Demand and Supply of Feed Ingredients for Farmed Fish and Crustaceans. Trends and Prospects

Technical Report · January 2011

CITATIONS
292

READS
1,436

3 authors:

Albert Tacon
University of Hawai'i System
77 PUBLICATIONS **7,824** CITATIONS
SEE PROFILE

Mohammad R Hasan
Food and Agriculture Organization of the United Nations
65 PUBLICATIONS **2,150** CITATIONS
SEE PROFILE

Marc Metian
International Atomic Energy Agency (IAEA)
156 PUBLICATIONS **6,185** CITATIONS
SEE PROFILE

FAO
FISHERIES AND
AQUACULTURE
TECHNICAL
PAPER

ISSN 2070-7010

564

Demand and supply of feed ingredients for farmed fish and crustaceans

Trends and prospects

Cover photograph:
Drying of farm-made aquafeed for Nile tilapia, Jamalpur, Bangladesh (courtesy of FAO/Mohammad R. Hasan).

Demand and supply of feed ingredients for farmed fish and crustaceans

Trends and prospects

FAO
FISHERIES AND
AQUACULTURE
TECHNICAL
PAPER

564

Albert G.J. Tacon
FAO Consultant
Hawaii, United States of America

Mohammad R. Hasan
Aquaculture Officer
Aquaculture Service
FAO Fisheries and Aquaculture Department
Rome, Italy

and

Marc Metian
Littoral Environment and Societies
University of La Rochelle
La Rochelle, France

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2011

ISBN 978-92-5-106933-2

Preparation of this document

This document was prepared as part of the Food and Agriculture Organization of the United Nations (FAO) Aquaculture Service's (FIRA) ongoing regular work programme on "Study and analysis on use of feed and nutrient in sustainable aquaculture development", under strategic objective "Sustainable management and use of fisheries and aquaculture resources", and was partially funded by the FAO Multidonor Partnership Programme.

This technical paper was reviewed for technical content by Dr Methil N. Kutty. Pedro Bueno is acknowledged for his comments on the manuscript. For consistency and conformity, scientific and English common names of fish species were used from FishBase (www.fishbase.org/search.php).

The authors would also like to acknowledge the following colleagues (commercial feed manufacturers and/or nutritionists) for their kind assistance in providing information during an electronic survey conducted for this study: Syed Ahamad Ali, Niels Alsted, Michel Autin, Christian Berger, Aliro Borquez, Hans Erik Bylling, Ian Carr, Rodrigo Carvalho, Silvio Coelho, José Duarte, Carlos Mastrokalo Durand, Fabricio Vargas Elias, Abdel-Fattah El-Sayed, Kevin Fitzsimmons, Brett Glencross, Ozlem Guzel, Brad Hicks, Santiago Panné Huidobro, Patricia Infante, Dave Jackson, Jeongdae Kim, Claudio Larraín, Daniel Lemos, Menghe Li, Christian Lückstädt, Umberto Luzzana, Cesar Molina, Jessica Montaño, Sigve Nordum, Dave Robb, Cheryl Shew, Shi-Yen Shiau, Supis Thongrod, Francisco Velasquez, Miao Weimin, Iannis Zarkadis and Jesus Zendejas.

The authors acknowledge Maria Giannini for her assistance in quality control and FAO house style and Koen Ivens for layout design. The publishing and distribution of the document were undertaken by FAO, Rome. Finally, Jiansan Jia, Chief of the Aquaculture 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

The rise into global prominence and rapid growth of finfish and crustacean aquaculture has been due, in part, to the availability and on-farm provision of feed inputs within the major producing countries. More than 46 percent of the total global aquaculture production in 2008 was dependent upon the supply of external feed inputs. For the aquaculture sector to maintain its current average growth rate of 8 to 10 percent per year to 2025, the supply of nutrient and feed inputs will have to grow at a similar rate. This had been readily attainable when the industry was young. It may not be the case anymore as the sector has grown into a major consumer of and competitor for feed resources. This paper reviews the dietary feeding practices employed for the production of the major cultured fed species, the total global production and market availability of the major feed ingredient sources used and the major constraints to feed ingredient usage, and recommends approaches to feed ingredient selection and usage for the major species of cultivated fish and crustacean. Emphasis is placed on the need for major producing countries to maximize the use of locally available feed-grade ingredient sources, and, in particular, to select and use those nutritionally sound and safe feed ingredient sources whose production and growth can keep pace with the 8 to 10 percent annual average annual growth of the fed finfish and crustacean aquaculture sector.

Tacon, A.G.J.; Hasan, M.R.; Metian, M.
Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects.
FAO Fisheries and Aquaculture Technical Paper No. 564. FAO, 2011. 87 pp.

Contents

TABLES

FIGURES

Contributors

Mohammad R. Hasan, Aquaculture Officer, Aquaculture Service
FAO Fisheries and Aquaculture Department, Rome, Italy
E-mail: mohammad.hasan@fao.org

Marc Metian, Littoral Environment and Societies
University of La Rochelle, La Rochelle, France
E-mail: marc.metian@univ-lr.fr

Albert G.J. Tacon, FAO Consultant, Aquatic Farms Ltd
Hawaii, United States of America
E-mail: agjtacon@aol.com

Abbreviations and acronyms

ABP	animal by-products
BM	blood meal
CGM	corn gluten meal
CP	crude protein
CPC	canola protein concentrate
CSM	cottonseed meal
DE	digestible energy
DHA	docosahexaenoic acid
DP	digestible protein
EFCR	economic feed conversion ratio
EPA	eicosapentaenoic acid
EU	European Union
FAQ	fair average quality
FBM	faba bean meal
FM	fishmeal
FO	fish oil
FOB	free on board
FPM	field pea meal
G/PM	groundnut/peanut meal
HFM	hydrolysed feather meal
IFFO	International Fishmeal and Fish Oil Organisation
KM	krill meal
LKM	lupin kernel meal
MA	maize/corn
MBM	meat and bone meal
MC	mustard seed cake
MM	meat meal
Mtoe	million tonnes of oil equivalent
nei	not elsewhere included
PBM	poultry by-product meal
PO	poultry oil
RB	rice bran
R/CM	rapeseed/canola meal
R/CO	rapeseed/canola oil
SBM	soybean meal
SCP	single cell protein
SL	soy lecithin
SM	squid meal
SO	soybean oil
SSM	sunflower seed meal
US$	US dollar
USDA	United States Department of Agriculture
WB	wheat bran
WF	wheat flour
WGM	wheat gluten meal
WH	wheat
WM	wheat middlings

Executive summary

The rapid rise and growth of finfish and crustacean aquaculture has been due, in part, to the availability and on-farm provision of feed inputs within the major producing countries. If the aquaculture sector is to maintain its current average growth rate of 8 to 10 percent per year to 2025, the supply of nutrient and feed inputs will need to grow at a comparable rate. While this may have been readily attainable when the industry was still in its infancy, this may not be the case in the future as the sector matures and grows into a major consumer and competitor for feed resources.

It is estimated that about 31.5 million tonnes of farmed fish and crustaceans (46.1 percent of the total global aquaculture production in 2008) is dependent upon the supply of external nutrient inputs provided in the form of fresh feed items, farm-made feeds or commercially manufactured feeds. Total industrial compound aquafeed production increased more than threefold, from 7.6 million tonnes in 1995 to 29.2 million tonnes in 2008, with production growing at an average rate of 11.0 percent per year. Aquafeed production is expected to continue growing at a similar rate to 71.0 million tonnes by 2020. Although current estimates for industrially produced aquafeed for the period 2007–2010 vary between 24.4 and 28.9 million tonnes, aquafeed volume represents only 4 percent of the total global animal feed production of the over 708 million tonnes in 2009. In contrast to compound aquaculture feeds, there is no comprehensive information on the global production of farm-made aquafeeds (estimated at between 18.7 and 30.7 million tonnes in 2006) and/or on the use of low-value fish/trash fish as feed, with 2008 estimates for China at 6 to 8 million tonnes.

