeds in pellet or other forms, consisting of one or more artificial and/or natural feedstuffs, produced for the exclusive use of a particular farming activity and not for commercial sale or profit. Kitchen waste may also be considered as one of the types of farm-made aquafeed as per FAO definition as it contains one or more natural feedstuffs in non-pellet form. De Silva and Hasan (2007) suggest that mixtures of ingredients subjected to some form of processing (simple mixing, grinding and cooking) done on-farm or in small processing plants are generally regarded as farm-made aquafeeds and are often the mainstay in small-scale semi-intensive aquaculture practices. Formulated commercial feeds are composed of several ingredients, mixed in various proportions to complement each other, and form a nutritionally complete compounded diet. De Silva and Hasan (2007) categorized Asian aquafeeds into the following four groups.

(i) 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;
(ii) materials of animal origin, primarily trash fish, that are used singly or in combination with others but with little or no processing;
(iii) 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; and
(iv) feeds that are manufactured in industrial feed milling plants and are distributed and sold using conventional market chains.

A very wide range of ingredients is used to prepare farm-made aquafeeds. They include aquatic and terrestrial plants (duckweeds, *Azolla*, water hyacinth, etc.), aquatic animals (snails, clams, etc.) and terrestrial-based live feeds (silkworm larvae, maggots, etc.), plant processing products (de-oiled cakes and meals, beans, grains and brans) and animal-processing by-products (blood and feather meal, bone meal, etc.). Vegetable ingredients are used singly or in combination with other ingredients of plant or animal origin as feeds with no or little processing in small-scale aquaculture at the lower end of semi-intensive practices, while material of animal origin such as trash fish is used singly or in combination with other ingredients with no or little processing at the upper end of semi-intensive practices (De Silva and Hasan, 2007). Usually in intensive practices, commercial complete feeds are used.

Irrespective of the feed category, the majority of the ingredients used in the feeds, particularly in categories (iii) and (iv) above, are fairly common ingredients and include fishmeal, soybean meal, various oilseed cakes (De Silva and Hasan, 2007). According to the FAO (2008b), aquaculture used 56 percent (3 million tonnes) of world fishmeal production in 2006 and 87 percent (800 000 tonnes) of fish oil production. Tacon (2008) puts this even higher, at 3.7 million tonnes of meal and 840 000 tonnes of oil. 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

TABLE 24
Ingredients used commonly as sources of protein, lipids and carbohydrates

Nutrient	Ingredients used in Asia	Ingredients used in Europe
Protein	Fishmeal, soybean meal, soy protein concentrate, maize gluten, wheat gluten, sunflower, CPSP, blood meal, meat meal	Fishmeal, soybean meal, soy protein concentrate, maize gluten, wheat gluten, sunflower, CPSP, blood meal, meat meal, krill meal, gelatin, brewer's yeast
Lipid	Fish oil, vegetable oil, tallow	Fish oil, vegetable oil, tallow
Carbohydrate	Wheat meal, extruded wheat meal, wheat remillings, extruded gelatinized starch	Wheat meal, extruded wheat meal, wheat remillings, extruded gelatinized starch

Source: Compiled by the authors.

TABLE 25

Typical composition of main nutrients in feeds used in Asia (% inclusion levels)

Species	Protein			Lipid	Carbohydrate	Crude fibre
	Fry[1]	Juvenile	Adult			
Common carps	43–47	37–42	28–35	4.6–8	38.5	3–7
Crucian carp	40	30	28	5–8	36	12.2
Grass carp	25–30	28–32		4.2–4.8	36.5–42.5	12
Indian carps			20	2		15
Nile tilapia	30–56	30–40	22–32	5–12	30–40a	4–20
Grouper			50	10		2.5
Milkfish	31–35	28–31	26–29	7–8		4–7
Catfish (*Ictalurus* spp.)	35–40	30–35	28–35	5–12	40	4
Catfish (*Pangasius* spp.)			28–30	4–6		4
Shrimp	38–45	38–42	35–44	4–8	20–26	3–4
Freshwater prawn		40–45	28–35	4–9	20–35	4–6

[1] For shrimp should read as post-larvae for fry stage.

Source: Hasan *et al.* (2007).

TABLE 26

Typical composition of main nutrients in feeds used in Europe (% inclusion levels)

Species	Protein	Lipid	Carbohydrate
Atlantic salmon	35–55	30–40	7–15
Rainbow trout	42–45	20–24	
Gilthead seabream	45–50	12–24	20
European seabass	43–50	12–25	20
Turbot	48–52	12	
European eel	40–49	12–16	20
Sea trout	52	12	17
Common carp	30–35	5–10	30–40

Source: Adapted from Aquamax (2008).

TABLE 27

Ingredients and their composition (% inclusion) in manufactured feeds in Asia

	Species									
	Nile tilapia		Grass carp	Common and crucian carp	Shrimp		Freshwater prawn		Milkfish	Grouper and Asian seabass
	Fry	Fingerling/ growout	Fingerling/ growout	Fingerling/ growout	Starter	Growout	Juvenile	Growout		
Animal by-products										
Fishmeal	50	4–12	4	3–6	30	23–25	23.3–33.8	11.3–22.5	11	20
Shrimp meal										10
Shrimp bran						1				
Shell meal							1–3.2	1.6–4.8		
Poultry by-product meal	2									
Hydrolysed protein	4									
Blood meal										8
Bone meal					1.1					20
Squid meal					3	2				1
Grains										
Corn		22.1–6.2	8.95–12.95	6.9–10						
Wheat flour			16.8–18.8	11.85			14.35–19.25	14.5–18.5		
Bread flour									5	
Rapeseed										
Grain by-products										
Soybean meal	17	34–46							30.8	6
Soybean cake			5–14	27–32	15	15	29.4–32	21–23.2		
Rapeseed meal										
Rapeseed cake			41–51	40–41			15.2–16	21.6–26		
Rice bran									49.2	7
Corn gluten meal	12									
Wheat bran			10–11	4				6.95–10		
Wheat meal	4.2				29.5	28.6–30.6				
Wheat middling	4	30								
Groundnut cake					11	16				

TABLE 27 – (CONTINUED)

	Species									
	Nile tilapia		**Grass carp**	**Common and crucian carp**	**Shrimp**		**Freshwater prawn**		**Milkfish**	**Grouper and Asian Seabass**
	Fry	**Fingerling/ Growout**	**Fingerling/ Growout**	**Fingerling/ Growout**	**Starter**	**Growout**	**Juvenile**	**Growout**		
Oils and fats										
Fish oil	1				1	1				
Cod liver oil									2	6
Soy oil									2	
Vegetable oil		0.5–3.6								
Premixes										
Vitamin				1			1	1		4
Mineral			1							3
Vitamin and mineral	0.5	0.5								
Additives										
Phosphates		1.4–2.6			3.5	3.5–4.5				
Growth and immune enhancements			1.25	1.25	1	1	1.25	1.25		
Molt-inducing agent							0.2	0.2		
Lure agent					0.1	0.1				
Polysaccharide					0.1	0.1				
High stability vitamin C					0.1	0.1				
Sea salt					1.5	1.5				
Yeast					3	3				
Binder		0.01	1	1	1.2	1.2	1.2	1–1.2		

Source: Hasan *et al.* (2007).

TABLE 28

Ingredients and their composition (% inclusion) in manufactured feed in Europe

Ingredients	Reference	
	Waagbø *et al.* (2001)[1]	**Skretting (2008)**[1]
	35	30
Fish oil	28	18
Fish ensilage	5	4
Corn and wheat gluten	7	
Vegetable protein		25
Soy products	6	
Soybean oil	3	
Vegetable oil		11
Wheat	12	
Wheat meal		10
Other	4	2

[1] Cited in Aqua Web (2009).

used by the regional animal feed industry (De Silva and Hasan, 2007). For example, while Asia produces only 17 percent of the global fishmeal supply, it consumes 47 percent of it.

Ingredients commonly used as nutrient sources are given in Table 24. Species-specific composition of main nutrients used in formulated commercial fish feeds in Asia and in Europe are given in Tables 25 and 26. In terms of ingredients used in commercial aquafeeds, Asia and Europe do not differ much (Tables 27 and 28). Irrespective of the region, the commercial aquafeeds largely depend on soybean products and corn or wheat products. Additives are mainly used in high-value shrimp aquaculture in Asia.

Apart from materials of animal and plant origin used as ingredients in aquafeeds, trash fish still remains the traditional feed for high-value marine carnivorous fish throughout the Asia-Pacific region and is likely to remain so for some time. They are currently an indispensable feed for carnivorous fish and are also used in farm-made feeds for omnivorous species in some countries such as China, Viet Nam and Indonesia. It has been estimated that Viet Nam uses nearly 900 000 tonnes of trash fish and China will require approximately 4 million tonnes of trash fish by 2013 to sustain marine cage culture activities (De Silva and Hasan, 2007). However, the depleting availability of trash fish is considered one of the most serious constraints for aquaculture development in Viet Nam. The supply of trash fish in Asia is highly seasonal and dwindling (Edwards, Tuan and Allan, 2004). Their efficacy as an aquafeed is debateable and their preferred use appears in many instances to be based more on farmer perceptions than economic reality (De Silva and Hasan, 2007). Moreover, the fishmeal manufactured mainly from trash fish, spoiled fish and processing waste is inferior in quality and often contains high levels of histamine and cadaverine substances (Hung and Huy, 2007). Dependency on trash fish may continue with the expansion of marine cage aquaculture despite the socio-economic and environmental consequences of using trash fish and feed. However, because of the negative consequences for sustainability of the use of trash fish in terms of: (i) the impact on near-shore fishery stocks; (ii) damage to the coastal environment; (iii) their potential to introduce disease in the cultured fish; (iv) inconsistent and inferior quality; and (v) depleting availability, the growth of high-value marine carnivores will have to depend on commercial complete feeds sooner rather than later.

2.4 POSITIONING OF THE INDUSTRY TO MEET THE CHALLENGE OF SECURING AQUAFEED TO SUSTAIN AQUACULTURE

2.4.1 Search for substitution of fishmeal and fish oil due to rising prices and availability

Fishmeal and fish oil are highly favoured ingredients in aquafeeds for a number of reasons, including:

- high protein, essential amino acids, mineral and essential fatty acids;
- high palatability and digestibility, thus increased growth of fish and less feed wastage; and
- health benefits such as improved immunity, survival rate and reduced incidences of deformities.

Fishmeal production is constrained by its dependency on a finite resource, viz, pelagic fish, the stocks of which are declining due to the cyclic El Niño effect, and the likely continuation of high prices. Landings of small pelagic fish for fishmeal production in South America, which produces around 40 percent of the world's fishmeal and fish oil, were very low in the first quarter of 2007, some 20 percent below the previous year and around 14 percent below the five-year average (Globefish, 2007). Apart from high prices, the aquaculture industry is in competition for fishmeal, because fishmeal is used for animal production and is a primary protein source in the diets of cattle, poultry and pigs. In real terms, world poultry and pig meat production increased from 76 million tonnes and 96 million tonnes in 2003, respectively, (FAO, 2004) to 83.7 million tonnes and 106.9 million tonnes in 2006, respectively, (FAO, 2007). Although current annual growth of poultry and pig meat production is not as high as that in aquaculture, higher protein percentages (15 percent to 20 percent) are used and absolute production levels in poultry and pig meat industries, lack of fishmeal availability may be of serious concern for fish-feed development. For Asia as a whole, the situation is further exacerbated as its contribution to the world supply of these principal ingredients is minimal in comparison with the proportion that is used by the regional animal feed industry (De Silva and Hasan, 2007). For example, while Asia produces only 17 percent, it consumes 47 percent of the global fishmeal supply.