Fed aquaculture production, in particular, of higher trophic level finfish and crustaceans (includes marine shrimps, salmonids, marine finfishes, eels) are largely dependent upon capture fisheries for the supply of their major dietary source of protein and lipids. For example, on a global basis, it is estimated that the aquaculture sector consumed 3.72 million tonnes of fishmeal (60.8 percent of global fishmeal production) and 0.78 million tonnes of fish oil (73.8 percent of global fish oil production) in 2008; it was 3.84 million tonnes of fishmeal (or 68.4 percent of global production) and 0.82 million tonnes of fish oil (or 81.3 percent of global production) in 2007. Despite this continued dependence of aquaculture production on fishmeal and fish oil, there remains a wide variation in fishmeal and fish oil usage between major producing countries for individual farmed species. This variation mainly reflects differences between countries concerning the selection and use of fishmeal and fish oil replacers from plant sources or by the use of land animal proteins and fats in feeds for high trophic-level fish and crustacean species.

The total use of fishmeal by the aquaculture sector is expected to decrease in the long term. It has gone down from 4.23 million tonnes in 2005 to 3.72 million tonnes in 2008 (or 12.8 percent of total aquafeeds by weight), and is expected to decrease to 3.49 million tonnes by 2020 (or 4.9 percent of total aquafeeds). The reasons for this are the diminishing amount of fishmeal and fish oil supplies owing to tighter quota setting and additional controls on unregulated fishing and the increased use of more cost-effective dietary fishmeal replacers. On the contrary, the use of fish oil by the aquaculture sector will probably increase in the long run albeit slowly; total usage will increase by more than 16 percent, from 782 000 tonnes (2.7 percent of total feeds by weight) in 2008 to the estimated 908 000 tonnes (1.3 percent of total aquafeeds for that year) by 2020. Increased usage will shift from salmonids to marine finfishes and crustaceans because of the current absence of cost-effective alternative lipid sources that are rich in long-chain polyunsaturated fatty acids. Increasing volumes of fishmeal and fish oil are likely to come from fisheries by-products, extracted from both wild capture and farmed fish. Estimates have been made that around 25 percent of fishmeal production in 2007 came from by-products. This will grow as it becomes increasingly viable to process this material.

It is estimated that the total usage of terrestrial animal by-product meals and oils within compound aquafeeds ranges between 0.15 and 0.30 million tonnes, or less than 1 percent of total global compound aquafeed production – clearly, there is considerable room for increased usage. In addition to meat meal, or, to a lesser extent meat and bone meal, ingredients such as blood meal, poultry by-product meal and poultry oil have all been very effective in feeds for a number of aquatic species.

Soybean meal is the most common source of plant proteins used in compound aquafeeds, with feeds for herbivorous and omnivorous fish species and crustaceans usually containing from 15 to 30 percent soybean meal, with a mean of 25 percent in 2008. In global usage terms, and based on a total compound aquafeed production of 27.1 million tonnes in 2007, it is estimated that the aquaculture feed sector consumed about 6.8 million tonnes of soybean meal (25.1 percent of total compound aquafeeds by weight). Other plant proteins being increasingly used include corn products, pulses, oilseed meals and protein from other cereals products.

Alternative lipid sources to fish oil are being used in greater amounts. Key alternatives include vegetable oils, preferably those with high omega-3 contents, and poultry oil. The use of oil from farmed fish offal is also a potential omega-3 source for other farmed fish. The production of marine microalgae or bacteria with very high contents of highly unsaturated fatty acids is currently expensive for use in most aquaculture feeds, but more cost efficient production methods will change this.

Prices for food and feed ingredients have been rising and are likely to continue to rise owing to the increasing demands from an increasing population, the diversion of some grains for use in biofuels, the increasing costs of production and transport, and the changes in global trade owing to the demand of food and raw materials from China and other emerging economies. The focus on carbohydrate-rich fractions for production of biofuels may indeed provide an opportunity to use protein fractions for feed ingredients.

Although current discussion on the use of marine products as aquafeed ingredients focuses on fishmeal and fish oil resources, the sustainability of the aquaculture sector is more likely to be linked with the sustained supply of terrestrial animal and plant proteins, oils and carbohydrate sources for aquafeeds. This is because a significant proportion of aquaculture production is of the non-carnivorous species. Therefore, aquaculture producing countries should place more emphasis to maximize the use of locally available feed-grade ingredient sources and use nutritionally sound and safe feed ingredients that can be sustainably produced and grow with the sector.

Cage culture of Atlantic salmon (Salmo salar) *in a fjord, Norway.*

Courtesy of FAO Fisheries and Aquaculture Department photo library

1. Introduction

The dramatic rise and emergence of acquaculture onto the global marketplace as a major provider of much-needed farmed aquatic food produce were spurred by a combination of factors. Chief among them include:

- the in-country promotion of aquaculture as a viable economic activity and source of livelihood;
- the in-country provision of an enabling legislative framework for conducting the activity;
- the in-country availability of suitable land and water resources and technical know-how for conducting aquaculture farming operations; and
- the in-country availability and on-farm provision of nutrient inputs in terms of fertilizers and/or feed.

For finfish and crustacean aquaculture to maintain its current average annual growth rate of 8 to 10 percent per year to 2025, the external provision of nutrient and feed inputs will have to grow at a similar rate. This had been easily attainable when the industry was young. It will be more difficult as the sector grows into a major consumer and competitor for feed resources.

The aim of this paper is to:

- review the dietary feeding practices employed for the production of the major cultivated fish and crustacean species, including major feed ingredients used;
- review the total production and market availability of the major feed ingredient sources, including current usage by sector;
- review the major constraints to feed ingredient availability and use by the aquaculture sector on a regional and global basis; and
- recommend approaches to feed ingredient selection and usage within dietary feeding regimes for the major cultivated fish and crustacean species.

For the purposes of this paper, only dietary feeds and feeding regimes based on the external provision of fresh feed (usually fed singly, and including low-value/trash fish and cut green fodder), farm-made feed, and commercial feed composed of mixtures of different feed ingredient sources will be considered.

Hand feeding (broadcasting) of Indian major carps in a pond, Myanmar. Hand feeding in ponds for carp culture has been adopted recently in Myanmar and is not very common; each pond generally varies from 1 to 4 hectares.

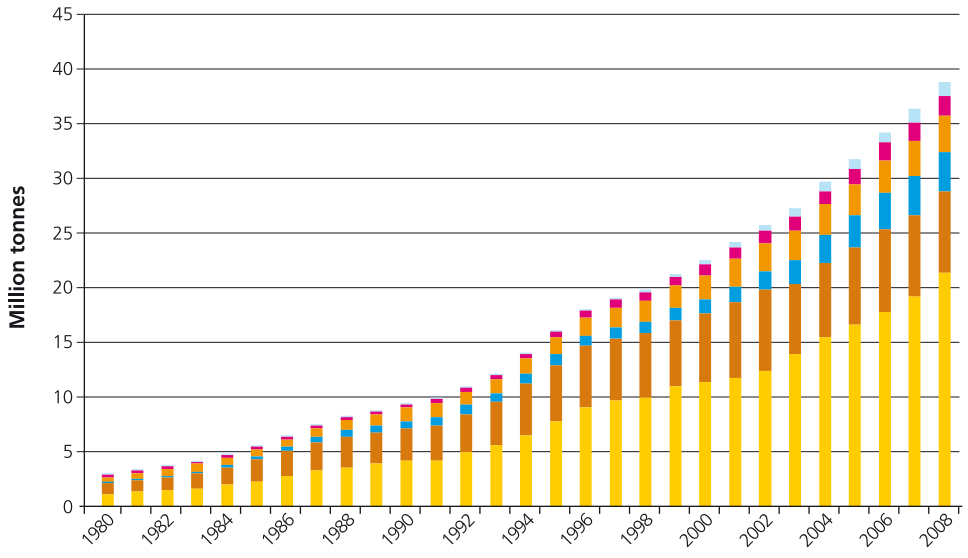
Courtesy of M.C. Nandeesha

2. Current feeds and feeding practices

2.1 MAJOR FED FISH AND CRUSTACEAN SPECIES

In 2008, about 31.5 million tonnes of farmed fish and crustaceans, or the equivalent of 46.1 percent of the total global production of farmed aquatic animals and plants, was dependent upon the supply of nutrient inputs in the form of externally provided fresh feed items, farm-made feeds or commercial pelleted feeds. The above estimate excludes filter-feeding fish species (silver carp and bighead carp: total production 6.10 million tonnes in 2008) and freshwater fish production not reported down to the species level (1.2 million tonnes in 2008; FAO, 2010a). Moreover, of the more than 200 species of fish and crustaceans currently believed to be fed on externally supplied feeds (Annex 1), nine species account for 62.2 percent of total global-fed species production, including grass carp (*Ctenopharyngodon idellus*), common carp (*Cyprinus carpio*), Nile tilapia (*Oreochromis niloticus*), catla (*Catla catla*), whiteleg shrimp (*Litopenaeus vannamei*),

FIGURE 1
Total global production of fed fish and crustacean species by major FAO species grouping, 1980–2008



GROWTH	APR (%/year)					Change (%)		
	80-85	85-90	90-95	95-00	00-05	05-06	06-07	07-08
Freshwater fishes: fed species	+14.9	+12.3	+13.5	+8.0	+7.9	+6.5	+8.5	+11.3
Freshwater fishes: non-fed species	+16.6	+8.2	+11.4	+3.7	+2.6	+7.5	-2.5	-1.0
Marine crustaceans: fed species	+24.4	+25.8	+7.3	+5.3	+17.8	+16.0	+5.9	+3.6
Diadromous fishes: fed species	+6.5	+12.4	+4.7	+8.2	+4.9	+4.7	+8.0	+2.2
Marine fishes: fed species	+4.0	+6.6	+11.5	+12.2	+8.1	+13.9	+5.8	+4.5
Freshwater crustaceans: fed species	+23.7	+12.2	+8.1	+32.7	+16.3	+4.5	+33.2	+7.7

Source: FAO (2010a).

crucian carp (*Carassius carassius*), Atlantic salmon (*Salmo solar*), pangasiid catfishes (striped/tra catfish [*Pangasianodon hypophthalmus*] and basa catfish [*Pangasius bocourti*]), and rohu (*Labeo rohita*; Table 1; FAO, 2010a). In this respect, aquaculture is no different from animal husbandry, in that global livestock production is concentrated in a few species; in agriculture, the top eight livestock species are pig, chicken, cattle, sheep, turkey, goat, duck and buffalo (FAO, 2010b).

Figure 1 shows the total global production of fed fish and crustaceans by major species grouping, together with their respective growth at five yearly intervals, from 1980 to 2008. In marked contrast to capture fisheries, freshwater fish species dominate finfish aquaculture production (Tacon, Metian and Hasan, 2009), with over 80.8 percent of fed finfish production being freshwater species in 2008 (FAO, 2010a; Annex 1).

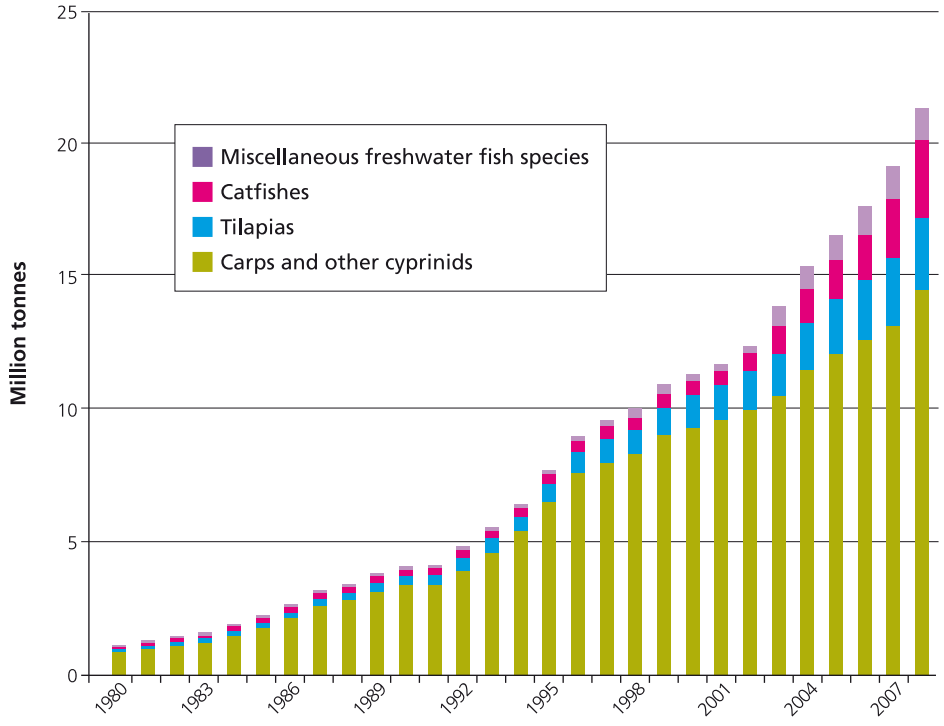
Of particular note is the double-digit growth rates of all major groupings during the 1980s and 1990s, with the overall growth of fed fish and crustacean aquaculture production stabilizing at an average of 10.5 percent per year by 2008. In contrast, livestock meat production and capture fisheries production have grown at an average rate of 2.5 percent and 1.3 percent per year, respectively, since 1980 (FAO, 2010b).

The major fed fish and crustacean species groups can be ranked in order of total global production by weight in 2008, as shown below.

Fed freshwater fishes: 21.34 million tonnes, valued at US$27.36 billion (Figure 2; Annex 1):

- carps and other cyprinids – 14.43 million tonnes, nine major species;
- tilapias – 2.80 million tonnes, two major species;
- catfishes – 2.78 million tonnes, six major species; and
- miscellaneous freshwater fishes – 1.33 million tonnes, six major species.

FIGURE 2
Growth of fed freshwater fish species, 1980–2008

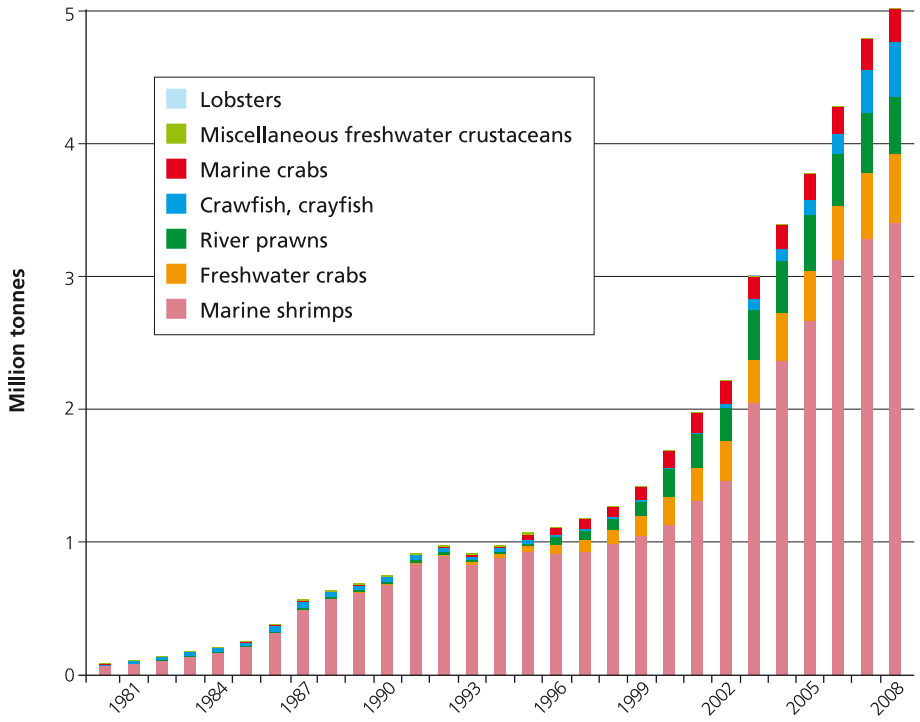


Source: FAO (2010a).

Fed marine crustaceans: 3.64 million tonnes, valued at US$15.0 billion (Figure 3; Annex 1):

- shrimps – 3.40 million tonnes, six major species; and
- crabs – 241 000 tonnes; one major species.

FIGURE 3
Growth of fed crustacean species, 1980–2008



Source: FAO (2010a).