A closer look at how the trade-offs are likely to take place in future between the main types of aquaculture will provide a clear insight into the danger of dependency on fishmeal for fish feeds. Within the aquaculture sector, the main consumers of fishmeal are shrimp (22.8 percent), marine fish (20.1 percent), salmonids (19.5 percent) and carps (14.9 percent) (Tacon, 2005). Increase in fishmeal and fish oil production to meet the demand of the aquaculture and livestock industries is very unlikely as the landings of the capture fisheries of forage fish, which are reduced to fishmeal and fish oil, are on the decline. Because the emphasis is on the high-value marine species and intensification of carp culture, dependency on fishmeal will be risky and the competition between livestock producers and aquaculturists could be more severe if an alternate to fishmeal is not found. Moreover, if aquaculture sustains its current growth rate, potentially all fishmeal and fish oil would be utilized by 2020 and 2010, respectively (Tacon, 2005), and finding suitable alternatives to fishmeal and fish oil that are sustainable, as well as improving feeding practices, would be a practical solution.

In the search for viable alternative feedstuffs to fishmeal for aquafeeds, candidate ingredients must possess certain characteristics, including wide availability, competitive price, as well as ease of handling, shipping, storage and use in feed production (Gatlin *et al*., 2007). The main challenge in replacing fishmeal and fish oil is to find alternatives that maintain acceptable growth rates, animal health and changes to the final product

TABLE 29

Alternate protein sources used in fish feeds

Alternative	Species	Inclusion level[1]	Limitation	Reference
Soybean meal	Atlantic salmon	34% (40% FM replacement)	Poor digestibility	Refstie, Storebakken and Roem (1998)
	Rainbow trout	42% (50% FM replacement)	Methionine 0.3%	Kaushik *et al.* (1995)
	Gilthead seabream	39.5% (47% FM replacement)	Poor amino acid profile	Martínez-Llorens *et al.* (2008)
	European seabass	25% (27%FM replacement) -50% (50% FM replacement)	Poor digestibility	Tibaldi *et al.* (2006)
	Nile tilapia	43–47% (100% FM replacement) (extruded soybean meal/extruded full-fat soybean)	DL methionine 0.5%, L-lysine 0.5%	Goda *et al.* (2007b)
	Milkfish	(67% FM replacement)	Methionine	Shiau *et al.* (1988)
	Carp	(100% FM replacement)	Methionine, lysine and oil	Viola *et al.* (1982)
	Catfish	61% (75% FM replacement)	Methionine	Fagbenro and Davies (2001)
Soy protein concentrate	Atlantic salmon	50% (75% dietary CP)	Methionine 0.3%	Storebakken, Shearer and Roem (2000)
	Rainbow trout	62% (100% dietary CP)	Low in methionine (methionine 0.4%)	Kaushik *et al.* (1995)
	Gilthead seabream	20% (30% FM replacement)	Poor palatability	Kissil *et al.* (2000)
	Nile tilapia	100%		Abdelghany (1997)
Pea seed meal	European seabass	40% (12% FM replacement)	Poorly digestible content	Gouveia and Davies (1998)
	Milkfish	26% (20% FM replacement)	Reduced nutrient and energy digestibility and energy utilization efficiency	Borlongan, Eustechio and Welsh (2003)
	Catfish	33%		Davies and Gouveia (2008)
Pea protein concentrate	Atlantic Salmon	27% (33% FM replacement)		Carter and Hauler (2000)
	European seabass	36% (60% FM replacement)	Poor palatability, low methionine	Tibaldi *et al.* (2005)
	Nile tilapia	14.8% (30% FM replacement)	Poor amino acid profile	Schultz *et al.* (2007)
	Catfish	30.8%		Davies and Gouveia (2008)
Canola meal/ concentrate	Atlantic salmon	35%	Presence of glucosinolates/phytic acid	Sajjad and Carter (2004)
	Rainbow trout	< 25% (100% FM Replacement)	Poor palatability and low amino acid	Carter and Hauler (2000)
Cotton seed cake	Nile tilapia	100		El-Sayed (1990)

TABLE 29 – CONTINUED

Alternative	Species	Inclusion level[1]	Limitation	Reference
Lupin concentrate	Atlantic salmon	22% (33% FM replacement)	Poor palatability & digestibility	Carter and Hauler (2000)
Corn gluten	Atlantic salmon	50% (60% FM replacement)	Low lysine content	Mente *et al.* (2003)
	Rainbow trout	23.41 (40% FM replacement)	Poorly digestible carbohydrate fraction	Morales *et al.* (1994)
	Gilthead seabream	40% (60% FM replacement)	Low arginine and lysine content	Pereira and Oliva-Teles (2003)
	Nile tilapia	≤ 30% (100% dietary CP)	Poor arginine, histidine and threonine content	Goda *et al.* (2007b)
Wheat gluten	Atlantic salmon	16.7% (36% FM replacement)	Lysine	Storebakken, Shearer and Roem (2000)
Rapeseed protein concentrate	Gilthead seabream	42.5% (60% FM replacement)	Poor palatability	Kissil *et al.* (2000)
Sunflower	Atlantic salmon	27% (33% FM replacement)	(DL methionine) and presence of hulls	Gill *et al.* (2006)
	Rainbow trout	42% (40% FM replacement)		Sanz *et al.* (1994)
	Gilthead seabream	12% (9% FM replacement)	High fibre content	Lozano *et al.* (2007)
Faba bean	Nile tilapia	24%(20% replacement of dehulled soybean meal)	Poor methionine content, high phenolics and tannins content	Azaza *et al.* (2009)
Animal by-products				
Meat and Bone meal	Gilthead seabream	28% (40% FM replacement)	Histological liver alterations, reduced protein and lipid digestibility	Robaina *et al.* (1997)
Poultry by-product meal	Gilthead seabream	71% (100% FM replacement)		Nengas, Alexis and Davies (1999)
	Nile tilapia	30% (66% FM replacement)		Fasakin, Serwata and Davies (2005)
	Catfish	27% (40% FM replacement)	Poor nutrient availability and amino acid imbalance	Abdel-Warith, Davies and Russell (2001)
Blood meal	Rainbow trout	22.7%		Luzier, Summerfelt and Ketola (1995)
	Gilthead seabream	5% (15% FM replacement)	Low dietary methionine content and low digestibility	Martínez-Llorens (2008)
	hybrid tilapia	< 21.7% (66% FM replacement	Amino acid imbalance and poor digestibility	Fasakin Serwata and Davies (2005)
Poultry by product meal	Rainbow trout	20 (40% FM replacement)		Mustafa and Huseyin (2003)
	African catfish	17%–34.5% (100% FM replacement)	Poor palatability, low nutrient availability and amino acid imbalance	Abdel-Warith, Davies and Russell (2001); Goda, El Haroun and Chowdhury (2007a)
	Chinook salmon	20%	Poor palatability	Fowler (1991)
Feather meal	Rainbow trout	15%	Deficiency in lysine or other amino acids	Bureau *et al.* (2000)
	Rainbow trout	15%		Fowler (1990)
	Rainbow trout	30%	Low lysine content	Pfeffer, Wiesmann and Heinrichfreise (1994)
	Nile tilapia	9.9% (66% FM replacement)	Poor amino acid profile	Bishop, Angus and Watts (1995)
Krill meal	Rainbow trout	8.9% (15% FM replacement)	Fluoride accumulation in vertebral bones	Yoshitomi *et al.* (2006)

[1] FM = Fishmeal

Source: see the references in the table.

TABLE 30

Advantages and disadvantages of some of the plant substitutes for fishmeal

Plant substitute	Advantages	Disadvantages
Soybean meal (SBM)	Economical and nutritious with high crude protein (44–48%) Cystine in higher concentration	Concentrations of the 10 essential amino acids (EAA) (lysine, methionine, cystine and threonine may be limiting) and tyrosine are lower; crude fat and ash content is lower but can be overcome with supplementation; high in non–starch polysaccharides; reduced feed intake; growth and development of intestinal enteritis; presence of anti–nutritional factors such as lectin; low in available phosphorous
Soybean protein concentrate (SPC)	EAA concentration matches or more to EAA concentrations in fishmeal	Methionine, cystine may be limiting; not economical for large scale use; crude fat and ash content is lower but can be overcome with supplementation
Soy protein isolate (SPI)	EAA concentration matches or more to EAA concentrations in fishmeal	Methionine, cystine may be limiting; not economical for large-scale use; crude fat and ash content is lower but can be overcome with supplementation
Canola meal	Not widely used in aquafeeds, similar to the protein content of SBM	The price similar to that of SBM; low in available phosphorous
Canola protein concentrate	Protein content similar to high-quality fish fishmeal, widely tested as a protein source for salmonids and other carnivorous species of farmed fish, supports growth rates similar to those of fish fed fishmeal-based diets	Amino acid supplements needed to overcome limiting amino acid levels; feeding stimulants are needed to overcome reduced feed intake
Corn gluten meal	Crude protein content of 60–73%; corn gluten meal is currently widely used in aquafeeds for salmon and several marine species such as European seabass and gilthead seabream; highly digestible	Limited in commercial production; deficient in EAA lysine
Corn distillers dried grains with solubles (DDGS)	28–32% crude protein	High in fibre content
Cottonseed meal	10 and 30% of solvent extracted; 40% protein CSM can be used in aquaculture diets without growth depression	Presence of gossypol may have toxic effects
Peas/lupins	High protein apparent digestibility coefficient	Lysine and methionine are limited; high levels of carbohydrate (fish do not metabolize non–starch polysaccharides in lupins); presence of anti–nutrient quinolizidine alkaloids; lysine is limiting
Wheat	Low in protein (<11)	Wheat is primarily an energy source based on its high starch composition (typically >70%); lysine is limiting
Barley	Barley protein is well digested	Low crude protein content (9–15%); high in fibre; low in available phosphorous; lysine and arginine may be limiting; high in fibre

Source: Gatlin *et al.* (2007).

TABLE 31

Advantages and disadvantages of some of the animal by-product substitutes for fishmeal

Animal by-product substitute	Advantages	Disadvantages	Reference
Hydrolysed feather meal (HFM) (either steam or enzyme treated)	Proposed optimum replacement rates of fishmeal by enzyme treated HFM are; European seabass ≤5%, turbot ≤5%, gilthead seabream 5%, red tilapia <66%, rainbow trout <20%	Steam treated is less digestible compared with enzyme treated; deficient in lysine and methionine	Laporte *et al.* (2007)
Poultry by-product meal (PBM)	Typically contain 66% CP, 13% CF and 10-18% ash. Proposed optimum replacement rates of fishmeal by PBM are: European seabass 25%, turbot 10%, gilthead sea bream 25%, red tilapia 66%, rainbow trout 15%	Deficient in lysine, methionine and histidine	Laporte *et al.* (2009)
Blood meal	Rich in lysine	Deficient in methionine; highly sensitive to heat damage and drying conditions with profound effect on protein digestibility	Bureau (2008)
Fish by-products from fish processing plants	Regarded as the best nutritional substitutes for fishmeal and fish oil due to their nutritional characteristics	Issues related to potential pathogens and contaminant harmful to both fish and consumers need to be addressed through proper treatment	Hardy (2004)

Source: see the references in the table.