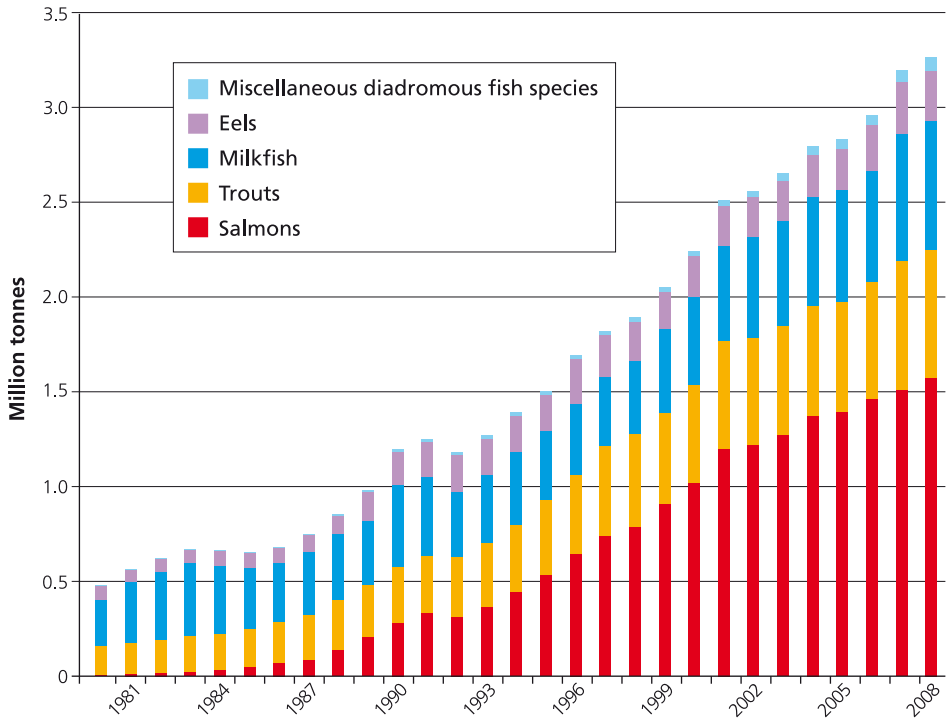
Fed diadromous fishes: 3.26 million tonnes, valued at US$12.95 billion (Figure 4; Annex 1):

- salmons – 1.57 million tonnes, two major species;
- trouts – 677 000 tonnes, one major species;
- milkfish – 676 000 tonnes, one major species;
- eels – 265 000 tonnes, one major species; and
- miscellaneous diadromous fish species – 71 000 tonnes; one major species.

Fed marine fishes: 1.77 million tonnes, valued at US$6.6 billion (Figure 5; Annex 1):

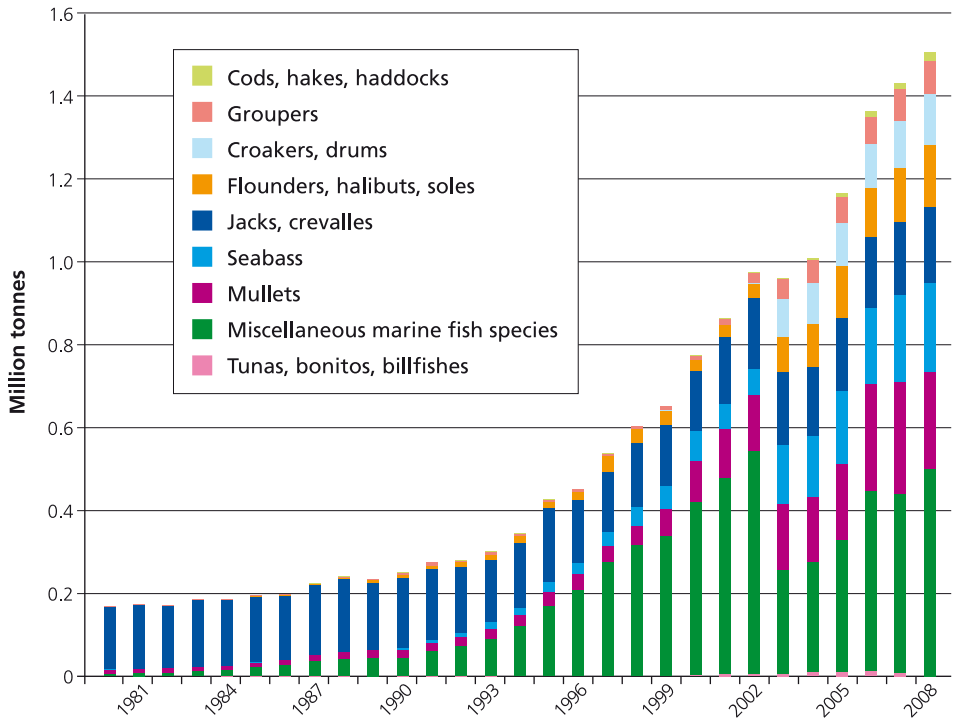
- seabass – 214 000 tonnes, two major species;
- mullets – 235 000 tonnes, one major species;
- porgies, seabreams – 253 000 tonnes, two major species;
- jacks, crevalles – 184 000 tonnes, one major species;
- flounders, halibuts, soles – 149 000 tonnes, two major species;
- croakers, drums – 123 000 tonnes, two major species;
- groupers – 78 000 tonnes;
- cods, hakes, haddocks – 21 387 tonnes, one major species;
- tunas, bonitos, billfishes – 8 926 tonnes, one major species; and
- miscellaneous marine fish species – 499 000 tonnes, three major species.

FIGURE 4
Growth of fed diadromous fish species, 1980–2008



Source: FAO (2010a).

FIGURE 5
Growth of fed marine fish species, 1980–2008



Source: FAO (2010a).

Fed freshwater crustaceans: 1.37 million tonnes, valued at US$7.7 billion (Figure 3; Annex 1):

- crabs – 518 000 tonnes, one major species;
- crawfishes, crayfishes – 418 000 tonnes, one major species; and
- river prawns – 426 000 tonnes, two major species.

Over the period 2000–2008, the fastest-growing major fed species group was catfishes (23.0 percent annual percentage rate [APR], Figure 2); followed by miscellaneous freshwater fishes (21.7 percent APR, Figure 4); freshwater crustaceans (15.9 percent APR, Figure 3); marine shrimps (14.7 percent APR, Figure 3); tilapias (11.3 percent APR, Figure 2); and marine fishes (8.1 percent APR, Figure 5; FAO, 2010a). This contrasts with the reduced growth of carps (5.6 percent APR, Figure 2); salmons (5.5 percent APR, Figure 4); milkfish (4.7 percent APR, miscellaneous diadromous species, Figure 4); trouts (3.5 percent APR, Figure 4); and eels (2.8 percent APR, Figure 4) over the same period.

2.2 IN-COUNTRY FED SPECIES PRODUCTION AND FEEDING PRACTICES

On a global basis, more than 85.5 percent of fed fish and crustacean aquaculture production was produced on the Asian continent in 2008 (26.9 million tonnes), followed by the Americas (1.93 million tonnes, or 6.1 percent), Europe (1.64 million tonnes, or 5.2 percent), Africa (0.94 million tonnes, or 3.0 percent), and Oceania (50 317 tonnes, or 0.2 percent; FAO, 2010a).

Twenty countries accounted for 94 percent of total global fed fish and crustacean production in 2008, with China alone accounting for about half of the global total (Table 1).

These top 20 fed species producers were also the largest consumers and producers of feed, either in the form of fresh feeds, farm-made feeds or commercial feeds.

Table 2 lists the top 53 fed cultured fish and crustacean species/species groups by main country producers in 2008, and includes the average in-country unit value of the cultured species (US$/kg), the reported farm production unit, and the reported feeding practices employed for each species.

TABLE 1
Top 20 country producers of fed fish and crustacean species in 2008

Country	Production (million tonnes)	Percent of total production
China	15.67	49.8
India	3.08	9.8
Viet Nam	2.12	6.7
Indonesia	1.64	5.2
Thailand	1.03	3.3
Norway	0.84	2.7
Philippines	0.70	2.2
Egypt	0.69	2.2
Myanmar	0.65	2.1
Chile	0.63	2.0
Bangladesh	0.62	2.0
United States	0.34	1.1
Japan	0.30	1.0
Brazil	0.27	0.8
Taiwan Province of China	0.22	-
Ecuador	0.17	-
Malaysia	0.17	-
Turkey	0.15	-
Mexico	0.14	-
United Kingdom	0.14	-

Source: FAO (2010a).

Fed carps and other cyprinids (Chinese carps, Indian major carps, other cyprinids): represent the largest and historically oldest fed species group, with an average growth rate of 5.6 percent per year over the last decade (Figure 2; FAO, 2010a). It is estimated that the percentage of total fed carp production (excluding Indian major carps) based on commercial feeds increased from 20 percent in 1995 to 48 percent in 2008, with total global commercial carp feed production increasing from 2.1 million tonnes in 1995 to 9.1 million tonnes in 2008 and estimated to reach 15.8 million tonnes by 2020 (Table 3). By contrast, almost all Indian major carp production is still based on the use of low-cost locally produced farm-made feeds (Ayyappan and Ahamad Ali, 2007), with fresh feed items still only being fed to Chinese carps (primarily grass carp), depending upon the financial resources of the farmer (Barman and Karim, 2007; Weimin and Mengqing, 2007).

Of particular note is the difference in the estimated farmgate unit value of the same species among producing countries, depending upon preferences. For example, grass carp has a minimum reported unit value of US$0.80/kg in China and a maximum reported unit value of US$3.0 in the Islamic Republic of Iran (FAO, 2010a); the latter higher market values would allow the use of more costly farm production methods and feeding methods.

Tilapias: represent the second-largest fed species group among freshwater fishes, with an average growth rate of 11.3 percent per year over the last decade (Figure 2; FAO, 2010a). The percentage of total fed tilapia production based on commercial feeds increased from 70 percent in 1995 to 83 percent in 2008, with total global commercial tilapia feed production increasing from 0.99 to 3.95 million tonnes from 1995 to 2008 and estimated to reach 12.0 million tonnes by 2020 (Table 3).

Catfishes: represent the third-largest fed species group among freshwater fishes, with the sector growing at a very high rate of 23.0 percent per year over the last decade (Figure 2; FAO, 2010a). About 72 percent of total fed global catfish production was based on commercial feeds in 2008 (Table 2), with commercial catfish feed production increasing from 586 000 tonnes in 1995 to 3.0 million tonnes in 2008 and estimated to reach 12.5 million tonnes by 2020 (Table 3).

Miscellaneous freshwater fishes: represent the fourth-largest fed species group among freshwater fishes, registering a high growth rate of 21.7 percent per year over the last decade (Figure 2; FAO, 2010a). It is estimated that about 18 percent of total fed miscellaneous freshwater fish production was based on commercial feeds in 2008 (Table 2), with commercial feed production increasing from 15 000 tonnes in 1995 to 480 000 tonnes in 2008 and estimated to reach 3.0 million tonnes by 2020 (Table 3). With the exception of omnivorous or herbivorous species (such as pirapatinga, cachama), the bulk of this species grouping is mostly piscivorous fish species and, as such, are still usually fed on live/trash fish feed items (Chen *et al.*, 2007; De Silva and Phillips, 2007; Weimin and Mengqing, 2007).

Salmons: represent the largest diadromous fish species group, with an average growth rate of 5.5 percent per year over the last decade (Figure 4; FAO, 2010a). All the salmon aquaculture production was based on commercial feeds, with total global commercial salmon feed production increasing from 806 000 tonnes in 1995 to 2.0 million tonnes in 2008. It is projected to reach 3.7 million tonnes by 2020 (Table 3).

Trouts: represent the second-largest diadromous fish species group, with an average growth rate of 3.5 percent per year over the last decade (Figure 4; FAO, 2010a). One hundred percent of the trout aquaculture production was based on commercial feeds, with total global commercial trout feed production increasing from 588 000 tonnes

in 1995 to 880 000 tonnes in 2008. It is projected to reach 1.6 million tonnes by 2020 (Table 2).

Milkfish: represent the third-largest diadromous aquaculture species after Atlantic salmon, with species production growing at an average rate of 4.7 percent per year over the last decade (Figure 4; FAO, 2010a). The milkfish production based on commercial feeds increased from 30 percent in 1995 to 42 percent in 2008, with total global commercial milkfish feed production increasing from 220 000 tonnes in 1995 to 568 000 tonnes in 2008 and estimated to reach 1.1 million tonnes by 2020 (Table 3).

Eels: represent the fourth-largest diadromous aquaculture species group, with species group production growing at an average rate of 2.8 percent per year over the last decade (Figure 4; FAO, 2010a). The eel production based on commercial feeds increased from 90 percent in 1995 to 95 percent in 2008, with total global commercial eel feed production increasing from 338 000 tonnes in 1995 to 403 000 tonnes in 2008 and estimated to reach 504 000 tonnes by 2020 (Table 3).

Marine fishes: represent the last major fish species group by production, with species group production growing at an average rate of 8.1 percent per year over the last decade (Figure 5; FAO, 2010a). The marine fish production based on commercial feeds increased from 50 percent in 1995 to 72 percent in 2008, with total global commercial marine fish feed production increasing from 533 000 tonnes in 1995 to 2.4 million tonnes in 2008 and estimated to reach 6.6 million tonnes by 2020 (Table 3).

At present, the bulk of marine finfish cage aquaculture production in China (Table 1) is still based on the use of lower-cost fresh feeds based on small-sized pelagic fish species in the form of fresh/frozen fish (Chen *et al.*, 2007; Weimin and Mengqing, 2007); China alone reportedly consumed between 4 and 5 million tonnes of low-value pelagic fish as aquaculture feed in 2005 (Jin, 2006).

Marine shrimps: represent the largest crustacean species group, with species group production growing at an average rate of 14.7 percent per year over the last decade (Figure 3; FAO, 2010a). The shrimp production based on commercial feeds increased from 75 percent in 1995 to 93 percent in 2008, with total global commercial shrimp feed production increasing from 1.4 million tonnes in 1995 to 5.0 million tonnes in 2008 and estimated to reach 11.3 million tonnes by 2020 (Table 3).

Freshwater crustaceans: represent the second-largest crustacean species group, with group production growing at an average rate of 15.9 percent per year over the last decade (Figure 3; FAO, 2010a). The total freshwater crustacean production based on commercial feeds increased from 35 percent in 1995 to 48 percent in 2008, with total global commercial freshwater crustacean feed production increasing from 91 000 tonnes in 1995 to 1.3 million tonnes in 2008 and estimated to reach 2.7 million tonnes by 2020 (Table 3).

TABLE 2
Top 53 major fed cultured fish and crustacean species/species groups by main country producers in 2008, the average value of the cultured species (US$/kg), reported farm production unit and feeding practice