(Tacon, Hasan and Subasinghe, 2006). Further, they must possess certain nutritional characteristics, such as low levels of fibre, starch, especially non-soluble carbohydrates, and anti-nutrients, and have relatively high protein content, favourable amino acid profile, high nutrient digestibility, and reasonable palatability (Gatlin *et al.*, 2007).

There is an increasing trend towards replacing fishmeal with alternate protein sources, particularly plant material (Table 29), which are believed to be in abundance at a reasonable price when compared with fishmeal, which is costly due to the dwindling supply and erratic price.

The plant materials and animal by-products used in fish feeds as substitutes for fishmeal, and their advantages and disadvantages are summarized in Tables 30 and 31.

2.5 RESEARCH AIMED AT SUSTAINABLE SUPPLIES OF AQUAFEEDS

Solutions to fishmeal inclusion in aquafeeds are multi-faceted. Apart from inclusion of plant protein sources (from more plant species) and animal by-products, other initiatives included: (a) pre-processing techniques of plant material to reduce the effects of anti-nutritional factors in order to enhance nutritional value; (b) breeding of plants with a better amino acid profile and less antinutritional factors; (c) selecting fish species with lower marine protein requirements (e.g. herbivores); (d) converting low grade land animal by-products into high-value protein, and e) most recently, the use of new innovative protein sources.

The excessive reliance of aquaculture on fishmeal and fish oil has already led to dedicated research such as RAFOA (Research on Alternatives to Fish Oil in Aquaculture, coordinated by the University of Stirling, Scotland) and PEPPA (Perspectives of Plant Protein Use in Aquaculture, coordinated by INRA, France) under the fifth framework of the EU. The targeted reduction of dependency on fishmeal and oil by this research is given in Table 32.

It has been established that blends of vegetable oils can replace fish oil for the major part of the growth period in several farmed fish (Atlantic salmon, rainbow trout, European seabass and gilthead seabream) (Aquamax, 2008). This has been achieved by blending vegetable oil to mimic the levels of total saturated, total monounsaturated and total polyunsaturated fatty acids in fish oils, and their high levels of omega-3 polyunsaturates, except that of the C18 linolenic acid (18:3w3).

Biological enhancement through micro-organisms such as yeast and bacterial and fungal fermentations have been investigated to determine their capacity to reduce the effects of anti-nutrients in plant materials and current results demonstrate great potential of this method for removing anti-nutrients and adding essential nutrients such as protein and amino acids (Mukhopadhyay and Ray, 1999; Bairagi *et al.*, 2004). The overall goal of these processes is to increase protein concentration and decrease the levels of anti-nutrients (Gatlin *et al.*, 2007). The knowledge on genetic manipulations to achieve better traits such as protein and oil content of plants has been extended to lower the anti-nutritional factors. Genetic manipulations have been investigated to achieve low levels of phytic acid and thereby enhance available phosphorous (Guttieri *et al.*, 2004), increase essential amino acids such as lysine (Gibbon and Larkins 2005; Stepansky *et al.*, 2004), increase the levels of oil (Laurie *et al.*, 2004) and increase micronutrients such as antioxidatives (Capell and Christou, 2004).

TABLE 32
Targeted reduction of dependency on fishmeal and oil

Species	Current inclusion (%)		Targeted inclusion (%)	
	Fishmeal	Fish oil	Fishmeal	Fish oil
Atlantic salmon	35–47	25–33	12–16	8–12
Rainbow trout	30–35	20–25	5	5
Seabream	40–45	15–20	15	10
Common carp	20–25	5–10	0	0

Source: RAFOA and PEPPA (personal communication).

Innovative new protein sources are mainly focused on microbial and algal species. However, cost of production will be an issue with most of the manufacturers of microbial proteins (Aquaculture Innovation, 2008). Locating the microbial protein manufacturing facilities very close to the major feed manufacturing locations may be a measure to keep the cost down by minimizing transport costs, which tend to increase over time. A company in Asia is developing microbial product at present with considerable interest from Asia's largest integrated feed company, Charoen Pokphand Group Thailand (Aquaculture Innovation, 2008). It will be interesting to see the uptake of this type of product in the aquafeed sector when commercialized in the near future.

There are several benefits of microbial and plankton products. Single-cell products include products from bacteria, microalgae, protists and yeasts comprised of protein and omega-3 oils. Plankton, including copepods, euphausiids, amphipods and krill, which feed in low trophic levels, contain bioactive compounds like omega-3, bound phospholipids and axastanthin and have the potential to serve as a source of protein, oil, attractants and pigments (Hardy, 2004). However, exploitation of plankton should strike a balance to avoid negative ecological consequences to organisms in higher trophic levels.

Converting low-grade land-animal by-products into high-value aquafeed protein, with the appropriate amino acid balance, may be an innovative and a low-cost method to achieve the high levels of fishmeal replacement necessary (Aquaculture Innovation, 2008). In addition to plankton, other invertebrates used as protein sources to replace fishmeal are polychaete worms and terrestrial insects. Polychaetes include both marine worms (e.g. *Nereis virens*) and the earthworms (e.g. *Eisenia foetida* and *Endrilus eugineae*). On dry matter basis, the earthworm has 60–70 percent protein with high essential amino acid content, especially lysine and methionine. Other nutrients include 6–11 percent fat, 5–21 percent carbohydrate, 2–3 percent minerals and a range of vitamins, particularly niacin and vitamin B_{12}. Marine worms, particularly known to induce sexual maturity, are used in broodstock and maturation feeds. The main limitation is their high moisture content (60 percent) and availability. These worms are a potentially valuable source of protein if they can be produced and processed economically. Among terrestrial insects, silkworm pupae, which contain a high content of free fatty acids, are being used. The de-oiled pupae are found to be most appropriate because of their high protein content and well-balanced amino acids.

In order to overcome poor growth and reduced immunity due to replacement of fishmeal, several initiatives have been taken in the feed industry. Some of the common initiatives are listed below.

Antibiotics: Drugs of natural or synthetic origin that have the capacity to kill or to inhibit the growth of micro-organisms are administered through feed. Prophylactic antibiotics are mostly used in intensive aquaculture to bolster the immune system, which tends to be weakened by stress caused by manipulations and high stocking densities or by replacement of fishmeal. Antibiotics are also used as growth promoters because of their positive effects on weight gain, feed utilization and mortality reduction.

However, antibiotics administered through feed can find their way to the wider aquatic environment through unconsumed feed and faeces. Consequently, residual antibiotics exert selective pressure, which alters composition of the indigenous micro-flora and increases their resistance to antibiotics. Residual antibiotics have also been detected in fish and shellfish products destined for human consumption with similar consequences. This has led to stern measures against use of antibiotics ranging from total ban to severe restrictions of their use in aquaculture.

Nutrient supplementation: Poor performance in terms of immune-competence and disease resistance is partly due to deficiencies of nutrients, particularly amino acids/

proteins, vitamins and minerals. These nutrients include the amino acids, arginine, glutamine and L–tryptophan. While arginine plays a key role in the microbial killing mechanism, glutamine serves as a source of energy for the immune system and as a precursor for nucleotide synthesis and facilitates proliferation of immunocytes during infection. L–tryptophan suppresses aggression in juvenile cod and cannibalism in juvenile grouper and prevents cortisol responses to stress in rainbow trout.

Probiotics, prebiotics and synbiotics: Probiotics are applied through feed or culture medium to prevent against pathogenic bacteria by minimizing the numbers of potentially pathogenic microbes by competitive exclusion, thereby modifying the composition of the microbial community in the organism as well as the culture medium in favour of harmless/beneficial microbes. Probiotics are natural viable micro-organisms such as *Bacillus* spp bacteria that have a beneficial effect on the health of the host upon ingestion by improving properties of its indigenous microflora. In general, the gastrointestinal microbiota of fishes, including those produced in aquaculture, have been poorly characterized, especially the anaerobic microbiota and, therefore, more detailed studies of the microbial community of cultured fish are needed to potentially enhance the effectiveness of probiotic supplementation (Gatlin *et al.*, 2007).

Prebiotics are non-digestible food ingredients, which have beneficial effects on the host by selectively stimulating growth and/or activating a limited number of health promoting bacteria in the intestinal tract, thus improving the host's intestinal balance and consequently decreasing the incidence of infection (Gibson and Roberfroid, 1995). Mostly oligosaccharides, such as mannan-oligosaccharides, fructo-oligosaccharides, transgalacto-oligosaccharide and inulin act as prebiotics (Vulevic, Rastall and Gibson, 2004).

Synbiotics are mixtures of probiotics and prebiotics, which are beneficial to the host by improving the survival and implantation of live microbial dietary supplements in the gastrointestinal tract by selectively stimulating the growth and/or activating the metabolism of one or a limited number of heat-promoting bacteria and thus improving host welfare. This is a new concept in aquaculture.

Nucleotides: These are low molecular weight biological compounds, which are building blocks of DNA and RNA and play vital roles in various physiological and biochemical functions of the body, often regarded as conditionally essential nutrients particularly during periods of rapid growth and physiological stress (Uauy, 1994). Dietary nucleotides are more preferential because de novo synthesis and salvage of nucleotides are metabolically costly processes that account for 5–10 percent of the energy used in the synthesis of tissue protein (Carver, 1994; Grimble, 1994). Dietary nucleotides in aquaculture have shown a number of beneficial effects such as:

- enhanced feed intake observed in largemouth bass (Kubitza, Lovshin and Lovel, 1997);
- improvement in growth observed in tilapia (Ramadan and Atef, 1991) and salmonids (Adamek *et al.*, 1996; Burrells *et al.*, 2001);
- increased resistance to pathogens observed in salmonids (Burrells *et al.*, 2001; Leonardi, Sandino and Klempau, 2003) and hybrid striped bass (Li, Lewis and Gatlin, 2004); and
- increased resistance to stress in salmonids (Burrells *et al.*, 2001; Leonardi, Sandino and Klempau, 2003).

Acidifiers: Acidifiers are potential alternatives to antibiotics and include organic acids (formic, acetic, propionic, lactic and citric) and organic salts (calcium formate, sodium formate, potassium diformate, calcium propionate and calcium lactate). The modes of positive influence of acidifiers are:

- reducing pH of feeds, thus inhibiting growth of microbes, some of which are potentially pathogenic;
- reducing pH in the stomach and small intestines, thus improving pepsin activity particularly during periods where levels of free hydrochloric acid are reduced, e.g. during high feed intake in young animals or when animals are fed diets with high protein content; and
- supplying energy for metabolism, as organic acids contain substantial amounts of energy, e.g. propionic acid contains one to five times more energy than wheat (Diebold and Eidelsburger, 2006).

Acidifiers have been reported to positively improve performance in arctic charr (Ringø, 1991), rainbow trout (de Wet, 2005) and tilapia (Ramli, Heindl and Sunanto, 2005).

Enzymes: Feed enzyme supplements have been predominantly used in pig and poultry diets. Use of enzymes in aquaculture has been relatively low perhaps due to reliance on fishmeal as a major source of protein in aquafeeds. Fishmeal is highly digestible and, therefore, little could be gained by adding enzymes. However, the application of enzymes in aquafeed deserves adequate consideration with the increasing utilization of plant products as partial or complete replacement of fishmeal. Plant products usually contain large amounts of fibre and a number of anti-nutritional factors that limit their nutrient availability, and feed enzymes have often been used to increase nutrient availability by both releasing bound nutrients and breaking down compounds. Feed enzymes work best when they complement endogenous enzymes in breaking down compounds to a size, that can be easily utilized by the animal. In this regard, phytase has proven consistently to improve availability of P, while protease and carbohydrase enzymes have given variable responses. Gatlin *et al.* (2007) reviewed the following researchable issues and approaches to increased use of plant products in aquafeeds.

Enhancing utilization by genetic selection of fish: Of great interest is the determination of whether carnivorous fish that have a natural capacity to utilize protein as their main energy source can be genetically selected for effecting improved utilization of plant material.

Optimizing bioactive compounds: Several plant feedstuffs contain bioactive compounds that may have positive or negative effects on aquatic animals and, thus, investigations to adjust their concentrations accordingly in aquafeeds are needed.

Monitoring effects of plant feedstuffs on fish product quality and consumer health: Given the physiological, nutritional, environmental and compositional differences among farmed finfish, conclusions reached about the product quality of one species cannot be automatically applied to another species. Further research is needed to clarify the influence of dietary ingredients on the quality of each aquaculture species of interest.

Enhancing palatability of plant feedstuffs: Research regarding palatability of various feedstuffs may indicate why feed intake often is reduced when certain feedstuffs are included in fish diets, and may also suggest how processing methods are to be improved for optimizing palatability.

3. Potential impact of nutrient substitutes in aquafeeds on fish health and on the food safety of aquaculture products

3.1 IMPACTS OF RISING AQUAFEED COSTS AND PRICE VOLATILITY ON THE HEALTH AND PRODUCTIVITY OF FISH

In most major aquafeed-based intensive aquaculture production systems there is a high reliance on nutritionally balanced complete aquafeeds. In situations where on-farm feeds are made, farmers attempt to produce a balanced feed using vitamin and mineral premixes. In all regions of the world, the increase in the cost of raw ingredients for commercially manufactured or on-farm aquafeeds resulted in an increase in aquafeed prices from 20 to 40 percent, thus forcing farmers to adopt alternative strategies to secure feeds. In the light of such price increases, farmers are increasingly looking for alternative sources of feeds such as trash fish, animal by-products and grain by-products, or are reverting to the use of single ingredient supplementary feeding regimes, reduced feeding frequency and ration. These types of interventions to mitigate against rising feed costs will compromise fish growth, health and welfare and could reduce fish productivity and production.

As prices of raw ingredients increase, farmers have to travel farther distances to obtain cheaper and alternative feedstuffs, incurring longer transport times under suboptimal conditions of heat and humidity, and store greater than normal quantities of ingredients under suboptimal storage conditions, resulting in spoilage, and fungal and bacterial contamination. These contaminants are pathogenic to fish as well as humans. The subsequent use of such ingredients or contaminated diets could reduce growth and reduce survival. Aquafeeds can serve as a carrier for a range of microbial contaminants such as moulds, mycotoxins and bacteria (Maciorowski *et al*., 2007).

Bacterial contamination of feed ingredients or diets with potential pathogens such as *Salmonella, E. coli, Staphylococcus, Streptococcus, Pasteurella, Pseudomonas,* and *Clostridia* will compromise fish and human health. Its impact may be relevant across the whole aquaculture sector, because the route of such contamination can be through both plant and rendered animal protein sources (Barakat, 2004; PDV, 2007).

3.1.1 Implications of fungal contamination in aquafeeds

The use of plant-based ingredients as substitutes for fish protein and oil in aquafeeds increases the risk of contamination by mycotoxins (fungal toxins produced by naturally occurring filamentous fungi or moulds). To date, several potent mycotoxins have been identified and those of serious concern, based on their toxicity and ubiquity, are aflatoxin, ochratoxin A, the trichothecenes (DON, T–2 toxin), zearalenone, fumonisin, and moniliformin (Bhatnagar *et al.*, 2004).

Mycotoxin producing moulds can infect agricultural crops, particularly cereals and oilseeds, during crop growth, harvest, storage, processing or during the storage of the manufactured compounded feed. Suitable conditions for fungal growth, in terms of warm temperature and moisture, promote mycotoxin contamination. Aflatoxin, a ubiquitious mycotoxin, which is produced primarily by the fungus *Aspergillus flavus* is a major concern because of its carcinogenicity, especially in warm and humid climates. The production of aflatoxins increases at temperatures above 27°C, humidity levels above 62 percent and moisture levels above 14 percent in the feed. For the main aquaculture producing regions of the world, notably Asia, these climatic factors increase the risk of such contamination. The extent of contamination will further be affected by ingredient and feed storage practices and processing methods. Additionally, long duration of transport under poor conditions and improper storage are crucial factors favouring the growth of aflatoxin-producing moulds. Consequently, poorer aquafarmers in developing countries, where quality control of feeds may not be as high as in developed countries, are more likely to acquire contaminated feeds. Further, the recent increase in prices of feed ingredients is likely to drive poor farmers to look for cheaper sources and run the risk of purchasing rejected or contaminated ingredients and feeds.

Mycotoxins pose a serious threat to fish health and well-being. For example, aflatoxins are known to suppress the immune system and growth and increase mortality (Lim and Webster, 2001). Studies on Nile tilapia (*Oreochromis niloticus*) fed diets containing 1.8 mg of aflatoxin/kg of feed for 75 days showed reduced growth rates (Tuan *et al.*, 2002). Impaired immune function has been observed in Indian major carp (*Labeo rohita*) subjected to as low as 1.25 mg of aflatoxin B1/kg body weight in the feed (Sahoo and Mukherjee, 2001). Aflatoxin B1 concentrations of 75 ppb have been demonstrated to significantly reduce growth performance in pre-adult shrimp, Penaeus monodon (Bautista et al., 1994).

The condition, aflatoxicosis, caused by such contamination could be minimized by enforcing strict regulations for screening aquafeed ingredients, such as oilseeds, corn and other feed ingredients, for aflatoxins. As the principal route of such contamination is through ingredients of plant origin, the effects of such contamination on cultured warm-water fishes, such as tilapia, carps, milkfish and catfishes (*Pangasius* spp.), may be more significant because their diets contain more plant than animal ingredients. Effective methods of reducing the effects of mycotoxins using mycotoxin-adsorption agents such as Mycosorb® (Alltech, Inc.) are available, but such additives will increase feed costs further.

3.1.2 Implications of bacterial contamination in fish feeds

Contrary to fungal contamination, bacterial contamination is frequently overlooked but can have serious implication for fish and human health. Feed contaminated with bacteria, pathogenic to humans, can contribute to food borne human illness through the feed-animal-food-human chain.

Feed has been shown to be a major vector for transmission of *Salmonella* to farms and processing plants. Corry *et al.* (2002) compared the number of *Salmonella* serovars found in the feed mills of two integrated companies with those isolates found at their respective processing plants. The percentage of isolates found at the processing plants and feed mills were 56.3 and 54.5 percent, respectively. Hals *et al.* (2006) also found that out of 82 *Salmonella* serotypes found in both production animals and humans, 45 of these were isolated in feed.

Bacterial contamination of feed ingredients affects protein sources of both animal and plant origin. Recent studies have shown that vegetable protein sources, e.g. grains and their by-products, have incidences of Salmonella similar to rendered animal proteins (Barakat, 2004; PDV, 2007). Many bacteria associated with environmental contamination of feed ingredients are of the family Enterobacteriacea and their abundance in ingredients such as unprocessed soybean can be as high as 106–108/g of ingredient (Veldman *et al.*, 1995).

Bacterial contamination of feed can affect animal performance especially through its impact on the form and functioning of the gastrointestinal tract and, hence, growth performance.

Under conditions of increasing feed ingredient prices, farmers and small feed producers may compromise standards and inadvertently acquire contaminated feed ingredients in order to lower costs and in doing so, compromise fish and human health.

3.1.3 Trash fish as aquafeed

In many Asian countries using cheap trash fish as aquafeed is a common practice. As prices for formulated feeds increase, there will be a tendency for farmers elsewhere also to revert to using such sources of feed. In addition to the significant quantities of trash fish required, compared with pelleted diets, the increased frequency of use of trash fish will exasperate water quality problems and compromise fish growth and survival. The direct infection of cultured fish through the consumption of trash fish containing high bacterial loads, particularly of the streptococcal types, are well documented (Austin, 1997; Muroga, 2001; Ghittino *et al.* 2003).

In addition, the procurement of increased quantities of trash fish will require increased capacity to refrigerate and to store feed. For example, in Viet Nam, 3 tonnes of feed are required per day to maintain just two ponds (see Box 5).

3.1.4 Rise in fishmeal replacement with plant ingredients and anti-nutritional factors

The greater pressure on inclusion of proteins and oils of plant origin, will increase the overall negative impacts of anti-nutritional factors present in such ingredients. Greater details on the influence of anti-nutritional factors on diet performance are given in Section 2.5. While these effects may be reduced through processing or through the addition of enzymes, which will increase costs, the use of unprocessed ingredients, which may be cheaper, will compromise fish growth, suppress immune response and reduce survivability.

In addition, reverting to the use of single ingredient supplementary diets, e.g. soybean meal, may also result in the use of nutritionally unbalanced diets. The amino acid in soybean protein, for example, is well known to be limiting in total sulphur amino acids (methionine plus cysteine). Soybeans are characterized by a high content of non-starch polysaccharides (NSPs), which provide marginal energy for the fish and may negatively affect nutrient utilization and reduce feed efficiency (Gatlin *et al.*, 2007). The oligosaccharide component of soybean meal (SBM) also has been linked with reduced growth performance (Refstie, Storebakken and Roem, 1998) and the occurrence of SBM-induced enteritis in several salmonid fish species (van den Ingh *et al.*, 1991; van den Ingh, Olli and Krogdahl, 1996; Bureau, Harris and Cho, 1998). Proteins in plant seeds and seed products often contain anti-nutritional factors such as antigenic compounds, protease inhibitors and lecithin. Lecithin can cause alteration in the intestinal structure and changes in the immune function of fish, while protease inhibitors cease protease enzyme activity. In addition, protease inhibitors, present in many seed meals, can also affect gut health and fish performance. Enzymes of fish seem to be particularly sensitive to these protease inhibitors (Krogdahl and Holm, 1983), but heat treatment will inactivate protease inhibitors if applied correctly.

Approximately two-thirds of the total phosphorus in oilseed meals or grains and their by-product meals is present as phytic acid (phytate), which prevents or lowers the bioavailability of phytate-phosphorus to fish (Gatlin *et al.*, 2007). Further, phytic acid lowers the availability of certain divalent cations, notably zinc, to carnivorous species of fish (trout and salmon) and to omnivorous species (catfish), and also has been reported in some studies to reduce the apparent digestibility of protein. Heat treatment associated with extrusion pelleting does not improve the availability of phytate-phosphorus in oilseed meals or grains (Gatlin *et al.*, 2007).

Greater details on influence of anti-nutritional factors on diet performance is given in Section 2.5.