Species	Production (tonnes)[a]	Major producers (% total production)[a]	Unit value (US$/kg)[a]	Farming unit[b]	Feeding practice[b]	Reference
Freshwater fish species						
Carps						
Grass carp	3 775 267	China 98.2%*; Bangladesh 0.44%; Islamic Republic of Iran 0.35%**; Myanmar 0.33%	0.80* – 3.0**	Ponds, lakes/reservoirs, paddy fields, cages, pens	Fresh feeds, farm-made feeds, commercial feeds	1, 2
Common carp	2 987 433	China 78.7%; Indonesia 8.1%*; Viet Nam 2.5%; Russian Federation 1.6%**	0.92* – 2.5**	Ponds, cages, pens, lakes/reservoirs, paddy fields	Commercial feeds, fresh feeds	1, 3
Catla	2 281 838	India 91.4%; Bangladesh 6.6%**; Myanmar 1.6%; Lao People's Democratic Republic 0.22%*	1.20* – 1.68**	Ponds, lakes/reservoirs, paddy fields	Farm-made feeds	2, 4
Crucian carp	1 957 337	China 99.9%*; Taiwan Province of China 0.044%; Belarus 0.037%**; Armenia 0.006%	1.09* – 2.7**	Ponds, pens, cages	Commercial feeds, fresh feeds	1, 5
Rohu	1 159 454	India 44.1%; Myanmar 37.4%*; Bangladesh 17.5%**; Lao People's Democratic Republic 0.5%	0.90* – 1.90**	Ponds, lakes/reservoirs, paddy fields	Farm-made feeds	2, 4
Wuchang bream	599 623	China 100%*	1.65*	Ponds, cages, lakes/reservoirs	Commercial feeds, fresh feeds	1, 5
Black carp	360 332	China 99.85%*; Taiwan Province of China 0.15%**	1.64* – 2.32**	Ponds, cages, pens	Fresh feeds, commercial feeds	1, 5
Mrigal	463 520	India 66.3%; Bangladesh 26.5%; Myanmar 5.4%**; Lao People's Democratic Republic 1.0%*	1.00* – 1.90**	Ponds, lakes/reservoirs, paddy fields	Farm-made feeds	2, 4
Silver barb	107 457	Thailand 51.4%; Indonesia 24.2%; Myanmar 11.5%*; Cambodia 6.5%**	0.60* – 1.50**	Ponds, paddy fields, ditch, cages	Farm-made feeds	6, 7
Tilapias						
Nile tilapia	2 334 432	China 47.6%**; Egypt 16.5%; Indonesia 12.5%*; Thailand 9.0%	0.74* – 1.49**	Ponds, cages, paddy fields	Commercial feeds	1, 3, 8
Catfishes						
Pangasiid catfishes	1 380 702	Viet Nam 90.0%**; Indonesia 7.3%*; Cambodia 1.0%**; Myanmar 1.0%	0.84* – 1.5**	Ponds, cages	Commercial feeds, farm-made feeds	10, 11, 31
Channel catfish	462 416	United States 50.5%; China 48.5%; Cuba 0.5%*; Brazil 0.4%**	1.00* – 2.1**	Ponds, cages	Commercial feeds	1, 12
Amur catfish	321 071	China 98.3%; Republic of Korea 1.4%*; Taiwan Province of China 0.5%**	0.89* – 2.99**	Ponds, cages	Fresh feeds, commercial feeds	1, 13
Torpedo shaped catfishes	237 634	Indonesia 48.1%*; Malaysia 17.5%; Uganda 14.7%**; Egypt 5.9%	0.77* – 2.10**	Ponds, tanks	Commercial feeds, farm-made feeds	3, 14

TABLE 2, continued

Top 53 major fed cultured fish and crustacean species/species groups by main country producers in 2008, the average value of the cultured species (US$/kg), reported farm production unit and feeding practice

Species	Production (tonnes)[a]	Major producers (% total production)[a]	Unit value (US$/kg)[a]	Farming unit[b]	Feeding practice[b]	Reference
Catfishes, continued						
Catfish, hybrid	135 507	Thailand 100%	0.99	Ponds, cage, ditch, paddy fields	Commercial feeds, farm-made feeds, fresh feeds	6
Yellow catfish	134 448	China 100%	1.30	Ponds, cages, paddy fields	Commercial feeds, fresh feeds	1, 5
North African catfish	47 428	Nigeria 79.3%; Netherlands 9.5%*; Hungary 4.0%**; Syrian Arab Republic 3.2%	1.4* – 3.4**	Ponds, tanks	Commercial feeds, farm-made feeds	14, 15
Others						
Snakeheads	324 318	China 99.9%*; Republic of Korea 0.1%**	1.22* – 6.12**	Ponds, paddy fields, cages	Farm-made feeds, fresh feeds	1, 16
Mandarin fish	229 269	China 100%	9.3	Ponds, cages	Fresh feeds	1, 5
Asian swamp eel	212 209	China 99.96%**; Thailand 0.02%; Cambodia 0.02%*	1.50* – 2.61**	Paddy fields, cages	Fresh feeds	1, 5
Largemouth black bass	166 672	China 99.957%*; Italy 0.021%**; Morroco 0.021%; Mexico 0.001%	1.56* – 8.09**			
Pirapatinga	91 951	China 84.2%; Myanmar 6.7%*; Viet Nam 6.5%; Colombia 2.4%**	0.6* – 2.6**	Ponds, cages	Commercial feeds, farm-made feeds	5, 17
Cachama	44 219	Brazil 69.2%; Colombia 23.5%; Venezuela 5.3%*; Peru 1.22%**	1.5* – 3.05**	Ponds, cages	Commercial feeds, fresh feeds	17, 18
Diadromous fish species						
Salmons						
Atlantic salmon	1 456 721	Norway 51.0%*; Chile 26.7%**; United Kingdom 8.8%; Canada 7.1%	3.6 * – 6.4**	Cages	Commercial feeds	17, 19, 20
Coho salmon	105 117	Chile 87.8%*; Japan 12.2%**	4.1* – 4.5**	Cages	Commercial feeds	17, 19
Trouts						
Rainbow trout	576 289	Chile 25.9%*; Norway 13.1%; Islamic Republic of Iran 10.9%*; Italy 6.6%	3.00* – 5.84**	Cages, raceways, ponds	Commercial feeds	17, 19, 20
Eels						
Japanese eel	253 795	China 80.9%*; Taiwan Province of China 8.3%; Japan 8.3%; Republic of Korea 2.5%**	2.74* – 20.3**	Ponds, indoor tanks	Commercial feeds	1, 21
Others						
Milkfish	676 228	Philippines 51.9%; Indonesia 41.0%*; Taiwan Province of China 6.9%**, Singapore 0.1%	0.90* – 2.01**	Ponds, pens, cages	Commercial feeds, fresh feeds	3, 22

TABLE 2, continued

Top 53 major fed cultured fish and crustacean species/species groups by main country producers in 2008, the average value of the cultured species (US$/kg), reported farm production unit and feeding practice

Species	Production (tonnes)[a]	Major producers (% total production)[a]	Unit value (US$/kg)[a]	Farming unit[b]	Feeding practice[b]	Reference
Others, continued						
Barramundi	44 959	Thailand 33.8%, Malaysia 26.0%**, Taiwan Province of China 22.9%, Indonesia 9.7%*	1.26* – 3.95**	Cages, ponds	Fresh feeds, commercial feeds	3, 6, 23
Marine fish species						
Mullets						
Flathead grey mullet	220 932	Egypt 94.8%*, Republic of Korea 2.8%**, Israel 0.9%, Taiwan Province of China 0.6%	2.86* – 4.15**	Ponds, lakes	Commercial feeds	8
Seabass						
Japanese seabass	97 754	China 97.95%*, Republic of Korea 2.05%**	1.20* – 8.53**	Cages	Fresh feeds, commercial feeds	1, 5
European seabass	66 738	Greece 52.5%, Spain 14.6%, Italy 12.7%**, Egypt 6.6%*	3.39* – 10.7**	Cages	Commercial feeds	24
Jacks, crevalles						
Japanese amberjack	158 508	Japan 99.87%**, Republic of Korea 0.13%*	5.45* – 8.50**	Cages, pens	Commercial feeds, farm-made feeds, fresh feeds	23, 25
Porgies, seabreams						
Gilthead seabream	133 026	Greece 39.1%, Turkey 23.8%*, Spain 16.7%, Italy 6.3%**	4.20* – 10.3**	Cages	Commercial feeds	24
Silver seabream	78 515	Japan 90.4%*, Republic of Korea 9.5%, Taiwan Province of China 0.1%**	6.00* – 15.1**	Cages	Commercial feeds, farm-made feeds, fresh feeds	16
Groupers						
Groupers	70 232	China 64.4%*, Taiwan Province of China 24.3%**, Indonesia 6.6%, Thailand 4.4%	1.19* – 9.08**	Cages	Fresh feeds, commercial feeds	1, 3, 5, 6
Flounders, halibuts						
Lefteye flounders	78 141	China 100%	1.19	Indoor tanks	Fresh feeds, commercial feeds	1
Bastard halibut	50 632	Republic of Korea 91.7%*, Japan 9.3%**	8.13* – 16.00**	Indoor tanks, cages	Fresh feeds, commercial feeds	16
Croakers, drums						
Large yellow croaker	65 977	China 100%	1.19	Cages	Fresh feeds, commercial feeds	1, 5
Red drum	53 511	China 95.2%*, United States 4.2%, Mauritius 0.3%**, Mayotte 0.15%**	1.19* – 8.45**	Cages	Fresh feeds, commercial feeds	1, 5
Others						
Korean rockfish	35 564	Republic of Korea 100%	5.98	Cages	Fresh feeds, commercial feeds	16