3.1.5 Adulteration of fishmeal and implication for fish and human health

The rise in costs of fishmeal and the shortage of supply has resulted in the addition by several companies in China of the toxic chemical melamine to fish and animal feeds to artificially inflate protein content (see Box 4). These toxic chemicals entered the human food chain resulting in fatalities and illness (www.naturalnews.com/025836.html).

3.1.6 Contaminants in lower quality fishmeal

As regulations on screening standards for fishmeal form part of enforcement, there is a probability that substandard fishmeal will be disposed at discounted prices and could be acquired by farmers for on-farm feed production and by smaller feed manufactures. In such circumstances, using such contaminated ingredients by farmers, especially those operating on a small scale, will result in bioaccumulation in farmed fish (see Box 4).

BOX 4

Contamination of fishmeal with melamine

According to Chinese media reports, melamine is routinely added to animal feed because it mimics protein in quality tests.

"The feed industry seems to have acquiesced to agree on using the chemical to reduce production costs while maintaining the protein count for quality inspections," the *China Daily* said in an editorial. "We cannot say for sure if the same chemical has made its way into other types of food."

Because the news media in China are state controlled, analysts interpreted the recent reports as a tacit government admission that melamine has widely contaminated animal food products across the country.

In one of the biggest food safety operations in years, 369 000 government agents inspected animal feed operations across the country at the beginning of November, destroying 3 600 tonnes of feed and shutting down 238 producers.

The agriculture ministry reported that a nationwide inspection of the country's quarter of a million animal-feed makers has found at least 500 suspected producers of deliberately adding melamine to their products or of engaging in other questionable practices.

Source: www.naturalnews.com/025836.html

4. Coping strategies and management measures to strengthen national capacity to ensure aquafeed supply

This section provides a brief overview of coping strategies and management measures to strengthen national capacity to address aquafeed supply and to mitigate against rising costs of aquafeed ingredients in terms of policies, research and private sector and farmers' initiatives.

4.1 GOVERNMENT AND POLICIES

- Research institutes should build "institute-industry research partnerships" with feed manufacturers to improve stability of feeds and to increase dietary nutrient retention.
- Given the current limited capacities of national, highly decentralized institutions to conduct the necessary research, development of networking between regional and national institutions appears to be essential. Policies to foster collaboration among the various stakeholders must be formulated and nurtured. Collaboration among local and international research centres, universities, non-governmental organizations and the private sector must also be strengthened.
- Government must formulate policy guidelines that encourage the private sector to participate in research and to build institute-industry partnerships in research. Roles and activities that require public support and those that need to be left to the private sector need to be identified.
- Research policies in aquaculture must reflect present and future incentives for feed manufacturers and incorporate links to other policies regarding taxes, tariffs and subsidies. Import tariffs on feed ingredients and on equipment should be reduced or removed to lower the cost of producing fish feeds and to maintain and improve the country's competitiveness in the world market.
- Government should grant tax holidays for feed manufacturers to compensate for price increases.
- Other sectoral policies regarding credit and investments continue to play significant roles in promoting the expansion of aquaculture throughout the country. Credit is still needed to finance different aquaculture activities, including feed manufacturing and feed operation costs of farmers. An appropriate credit programme should be devised to serve these functions. While private investment should be encouraged, considerable public investment in infrastructure, capacity building (of farmers and small-scale feed producers) and institutional strengthening are needed to sustain the growth and development of the aquaculture sector.
- Capacity building of small-scale farmers should particularly be targeted towards improved feed management at the farm level, including selection of appropriate feed, quantity of feed and feeding methods.
- Water scarcity due to climatic changes has triggered food crisis in many regions of the world and led to recent food shortages and an increase in prices, including prices for ingredients such as grains used in fish feeds. Therefore, agriculture needs to be more efficient to reduce water consumption. Increasing population,

BOX 5

Farmer response to rising aquafeed prices

As of December 2007, farmers and feed producers in the Mekong (Cuu Long) delta region were faced with serious losses as the price of fish feed continued to rocket.

The director of a domestic feed-producing company said that the crux of the problem was the rising costs of raw materials such as bran, soybean residue and saltwater fish.

"They are becoming just too expensive, especially imported material. Producers in the region are looking for replacements but it's a challenge to find products with a high enough protein content."

During November 2007, the prices of these basic ingredients increased by 30 percent, pushing up the cost of feed by VND13 000-VND13 500 per kg.

For fish farmer Le Thi Thu from Tan Khanh Trung village in Dong Thap province, the accelerating prices had a huge impact on her spending, as she needed at least 3 tonnes of feed per day to maintain her two ponds.

"It means I have to spend an additional VND1.8 million per day if I want to buy my favourite brand Pro Conco," she said.

Things were just as bad in the neighbouring provinces of An Giang and Can Tho, fish farmer Nguyen Thi Tien in Thot Not district, Can Tho, complained.

"With the current price of feed, my family has to spend about VND120 million extra to maintain our pond, which is capable of producing 100 tonnes of fish."

Many farmers were reduced to taking out high-interest bank loans to cope with the crisis, while others were turning to home-produced feed. One fish farmer in Chau Phu district, An Giang province said he invested VND500 million in setting up a feed production line and was reaping the rewards.

"I can make as much as I want when I want," he said.

Experienced farmer Sau Huu, from Thot Not district, said he heads to border areas to barter for cheaper materials. Being the owner of a pond capable of producing 8 000 tonnes of *tra* catfish a day, his needs were great.

"I go to the border area near Cambodia to buy soybean residue and place orders with domestic seaports to get cheaper seafish," he said.

Source: http://vietnamnews.vnanet.vn/showarticle.php?num=03ECO061207

pressure on limited land and increasing industrialization and urbanization require agriculture to increase productivity and yield. Thus, the key solution is to improve water use ratio and efficiency. Therefore, governments should invest in innovative technologies for water efficient practices in agriculture to face the food crisis. This in turn will benefit the aquaculture feed industry.

4.2 THE ROLE OF REGIONAL/INTERNATIONAL ORGANIZATIONS

- Research to replace proteins and lipids with alternate plant sources, and to produce nutritionally balanced diets in a cost-effective manner needs to be coordinated at a regional and international level.
- Promotion of low polluting feeds such as low phosphorus diets, improvement of food conversion ratios (FCRs) and reduction of nutrient release to the ecosystem should be given higher priority.
- There is a knowledge gap about the dietary requirements of many commercially important cultured species which is evidenced by fish feeds which lack the balanced nutrient regime required by target species and may well inadvertently increase feed costs.

- Solutions to fishmeal substitution are multifaceted. Recently, microbial and algal species have provided new innovative sources of proteins and land-based animal by-products are being investigated. Research on these new protein sources needs to continue with special emphasis on the issue of the cost of manufacturing.
- To address the critical information gap and to establish networking among the various stakeholders, it would be useful to develop a web-based information network, focusing on aquaculture nutrition and feed resources together with guidelines on how to use and apply the information. The information network would also include analysis of the availability and accessibility of aquaculture feed and feed ingredients and commodity prices as part of a programme to understand the impact of soaring feed prices. The database would be linked to the market prices of feed and commodities and would assist the various stakeholders in devising coping strategies under different scenarios and with different options.

4.3 ROLE OF THE PRIVATE SECTOR

- The private sector should establish small-scale feed producers'/manufacturers' associations catering to farm clusters and the concurrent organization of clusters of small farmers in aquaclubs and/or farmers' associations.
- To reduce production costs, farmers should conduct a technical audit to optimize feed management techniques (selection of appropriate feed [e.g. extruded vs sinking pellet], quantity of feed used and feeding methods [e.g. increasing feeding frequency]).
- To reduce production costs further, farmers should minimize other operating costs.
- The private sector should improve natural productivity (e.g. use of fertilizers) in the relevant production systems to offset costly micronutrients and, therefore, feed costs.

4.4 FARMERS' COPING STRATEGIES TO MITIGATE THE RISING COSTS OF AQUAFEED

Aquafeeds account for 50–70 percent of production costs and, therefore, aquafeed producers require significant working and operational capital for aquafeed production. Farmers who depend on aquafeed ingredients for their own feed production are particularly vulnerable because their inventories and, therefore, risks are invariably higher than commercial aquafeed producers who can buy aquafeed ingredients in bulk. During the recent escalation of feed ingredient prices, costs to farmers of aquafeeds increased by 30–50 percent, thus requiring farmers to secure additional funds to purchase feeds. To mitigate these price increases, farmers in Viet Nam, for example, had to borrow money at significantly high interest rates, travel long distances to obtain cheaper and alternative feedstuffs and in some instances even build their own feed plants (Box 5). In the Mekong Delta, sustained price increases of fish feed had also forced many farmers out of business (Box 6), reducing the area under catfish production by as much as 50 percent. Besides catfish farmers, shrimp farmers are also affected by increasing feed prices and the area under production has decreased by 75 percent in a year (Box 6).

BOX 6

Rising feed prices have forced a significant number of catfish, shrimp and livestock breeders in the southern region of Viet Nam to give up their occupations

The shrimp breeding area in Bac Lieu province fell from 10 000 ha last year to 2 000 ha this year.

More than 30 percent of the catfish breeders in the Cuu Long (Mekong) Delta closed their businesses because of losses caused by high fish-feed prices, according to the Viet Nam Association of Seafood Exporters and Processors (VASEP).

The rise in fish-feed prices was mainly responsible for a loss of VND1 000 (US$0.06) on every kilogram of catfish, said Le Viet Tien, a catfish breeder in Tien Giang province. Many shrimp ponds in the region were also idle for the same reason. The shrimp breeding area in Bac Lieu province had decreased from 10 000 ha in 2008 to 2 000 ha in 2009.

The Animal Feed Association said catfish sold at VND16 500 (US$0.90) a kilogram, up about VND3 000 ($0.20) over the last five months of 2009. The increase in animal feed prices of around VND160 per kilogram, therefore, was reasonable but had no impact on breeders, an association official said.

However, the peak prices, according to catfish breeders, lasted for a very short time, and selling prices at the end of 2009 were just VND14 000 ($0.80) per kilogram. Experts noted that while livestock breeders had expanded production during 2008 by 15 to 20 percent, the area for catfish and shrimp breeding in the Mekong Delta had reduced sharply by 50 percent.

Source: http://english.vietnamnet.vn/biz/2009/06/853846

References

Abdelghany, A.E. 1997. Optimum ratio between anchovy fish meal and soy protein concentrate in formulated diets for Nile tilapia (*Oreochromis niloticus* L.). *In* K. Fitzsimmons (ed.) *Proceedings from the Fourth International Symposium on Tilapia in Aquaculture,* pp. 31–39. Volume 1. Ithaca, New York, Northeast Regional Agricultural Engineering Service. 106 pp.

Abdel-Warith, A., Davies, S.J. & Russell, P. 2001. Inclusion of a commercial poultry by-product meal as a protein replacement of fish meal in practical diets for the African catfish, *Clarias gariepinus*. *Aquaculture Research*, 32: 296–306.

Adamek, Z., Hamackova, J., Kouril, J., Vachta, R. & Stibranyiova, I. 1996. Effect of Ascogen probiotics supplementation on farming success of rainbow trout (*Oncorhynchus mykiss*) and wels (*Silurus glanis*) under conditions of intensive culture. *Krmiva* (Zagreb), 38: 11–20.

AFSD–BAI. 2005. Profile of the feed milling industry. Quezon City, Philippines, Animal Standard Division, Bureau of Animal Industry, Department of Agriculture.

Aquaculture Innovation. 2008. Fishmeal: major limiter of aquaculture growth. Aquaculture Innovation. (available at www.finfish.org/blog/fishmeal–major–limiter–of–aquaculture–growth/)

Aquamax. 2008. Sustainable alternatives to fishmeal and fish oil to produce fish feeds. Aquamax News, August, 2008, No. 3.
(available at www.aquamaxip.eu/files/News_Aquamax_Issue_03.pdf)

Aqua Web. 2009. What is fish feed made of? Bellona Foundation.
(available at www.bellona.org/aquaculture/artikler/Feed_ingredients)

Asean Affairs. 2008. Petrol price hike may trigger domino effect.
(available at www.aseanaffairs.com/page/vietnam)

Asia-Pacfic News. 2008. (available at www.monstersandcritics.com/news/asiapacific/news/article_1407519.php)

Austin, B. 1997. Progress in understanding the fish pathogen *Aeromonas salmonicida*. *Trends in Biotechnology,* 15: 131–134.

Ayyappan, S. & Ahamad Ali, S.A. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in India. *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*, pp. 192–219. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Azaza, M.S., Wassim, K., Mensi, F., Abdelmouleh A., Brini, B. & Kraïem, M.M. 2009. Evaluation of faba beans (*Vicia faba* L. var. minuta) as a replacement for soybean meal in practical diets of juvenile Nile tilapia *Oreochromis niloticus.* Aquaculture, 287: 174–179

Bairagi, A., Gosh, K.S., Sen, S.K. & Ray, A.K. 2004. Evaluation of the nutritive value of *Leucaena leucocephala* leaf meal, inoculated with fish intestinal bacteria *Bacillus subtillis* and *Bacillus circulans* in formulated diets for roho, *Labeo rohita* (Hamilton) fingerlings. *Aquaculture Research*, 35: 436–446.

Barakat, R. 2004. Monitoring feeds for Salmonella in Canada. Animal Feeds Workshop, Atlanta, Georgia, USA, 2004.

Barlow, S. 2000. Fishmeal and fish oil: sustainable ingredients for aquafeeds. *Global Aquaculture Advocate,* 4: 85–88.

Barman, B.K. & Karim, K. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Bangladesh. *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,* pp. 113–140. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Bautista, M.N., Lavilla-Pitogo, C.R., Subosa, P.F. & Begino, E.T. 1994. Aflatoxin B1 contamination of shrimp feeds and its effect on growth and hepatopancreas and pre–adult *Penaeus monodon*. *Journal of the Science of Food and Agriculture*, 65: 5–11.

Bhatnagar, D., Payne, G.A., Cleveland, T.E. & Robens, J.F. 2004. Mycotoxins: current issue in USA. *In* H. Barug, H.P. van Egmond, R. Lopez-Garcia, W.A. van Osenbruggen and A. Visconti (eds). *Meeting the mycotoxin menace,* pp. 17–47. Wageningen, the Netherlands, Wageningen Academic Publisher.

BioMar. 2007. BioMar Annual Report. (available at www.biomar.com)

BioMar. 2008. BioMar Annual Report. (available at www.biomar.com)

Bishop, C.D., Angus, R.A. & Watts, A. 1995. The use of feather meal as a replacement for fishmeal in the diet of *Oreochromis niloticus* fry. *Bioresource Technology*, 54: 291–295.

Bose A.N., Ghosh, S.N., Yang, C.T. & Mitra, A. 1991. *Coastal aquaculture engineering*. New York, Chapman and Hall, Inc. 361 pp.

Borlongan, I.G., Eusebio, P.S. & Welsh, T. 2003. Potential of feed pea (*Pisum sativum*) meal as a protein source in practical diets for milkfish (*Chanos chanos* Forskaal). *Aquaculture,* 225(1–4): 89–98.

Brugère, C. & Ridler, N. 2004. *Global aquaculture outlook in the next decades: an analysis of national aquaculture production forecasts 2030.* FAO Fisheries Circular No. 1001, Rome, FAO. 47 pp.

Bureau D.P. 2008. Meaningful characterisation of the nutritive value of processed animal proteins. *International Aquafeed,* 11(5): 18–19.

Bureau D.P., Harris, A.M. & Cho C.Y. 1998. The effects of purified alcohol extracts from soy products on the feed intake and growth of Chinook salmon (*Oncorhychus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 161: 27–43.

Bureau, D.P., Harris, A.M., Bevan, D.J., Simmons, L.A, Azevedo, P.A. & Cho, C.Y. 2000. Feather meals and meat and bone meals from different origins as protein sources in rainbow trout (*Oncorhynchus mykiss*) diets. *Aquaculture*, 181 281–292.

Burrells, C., William, P.D., Southage, P.J & Wadsworth, S.L. 2001. Dietary nucleotides: a novel supplement in fish feeds 2. Effects on vaccination, salt water transfer, growth rate and physiology of Atlantic salmon. *Aquaculture*, 199: 171–184.

Capell, T. & Christou, P. 2004. Progress in plant metabolic engineering. *Current Opinion in Biochemistry,* 15: 148–154.

Carter, C.G. & Hauler, R.C. 2000. Fish meal replacement by plant meals in extruded feeds for Atlantic salmon, *Salmo salar* L. *Aquaculture*, 185(3–4): 299–311.

Carver, J.D. 1994. Dietary nucleotides: cellular immune, intestinal and hepatic system effects. *Journal of Nutrition*, 124(Suppl. 1S): 144S–148S.

Cline, W.R. 2007. *Global warming and agriculture: impact estimates by country*. Washington, DC, The Peterson Institute for International Economics.

Corry, J.E.L., Allen, V.M., Hudson, W.R., Breslin, M.F. & Davies, R.H. 2002. Sources of salmonella on broiler carcasses during transportation and processing: modes of contamination and methods of control. *Journal of Applied Microbiology*, 92: 424–432.

Davies, S.J. & Gouveia, A. 2008. Enhancing the nutritional value of pea seed meals (*Pisum sativum*) by thermal treatment or specific isogenic selection with comparison to soybean meal for African catfish, *Clarias gariepinus*. *Aquaculture*, 283(1–4): 116–122.

De Silva, S.S. & 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,* pp. 19–48. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Delgado, C.L. 1999. Rising consumption of meat and milk in developing countries has created a new food revolution. *Journal of Nutrition*, 133: 3907S–3910S.

Delgado, C.L, Nickolas, W., Rosegrant, M.W., Meijer, S. & Ahmed, M. 2003. *Fish to 2020. Supply and demand in changing markets*. Washington DC, IFPRI, and Penang, Worldfish Center.

de Wet, L. 2005. Can organic acid effectively replace antibiotic growth promotants in diets for rainbow trout *Oncorhynchus mykiss* raised under sub-optimal water temperatures? Abstract CD-Rom. World Aquaculture Society Conference, Bali, Indonesia, 9–13 May 2005.

Dey, M., Rodriguez, U.P. & Briones, R. 2004. Disaggregated projections on supply, demand and trade for developing Asia: preliminary results and conclusions from the AsiaFish model. *Proceedings of the Biennial Conference of the IIFET*. Corvallis, Oregon, USA, IIFET.

Diebold, G. & Eidelsburger, U. 2006. Acidification of diets as an alternative to antibiotic growth promoters. *In* D. Barug, J. de Long, A.K. Kies & M.W.A. Verstegen (eds), *Antimicrobial growth promoters: Where do we go from here?*, pp. 311–327. The Netherlands, Wageningen Academic Publishers.

Edwards P., Tuan, L.A. & Allan, G.L. 2004. *A survey of marine trash fish and fish meal as aquaculture feed ingredients in Vietnam*. Australian Centre for International Agricultural Research, ACIAR Working Paper No. 57. Canberra, Elect Printing. 56 pp.

El-Sayed, A.F.M. 1990. Long-term evaluation of cotton seed meal as a protein source for Nile tilapia *Oreochromis niloticus. Aquaculture*, 84: 315–320.

Energy Information Administration. 2009. (available at www.eia.doe.gov/)

Fagbenro, O.A. & Davies, S.J. 2001. Use of soybean flour (dehulled, solvent-extracted soybean) as a fish meal substitute in practical diets for African catfish, *Clarias gariepinus* (Burchell 1822): growth, feed utilization and digestibility. *Journal of Applied Ichthyology*, 17**:** 64–69.

Failler, P. 2008. *Future prospects for fish and fishery products. 4. Fish consumption in the European Union in 2015 and 2030. Part 2. Country projections.* FAO Fisheries Circular. No. 972/4, Part 2. Rome, FAO. 392 pp.

FAO. 1997. *Land quality indicators and their use in sustainable agriculture and rural development.* FAO Land and Water Bulletin 5. Rome. 212 pp.

FAO. 2000. The state of food insecurity in the world. Rome.
(available at www.fao.org/focus/e/sofi00/img/sofirep–e.pdf)

FAO. 2003. *World agriculture: Towards 2015/2030. An FAO perspective*. Rome. 430 pp.

FAO. 2004. *Food outlook*. Rome.
(available at www.fao.org/docrep/006/J2518e/J2518e00.htm)

FAO. 2006. *Cultured Aquatic Species Information Programme. Penaeus vannamei.* FAO Fisheries and Aquaculture Department, Rome.
(available at www.fao.org/fishery/culturedspecies/Litopenaeus_vannamei/en)

FAO. 2007. *Food outlook*. Rome.
(available at www.fao.org/docrep/010/ah864e/ah864e09.htm)

FAO. 2008a. Fishery Information, Data and Statistics Unit, FAO Fisheries Department. Fishstat Plus: Universal software for fishery statistical time series. Version 2008–11–02. Release date: March 2008. (available at www.fao.org/fi/statist/FISOFT/FISHPLUS.asp)

FAO. 2008b. *Opportunities for addressing the challenges in meeting the rising global demand for food fish from aquaculture*. Committee on Fisheries: Sub-Committee on Aquaculture, Fourth Session, Puerto Varas, Chile, 6–10 October, 2008. COFI/AQ/IV/2008/6. Rome.

Fasakin, E.A. Serwata, R.D. & Davies, S.J. 2005 Comparative utilization of rendered animal derived products with or without composite mixture of soybean meal in hybrid tilapia (*Oreochromis niloticus* × *Oreochromis mossambicus*) diets. *Aquaculture*, 249: 329–338.

FIN (Fishmeal Information Network). 2007. World production, supply and consumption of fishmeal and fish oil. Information Network.
(available at www.gafta.com/fin/index.php?pge_id=16, accessed on 27 September 2008)

FIN (Fishmeal Information Network). 2008. Annual review of the feed grade fish stocks used to produce fishmeal and fish oil for the UK market. FIN Dossier 2008.
(available at www.iffo.net/intranet/content/archivos/79.pdf)

Fish Site. 2007. Seabass and seabream market report. Fish Site. (available at www.thefishsite.com/articles/330/seabass–and–seabream–market–report)

Fowler, L.G. 1990. Feather meal as a dietary protein source during parr-smolt transformation in fall chinook salmon. *Aquaculture*, 89: 301–314.

Fowler, L.G. 1991. Poultry by-product meal as a dietary protein source in fall chinook salmon diet. *Aquaculture*, 99: 309–321.