TABLE 2, continued

Top 53 major fed cultured fish and crustacean species/species groups by main country producers in 2008, the average value of the cultured species (US$/kg), reported farm production unit and feeding practice

Species	Production (tonnes)[a]	Major producers (% total production)[a]	Unit value (US$/kg)[a]	Farming unit[b]	Feeding practice[b]	Reference
Others, continued						
Cobia	29 859	China 86.6%*, Taiwan Province of China 13.4%**, Mayotte 0.02%	1.18* – 7.37**	Cages	Fresh feeds, commercial feeds	5, 26
Marine crustaceans						
Marine shrimps						
Whiteleg shrimp	2 259 183	China 47.0%, Thailand 22.1%*, Indonesia 9.2%, Ecuador 6.6%**	2.86* – 4.80**	Ponds	Commercial feeds	1, 3, 6, 27, 28
Giant tiger prawn	721 867	Viet Nam 45.0%*, Indonesia 18.7%, India 10.5%**, China 8.4%*	4.00* – 5.00**	Ponds	Commercial feeds	3, 6, 28, 29
Banana prawn	80 165	Malaysia 46.8%**, Indonesia 40.1%, Viet Nam 10.1%, Philippines 2.6%*	3.26* – 4.23**	Ponds	Commercial feeds	3, 22, 29
Kuruma prawn	49 512	China 96.4%*, Japan 3.2%, Taiwan Province of China 0.2%, Spain 0.1%**	4.00* – 35.1**	Ponds	Commercial feeds	1
Fleshy prawn	42 720	China 98.9%*, Republic of Korea 1.1%**	3.96 – 11.34**	Ponds	Commercial feeds	1
Marine crabs						
Indo-Pacific swamp crab	138 032	China 82.5%, Philippines 8.4%**, Indonesia 5.5%*, Myanmar 3.3%	2.08 * – 5.68**	Ponds, pens, coves	Fresh feeds, farm-made feeds	1, 22
Swimming crabs	83 803	China 100%	3.51	Ponds, pens, coves	Fresh feeds, farm-made feeds	1
Freshwater crustaceans						
Freshwater crabs						
Chinese mitten crab	518 365	China 99.998%*, Republic of Korea 0.002%**	6.96* – 45.1**	Pond, pen, paddy fields	Fresh feeds, farm-made feeds	1
Crawfish, crayfish						
Red swamp crawfish	417 904	China 87.25%**, United States 12.75%*	2.39* – 4.76**	Ponds	Fresh feeds, commercial feeds	1, 30
River prawns						
Giant river prawn	207 749	China 61.5%, Thailand 13.7%*, Bangladesh 11.2%**, India 6.2%	4.06* – 7.43**	Ponds	Commercial feeds, farm-made feeds	1, 6, 28
Oriental river prawn	205 010	China 100%	4.76	Ponds	Commercial feeds, fresh feeds	1

*Lowest unit cost as reported in one of the major producing countries; ** highest unit cost as reported in one of the major producing countries.

1. Weimin and Mengqing (2007); 2. Barman and Karim (2007); 3. Nur (2007); 4. Ayyappan and Ahamad Ali (2007); 5. Chen *et al.* (2007); 6. Thongrod (2007); 7. Gupta and Abdur Rab (1994); 8. El-Sayed (2007); 9. Hempel (2009); 10. Phan *et al.* (2009); 11. Hung, Truc and Huy (2007); 12. Robinson and Li (2007);13. Nam *et al.* (2001); 14. Ayinla (2007); 15. Hecht (2007); 16. De Silva and Phillips (2007); 17. Flores-Nava (2007); 18. Gomes *et al.* (2006); 19. Rojas and Wadsworth (2007); 20. Grottum and Beveridge (2007); 21. Heinsbroek (2008); 22. Sumagaysay-Chavoso (2007); 23. Rimmer and Ponia (2007); 24. Cardia and Lovatelli (2007); 25. Nakada (2008); 26. Liao *et al.* (2004); 27. Hasan *et al.* (2007); 28. Suresh (2007); 29. Hung and Huy (2007); 30. D'Abramo *et al.* (2002); 31.Merican (2009).

Source: [a]Data for production, % country contribution and unit value are from FAO (2010a); [b]Information for farming unit and feeding practices are obtained from the source(s) as shown in reference column.

TABLE 3
Estimated global aquaculture production and use of commercial aquafeeds, 1995–2020 (thousand tonnes)

Year	Total aquaculture production[1]	Growth (%/year)[2]	Percent on feeds[3]	Species EFCR[4]	Total feeds used[5]
Fed carps (excluding silver carp, bighead carp and Indian major carps)					
1995	5 154	-	20	2	2 062
2000	7 508	3.9	37	2	5 556
2005	9 100	5.5	45	1.8	7 371
2007	9 814	4.5	47	1.8	8 303
2008	10 585	7.9	48	1.8	9 145
2010	11 670	5	50	1.8	10 503
2015	14 198	4	55	1.7	13 275
2020	16 459	3	60	1.6	15 801
Tilapias					
1995	704	-	70	2	985
2000	1 190	14.7	75	1.9	1 696
2005	1 980	11.3	80	1.8	2 852
2007	2 505	12.9	82	1.7	3 493
2008	2 798	11.7	83	1.7	3 948
2010	3 386	10	85	1.7	4 893
2015	5 453	10	90	1.6	7 852
2020	8 012	8	95	1.6	12 178
Catfishes					
1995	345	-	85	2	586
2000	529	-2.4	81	1.8	772
2005	1 496	18.1	73	1.6	1 747
2007	2 267	26.7	72	1.5	2 448
2008	2 718	19.9	72	1.5	2 935
2010	3 872	19.4	73	1.5	4 240
2015	7 456	14	75	1.4	7 829
2020	12 008	10	80	1.3	12 488
Miscellaneous freshwater fishes					
1995	155	-	5	2	15
2000	278	-14.7	10	2	56
2005	834	10.3	15	2	250
2007	1 057	14.9	17	2	360
2008	1 334	26.2	18	2	480
2010	1 794	16	20	2	718
2015	3 161	12	25	2	1 581
2020	5 091	10	30	2	3 055
Salmons					
1995	537	-	100	1.5	806
2000	1 021	12.2	100	1.3	1 327
2005	1 382	0.6	100	1.3	1 796
2007	1 561	6.3	100	1.3	2 029
2008	1 573	0.8	100	1.3	2 045
2010	1 734	5	100	1.3	2 255
2015	2 213	5	100	1.3	2 877
2020	2 825	5	100	1.3	3 672
Trouts					
1995	392	-	100	1.5	588
2000	512	7.8	100	1.3	666
2005	571	-0.9	100	1.3	743
2007	694	11.4	100	1.3	903
2008	677	-2.4	100	1.3	880
2010	746	5	100	1.3	970
2015	953	5	100	1.3	1 238
2020	1 216	5	100	1.3	1 581
Milkfish					
1995	366	-	30	2	220
2000	468	5.9	34	2	318
2005	595	3.7	39	2	464
2007	667	14	41	2	547
2008	676	1.3	42	2	568
2010	745	5	45	2	671
2015	951	5	50	1.8	856
2020	1 214	5	55	1.6	1 068

TABLE 3, continued

Estimated global aquaculture production and use of commercial aquafeeds, 1995–2020 (thousand tonnes)

Year	Total aquaculture production[1]	Growth (%/year)[2]	Percent on feeds[3]	Species EFCR[4]	Total feeds used[5]
Eels					
1995	188	-	90	2	338
2000	212	6.5	92	1.8	351
2005	217	-3.1	94	1.6	327
2007	274	14.6	95	1.6	416
2008	265	-3.3	95	1.6	403
2010	276	2.1	96	1.5	397
2015	304	2	98	1.5	447
2020	336	2	100	1.5	504
Marine fishes					
1995	533	-	50	2	533
2000	949	16.9	60	2	1 139
2005	1 402	13.5	70	1.9	2 050
2007	1 690	5.8	72	1.9	2 533
2008	1 766	4.5	72	1.9	2 416
2010	2 137	10	73	1.9	2 964
2015	3 140	8	75	1.8	4 239
2020	4 613	8	80	1.8	6 643
Marine shrimps					
1995	925	-	75	2	1 387
2000	1 133	8.2	82	2	1 857
2005	2 664	13	89	1.8	4 268
2007	3 275	5.3	92	1.6	4 821
2008	3 399	3.8	93	1.6	5 058
2010	4 113	10	95	1.6	6 251
2015	6 043	8	97	1.5	8 793
2020	8 087	6	100	1.4	11 322
Freshwater crustaceans					
1995	104	-	35	2.5	91
2000	429	57.1	40	2.4	412
2005	913	8	45	2.2	904
2007	1 337	40.3	47	2.1	1 320
2008	1 370	2.5	48	2	1 315
2010	1 510	5	50	2	1 510
2015	1 928	5	55	1.9	2 015
2020	2 460	5	60	1.8	2 657