Gatlin III, D.M., Barrows, F.T., Brown, P., Dabrowski, K., Gaylord, T.G., Hardy, R.W. Herman, E, Krogdahl, G.H., Nelson, R, Overturf, K., Rust, M., Sealey, W., Skonberg, D., Souza, E.J., Stone, D., Wilson, R. & Wurtele, E. 2007. Expanding the utilization of sustainable plant products in aquafeeds – a review. *Aquaculture Research*, 38: 551–579.

Ghittino, C., Latini, M., Agnetti, F., Panzieri, C., Lauro, L., Ciappelloni, R. & Petracca, G. 2003. Emerging pathologies in aquaculture: effects on production and food safety. *Veterinary Research Communications,* 27: 471–479.

Gibbon, B.C. & Larkins, B.A. 2005. Molecular genetic approaches to developing quality protein maize. *Trends in Genetics*, 21: 227–233.

Gibson, G.R. & Roberfroid, M.B. 1995. Dietary modulation of the human colonic microbiotica: introducing the concept of prebiotics. *Journal of Nutrition*, 125: 1401–1412.

Gill, N., Higgs, D.A., Skura, B.J., Rowshandeli, M., Dosanjh, B.S., Mann, J. & Gannam, A.L. 2006. Nutritive value of partially dehulled and extruded sunflower meal for post-smolt Atlantic salmon (*Salmo salar* L.) in sea water. *Aquaculture Research*, 37: 1348–1359.

Globefish. 2007. Fishmeal Market Report: December 2007. FAO Globefish. (available at www.thefishsite.com/articles/370/fishmeal–market–report–december–2007)

GMA News. 2008. GenSan tuna firms hang on despite high diesel price. (available at www.gmanews.tv/story/111434)

Goda, A.M., El-Haroun, E.R. & Chowdhury, M.A.K. 2007a. Effect of totally or partially replacing of fish meal by alternative protein sources on growth of African catfish *Clarias gariepinus* (Burchell, 1822) reared in concrete tanks. *Aquaculture Research*, 38: 279–287.

Goda, A.M.A-S., Wafa, M.E., El-Haroun, E.R., & Chowdhury, M.A.K. 2007b. Growth performance and feed utilization of Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758) and tilapia galilae *Sarotherodon galilaeus* (Linnaeus, 1758) fingerlings fed plant protein-based diets. *Aquaculture Research*, 38(8): 827–837.

Gouveia, A. & Davies, S.J. 1998. The nutritional evaluation of a pea seed meal (*Pisum sativum*) for juvenile European sea bass (*Dicentrarchus labrax*). *Aquaculture*, 166: 311–320.

Grimble, G.K. 1994. Dietary nucleotides and gut mucosal defence. *Gut*, 35(Suppl.): S46–S51.

Guttieri, M.J., Bowen, D., Dorsch, J.A., Souza, E. & Raboy, V. 2004. Identification and characterization of a low phytic acid wheat. *Crop Science*, 44: 418–424.

Hasan, M.R., Hecht, T., De Silva, S.S. & Tacon, A.G.J. (eds). 2007. *Study and analysis of feeds and fertilizers for sustainable aquaculture development.* FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Hals, T., Wingstrand, A., Bronsted, T. & Wong, D.M.A.L.F. 2006. Human health impact of Salmonella contamination in imported soybean products: a semi quantitative risk assessment. *Food borne Pathogens and Disease*, 3 (4): 422–431.

Hardy, R. 2004. Problems and opportunities in fish feeds-fisheries processing byproducts. *International Aquafeed*, 7 (2): 33–34.

Huang, J., Rozelle, S. & Rosegrant, M.W. 1997. *China's Food Economy to the 21st Century: Supply, Demand and Trade.* 2020 Vision Discussion Paper 19. Washington, DC, International Food Policy Research Institute.

Hung, L.T. & Huy, H.P.V. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Viet Nam. *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*, pp. 331–360. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Index Mundi. 2009. Commodity Price Indices. (available at www.indexmundi.com/)

International Monetary Fund. 2009. (available at www.imf.org/external/index.htm)

Kaushik, S.J., Cravedi, J.P., Lalles, J.P., Sumpter, J., Fauconneau, B. & Laroche, M. 1995. Partial or total replacement of fish meal by soybean protein on growth, protein utilization, potential estrogenic or antigenic effects, cholesterolemia and flesh quality in rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 133: 257–274.

Kissil, G.W., Lupatsch, I., Higgs, D.A. & Hardy, R.W. 2000. Dietary substitution of soy and rapeseed protein concentrates for fish meal, and their effects on growth and nutrient utilization in gilthead sea bream *Sparus aurata* L. *Aquaculture Research*, 31: 595–601.

Krogdahl, Å. & Holm, H. 1983. Pancreatic proteinases from man, trout, rat, pig, cow, chicken, mink and fox. Enzyme activities and inhibition by soybean and lima bean proteinase inhibitors. *Comparative Biochemistry and Physiology,* 74B: 403–409.

Kubitza, F., Lovshin, L.L. & Lovel, R.T. 1997. Identification of feed enhancers for juvinile largemouth bass *Micropterus salmoides. Aquaculture*, 148(2–3): 191–200.

Laporte, J., Woodgate, S.L., Davies, S.J., Serwata, R., Gouveia, A. & Nates, S.F. 2007. Evaluation of a novel protein source for the partial replacement of fish meal in aquafeeds. *International Aquafeed*, 10 (4): 16–23.

Laporte, J., Woodgate, S.L., Davies, S.J., Serwata, R., Gouveia, A. & Nates, S.F. 2009. Poultry meat meal: a valuable source of the partial replacement of fish meal in aquafeeds.. *International Aquafeed*, 12(2): 12–17.

Laurenti, G. 2007. 1961–2003 fish and fishery products: world apparent consumption statistics based on food balance sheets. FAO Fisheries Circular. No. 821, Rev. 8. Rome, FAO. 429 pp.

Laurie C.C., Chasalow S.D., LeDeaux J.R., McCarroll R., Bush D., Hauge B., Lai C., Clark, D., Rocheford, T.R. & Dudley, J.W. 2004. The genetic architecture of response to long-term artificial selection for oil concentration in the maize kernel. *Genetics*, 168: 2141–2155.

Leonardi, M., Sandino, A.M. & Klempau, A. 2003. Effect of a nucleotide-enriched diet on the immune system, plasma cortisol levels and resistance to infectious pancreatic necrosis (IPN) in juvenile rainbow trout (*Oncorhynchus mykiss*). *Bulletin of the European Association of Fish Pathologists*, 23: 52–59.

Li, P., Lewis, D.H. & Gatlin III, D.M. 2004. Dietary nucleotides from yeast RNA influence immune responses and resistance of hybrid bass (*Morone chrysops* x *M. saxatilis*) to *Streptococcus iniae* infections. *Fish and Shellfish Immunology*, 16: 561–569.

Lim, C. & Webster, C.D. 2001. Nutrition and fish health. New York, Food Products Press. 365 pp.

Lozano, N.B.S., Vidal, A.T., Martinez-Llorens, S., Merida, S.N., Blanco, J.E., Lopez, A.M., Torres, M.P. & Cerda, M.J. 2007. Growth and economic profit of gilthead sea bream (*Sparus aurata*, L.) fed sunflower meal. *Aquaculture,* 272(1–4): 528–534.

Lubchenco, J. 2003. The Blue Revolution: A Global Ecological Perspective. *World Aquaculture*, December 2003: 8–10.

Luzier J.M., Summerfelt, R.C. & Ketola, H.G. 1995. Partial replacement with spray-dried blood powder to reduce phosphorus concentrations in diets for juvenile rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Aquaculture Research*, 26: 577–587.

Maciorowski, K.G., Herera, P., Jones, F.T., Pillai, S.D. & Ricke, S.C. 2007. Effects on poultry and livestock of feed contamination with bacteria and fungi. *Animal Feed Science and Technology,* 133: 109–136.

Margat, J. 1996. Les ressources en eau: conception, évaluation, cartographie, compatabilité. Manuels and Méthodes N° 28. FAO/BRGM. Editions, Orleans, France, BRGM.

Martínez-Llorens, S., Vidal, A.T., Moñino, A.V., Ader, J.G., Torres, M.P. & Cerdá, M.J. 2008. Blood and haemoglobin meal as protein sources in diets for gilthead sea bream (*Sparus aurata*): effects on growth, nutritive efficiency and fillet sensory differences. *Aquaculture Research*. 39(10): 1028–1037.

Mente, E., Deguara, S., Santos, M.B. & Houlihan, D. 2003. White muscle free amino acid concentrations following feeding a maize gluten dietary protein in Atlantic salmon (*Salmo salar* L.). *Aquaculture*, 225(1–4): 133–147

Morales, A.E., Carderete, G., De La Higuera, M. & Sanz, A. 1994. Effects of dietary protein source on growth, feed conversion and energy utilization in rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 124: 117–126.

Mukhopadhyay, N. & Ray, A.K. 1999. Effect of fermentation on the nutritive value of sesame seed meal in the diets for rohu, *Labeo rohita* (Hamilton), fingerlings. *Aquaculture Nutrition*, 5: 229–236.

Muroga, K. 2001. Viral and bacterial diseases of marine fish and shellfish in Japanese hatcheries. *Aquaculture,* 202: 23–44.

Mustafa, E.M. & Huseyin, S. 2003. Effects of replacement of fishmeal with poultry by-product meals on apparent digestibility, body composition and protein efficiency ratio in a practical diets for rainbow trout, *Onchorynchus mykiss. Asian-Australasian Journal of Animal Sciences*, 16(9): 1355–1359.

National Bureau of Statistics of China. 2009. (available at www.stats.gov.cn/english/)

Nengas, I., Alexis, M.N. & Davies, S.J. 1999. High inclusion levels of poultry meals and related byproducts in diets for gilthead sea bream *Sparus aurata* L. *Aquaculture*, 179 (1–4): 13–23.

New Europe. 2008. EU sends fishing fleets to troubled waters, feud continues over quotas, and control. (available at www.neurope.eu/articles/87358.php)

Nur, A. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Indonesia. *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*, pp. 245–267. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Nutreco Annual Report. 2004. (available at www.nutreco.com/)

Nutreco Annual Report. 2006. (available at www.nutreco.com/)

Nutreco Annual Report. 2007. (available at www.nutreco.com/)

Pereira, T. G. & Oliva-Teles, A. 2003. Evaluation of corn gluten meal as a protein source in diets for gilthead sea bream (*Sparus aurata* L.) juveniles. *Aquaculture Research*, 34: 1111–1117.

Pfeffer, E., Wiesmann, D. & Henrichfreise, B., 1994. Hydrolyzed feather meal as feed component in diets for rainbow trout (*Oncorhynchus mykiss*) and effects of dietary protein/energy ratio on the efficiency of digestible energy utilization of digestible energy and protein. *Archives of Animal Nutrition*, 46: 111–119.

Popkin, B.M. 1999. Urbanization, lifestyle changes and the nutrition transition. World Development, 27 (11): 1905-1916.

Popkin, B.M. 2001, Nutrition in transition: the changing global nutrition challenge*. Asia Pacific Journal of Clinical Nutrition*, 10(Suppl. 1): 13–18.

PDV. 2007. Evaluation of the measures to control *Salmonella* in the feed sector 2006. Productschap Dievoeder, Quality Series No. 120, June 2007.

Ramadan, A. & Atef, M. 1991. Effect of the biogenic performance enhancer (Ascogen “S”) on growth rate of tilapia fish. *Acta Veterinaria Scandinavica*, 87: S304–S306.

Ramli, N., Heindl, U. & Sunanto, S. 2005. Effect of potassium-diformate on growth performance of tilapia challenged with *Vibrio anguillarum*. Abstract CD-Rom. World Aquaculture Society Conference, Bali, Indonesia, May 9–13, 2005.

Refstie, S., Storebakken, T. & Roem, A.J. 1998. Feed consumption and conversion in Atlantic salmon (*Salmo salar*) fed diets with fish meal, extracted soybean meal or soybean meal with reduced content of oligosaccharides, trypsin inhibitors, lectins and soya antigens. *Aquaculture*, 162: 301–312.

Ringø, E. 1991. Effects of dietary lactate and propionate on growth and digesta in Arctic charr, *Salvelinus alpines* (L). *Aquaculture*, 96: 321–333.

Robaina, L., Moyano, F. J., Izquierdo, M.S., Socorro, J., Vergara, J.M. & Montero, D. 1997. Corn gluten and meat and bone meals as protein sources in diets for gilthead sea bream (*Sparus aurata*): Nutritional and histological implications. *Aquaculture*, 157(3–4): 347–359.

Rola, W.R. & Hasan, M.R. 2007. Economics of aquaculture feeding practices: a synthesis of case studies undertaken in six Asian countries. *In* M.R. Hasan (ed.). *Economics of aquaculture feeding practices in selected Asian countries,* pp. 1–31. FAO Fisheries Technical Paper No. 505. Rome, FAO. 205 pp.

Rosegrant, M.W., Cai, X. & Cline, S.A. 2002. World Water and Food to 2025: Dealing with Scarcity. Washington D.C., International Food Policy Research Institute.

Sahoo, P.K. & Mukherjee, S.C. 2001. Immunosuppressive effects of aflatoxin B1 in Indian major carp (*Labeo rohita*). *Comparative Immunology, Microbiology & Infections Diseases*, 24(3):143–9.

Sajjadi, M. & Carter, C.G. 2004. Dietary phytase supplementation and the utilisation of phosphorus by Atlantic salmon (*Salmo salar* L.) fed a canola-meal-based diet. *Aquaculture*, 240(1–4): 417–431.

Sanz, A., Morales, A.E., De La Higuera, M. & Cardenete, G. 1994. Sunflower meal compared with soybean meal as partial substitutes for fish meal in rainbow trout (*Oncorhynchus mykiss*) diets: protein and energy utilisation. A*quaculture*, 128: 287–300.

Schmidhuber, J. & Tubiello, F.N. 2007. Global food security under climate change. *Proceedings of the National Acadademy of Science,* 104: 19703–19708, doi:10.1073/pnas.0701976104.

Schultz, C., Wickert, M., Kijora, C., Ogunji, J. & Rennert, B. 2007. Evaluation of pea protein isolate as alternative protein source in diets for juvenile tilapia (*Oreochromis niloticus*). *Aquaculture Research*, 38: 537–545.

Shiau, S-Y., Pan, B.S., Chen, S., Yu, H-L. & Sheung-Ling, L. 1988. Successful use of soybean meal with a methionine supplement to replace fish meal in diets fed to milkfish *Chanos chanos* Forskal. *World Aquaculture*, 19: 14–19.

Stepansky, A., Yao, Y., Tang, G. & Galili, G. 2004. Regulation of lysine catabolism in *Arabidopsis* through concertedly regulated synthesis of the two distinct gene products of the composite ATLKR/SDH locus. *Journal of Experimental Botany*, 56: 525–536.

Storebakken, T., Shearer, K.D. & Roem, A.J. 2000. Growth, uptake and retention of nitrogen and phosphorus, and absorption of other minerals in Atlantic salmon Salmo salar fed diets with fish meal and soy-protein concentrate as the main sources of protein. *Aquaculture Nutrition*, 6: 103–108.

Sumagaysay-Chavoso, N.S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in the Philippines. *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,* pp 269–308. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Tacon, A.G.J. 2005. *State of information on salmon aquaculture feed and the environment*. Report prepared for the WWF/US Initiated Salmon Aquaculture Dialogue. 80 pp. (available at www.worldwildlife.org/cci/dialogues/salmon.cfm)

Tacon, A.G.J. 2008. Compound aqua feeds in a more competitive market: alternative protein sources for a more sustainable future. L.E. Cruz Suárez, D. Ricque Marie, M. Tapia Salazar, M.G. Nieto López, D.A. Villarreal Cavazos, J.P. Lazo Corvea and M.T. Viana (eds). *Avances en Nutrición Acuícola IX*. Memorias del Noveno Simposium Internacional de Nutrición Acuícola, Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México, 24–26 Noviembre 2008.

Tacon, A.G.J., Hasan, M.R. & Subasinghe, R.P. 2006. *Use of fishery resources as feed inputs for aquaculture development: trend 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. *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,* pp. 309–330. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Tibaldi, E., Tulli, F., Messina, M., Franchin, C. & Badini, E. 2005. Pea protein concentrate as a substitute for fish meal protein in sea bass diet. *Italian Journal of Animal Science*, 4: 597–599.

Tibaldi, E., Hakim, Y., Uni, Z., Tulli, F., de Francesco, M., Luzzana, U. & Harpaz, S. 2006. Effects of the partial substitution of dietary fish meal by differently processed soybean meals on growth performance, nutrient digestibility and activity of intestinal brush border enzymes in the European sea bass (*Dicentrarchus labrax*). *Aquaculture,* 261: 182–193.

Tuan, N.A., Grizzle, J.M., Lovell, R.T., Manning, B.B. & Rottinghaus, G.E. 2002. Growth and hepatic lesions of Nile tilapia (*Oreochromis niloticus*) fed diets containing aflatoxin B1. *Aquaculture*, 212: 311–319.

Uauy, R. 1994. Nonimmune system responses to dietary nucleotides. *Journal of Nutrition*, 124 (Supplement): 1578–1598.

UN. 2007. *World Population prospects*. The 2006 Revision. Department of Economics and Social Affairs, Population Division of the United Nations.
(available at www.un.org/esa/population/publications/wpp2006/English.pdf)

USDA. 2009. (available at www.usda.gov/wps/portal/usdahome)

Van den Ingh, T.S.G.A.M., Krogdahl, Å., Olli, J.J., Hendrix, H.G.C.J.M. & Koninkx, J.G.J.F. 1991. Effects of soybean containing diets on the proximal and distal intestine in Atlantic salmon (*Salmo salar*): a morphological study. *Aquaculture*, 94: 297–305.

Van den Ingh, T.S.G.A.M., Olli, J.J. & Krogdahl, Å. 1996. Alcohol-soluble components in soybeans cause morphological changes in the distal intestine of the Atlantic salmon, *Salmo salar* L. *Journal of Fish Disease*, 19: 47–53.

Veldman, A., Vahl, H.A., Borgreve, G.J. & Fuller, D.C. 1995. A survey of the incidence of the Salmonella species and Enterobacteriacea in poultry feeds and feed components. *Veterinary Record*, 136: 169–172.

Viola, S., Mokady, S., Rappaport, U. & Arieli, Y. 1982. Partial and complete replacement of fishmeal by soybean meal in feeds for intensive culture of carp. *Aquaculture,* 26(3–4): 223–236.

Vulevic, R.A., Rastall, R.A. & Gibson, G.R. 2004. Developing a quantitative approach for determining the in vitro prebiotic potential of dietary oligosaccharides. *FEMS Microbiology Letters*, 236: 153–159.

Weimin, M. & Mengqing, L. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in China. *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,* pp. 141–190. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

WHO. 2002. Diet nutrition and the prevention of chronic disease. WHO Technical Report Series 916. WHO and FAO. (available at www.fao.org/docrep/005/AC911E/ac911e05.htm)

Wijkstrom, U.N. 2003. Short and long-term prospects for consumption of fish. *Veterinary Research Communications*, 27(Suppl.)1: 461–468.

WorldFish Center. 2004a. *Profile of Key Aquaculture Technologies and Fishing Practices: Indonesia. Sustaining aquaculture and fisheries to benefit poor households in Asia.* ADB-RETA 5945. Worldfish Center. (available at www.worldfishcenter.org/demandsupply/inception_reportaug02/ir_aug02_profileofkatfp_indonesia.asp)

WorldFish Center. 2004b. *Profile of Key Aquaculture Technologies and Fishing Practices: Thailand. Sustaining aquaculture and fisheries to benefit poor households in Asia.* ADB-RETA 5945. Worldfish Center.
(available at www.worldfishcenter.org/demandsupply/inception_reportaug02/ir_aug02_profileofkatfp_thailand.asp)

WorldFish Center. 2004c. *Profile of Key Aquaculture Technologies and Fishing Practices: Vietnam. Sustaining aquaculture and fisheries to benefit poor households in Asia*. ADB-RETA 5945. Worldfish Center. (available at www.worldfishcenter.org/demandsupply/inception_reportaug02/ir_aug02_profileofkatfp_vietnam.asp)

WRI. 2008. Earth Trends: The Environmental Information Portal. World Resource Institute online. (available at www.earthtrends.wri.org/searchable_db/index.php?theme=2&variable_ID=693&action=select_countries)

WW4 Report. 2008. Mexico: fishermen strike over fuel prices. (available at www.ww4report.com/node/6644)

Ye, Y. 1999. *Historical consumption and future demand for fish and fishery products: Exploratory calculations for the years 2015–2030*. FAO Fisheries Circular No. 946. Rome, FAO. 31 pp.

Yoshitomi, B., Aoki, M., Oshima, S. & Hata, K. 2006. Evaluation of krill (*Euphausia superba*) meal as a partial replacement for fish meal in rainbow trout (*Oncorhynchus mykiss*) diets. *Aquaculture*, 261(1): 440–446.

The present technical paper investigates and evaluates the underlying reasons for the recent dramatic rise in prices of many of the commodities (e.g., soybean, corn, fishmeal, fish oil, rice and wheat) used in aquafeed production and its consequences for the aquafeed industry, and in particular, on demand and expectations from aquaculture in securing current and future fish supplies with particular reference to Asia and Europe. This technical paper also discusses issues related to availability of and access to land and water resources, and the impact of other sectors, using these resources, on the direction of aquaculture both in terms of species produced and the production systems. In the light of probable increase in competition for land and water in many aquaculture producing countries in Asia, there will inevitably be increasing pressure to intensify aquaculture productivity through the use of more commercial feeds than farm-made feeds. Due to the increasing prices of ingredients, aquafeed prices, especially the prices of compound aquafeeds, may increase further and a shortfall in the local supplies will compel importation of aquafeeds. Of the ingredients, fishmeal and fish oil are highly favoured for aquafeeds and aquafeed production is under increasing pressure due to limited supplies and increasing price of fishmeal and fish oil. Considering these factors, this review also outlines initiatives that are searching for substitutes for fishmeal and fish oil so as to position the industry to meet the challenge of securing aquafeed for sustaining aquaculture. A brief overview of coping strategies to strengthen national capacity to address the issue of aquafeed supply and to mitigate rising prices of aquafeed ingredient is given. These strategies include policies, research and private sector and farmers' initiatives.

ISBN 978-92-5-106422-1 ISSN 2070-7010

9 789251 064221

I1143E/1/10.09/1700