Summary totals for fed species and aquafeed production (thousand tonnes)

Year	Total fed aquaculture production	Total feeds used
1995	4 028	7 612
2000	7 684	14 150
2005	13 048	22 585
2007	16 126	26 950
2008	17 476	29 194
2010	21 201	35 371
2015	32 315	51 002
2020	46 917	70 969

[1] Total reported species group production from 1995 to 2008 taken from FAO (2010a), and estimates for 2010, 2015 and 2020 are calculated based on expected growth.

[2] Mean estimated annual percentage growth rate (APR, %) of species group production for 2008–2010, 2010–2015 and 2015–2020 was modified from Tacon and Metian (2008a) based on the recent evolution of total production.

[3] Estimated percent of total species group production fed on commercial aquaculture feeds (modified after Tacon and Metian, 2008a).

[4] Estimated average species group economic feed conversion ratio (EFCR) – total feed fed/total species group biomass increase (modified after Tacon and Metian, 2008a).

[5] Estimated total species group aquaculture feed used (total species group production x EFCR).

2.3 GLOBAL AQUACULTURE FEED PRODUCTION BY MAJOR SPECIES GROUP AND COUNTRY

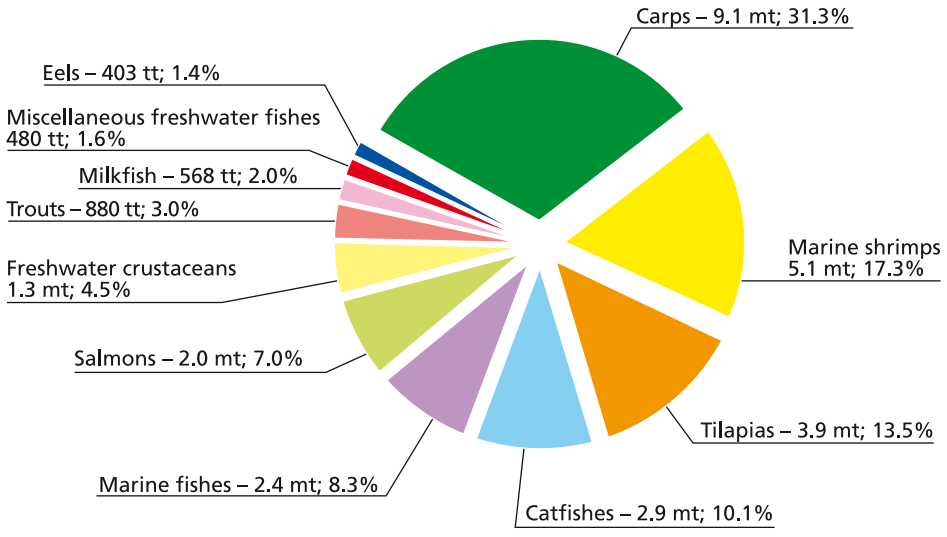
On the basis of the information presented in Table 3, it is estimated that the total global production of commercial aquaculture feeds was 29.2 million tonnes in 2008, including:

- carp feeds (9.1 million tonnes, or 31.3 percent total);
- marine shrimp feeds (5.1 million tonnes, or 17.3 percent);
- tilapia feeds (3.9 million tonnes, or 13.5 percent);
- catfish feeds (2.9 million tonnes, or 10.0 percent);
- marine fish feeds (2.4 million tonnes, or 8.3 percent);
- salmon feeds (2.0 million tonnes, or 7.0 percent);
- freshwater crustacean feeds (1.3 million tonnes, or 4.5 percent);
- trout feeds (880 000 tonnes, or 3.0 percent);
- milkfish feeds (568 000 tonnes, or 2.0 percent);
- eel feeds (403 000 tonnes, or 1.4 percent); and
- miscellaneous freshwater fish feeds (480 000 tonnes, or 1.6 percent).

The above estimate represents a 24.8 percent increase in production from the total estimated commercial aquaculture feed production of 23.4 million tonnes in 2006 (Gill, 2007). The commercial aquaculture feed sector has grown nearly fourfold, from 7.6 million tonnes in 1995 to 29.2 million tonnes in 2008 (average APR of 11.0 percent per year since 1995), and is expected to continue growing at a similar rate over the next decade to 71.0 million tonnes by 2020 (Figure 6; Table 3).

In some countries, however, the increase in the production of commercial acquafeed matched the rapid growth of the aquaculture sector. Thus, in Viet Nam, official figures show that aquafeed production increased from 336 000 tonnes in 1999 to 762 000 tonnes in 2004, with production more than doubling again to 1 863 000 tonnes in 2008 and estimated to be 2.4 million tonnes in 2009; over a 700 percent increase in feed production in a decade (Best, 2010a).

FIGURE 6
Estimated global production of commercial aquaculture feeds by major species grouping, 2008
Total global production in 2008 – 29.2 million tonnes



Note: tt = thousand tonnes; mt = million tonnes.
Source: Based on data from Table 3.

Table 4 shows the major country producers of commercial aquafeeds. The results, based on the responses received to an electronic survey conducted for this paper, show an estimated total production of between 24.4 and 28.9 million tonnes of commercial aquafeeds in 2007–2010. This is in line with the estimates given in Table 3 based on major aquaculture species production.

TABLE 4
Major country producers of commercial aquaculture feeds, 2007–2010

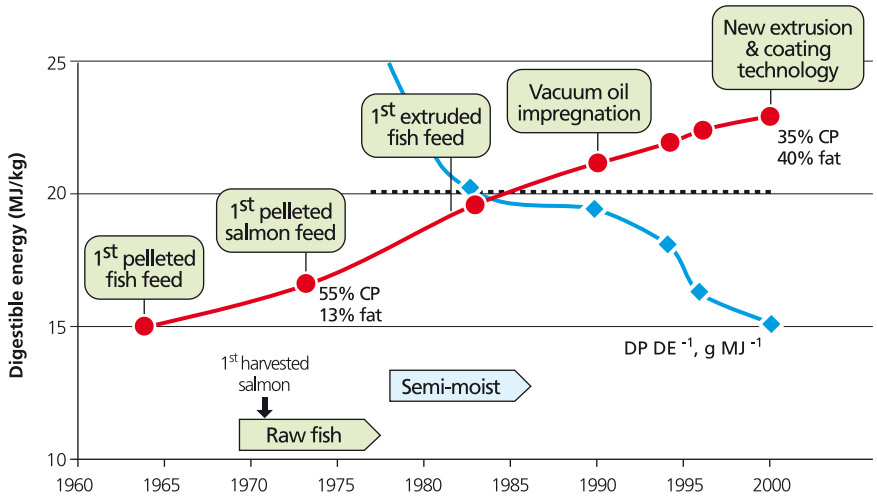
Country	Commercial aquaculture feed production estimate (tonnes)
China (2008)	13 000 000–15 000 000[1]
Viet Nam (2008/09)	1 625 000–2 800 000[2,3,31]
Thailand (2008/09)	1 210 327–1 445 829[2,4,31]
Norway (2008–2010)	1 136 800–1 382 000[5,6]
Indonesia (2008/09)	1 030 000–1 184 500[2,31]
Chile (2008)	883 305–1 050 000[7,8]
United States (2008)	700 000–750 000[9,10]
Japan (2008)	500–000[11]
Philippines (2007)	400 000–450 000[10]
Taiwan Province of China (2007)	345 054[12]
Brazil (2008)	324 000[13]
Egypt (2008)	310 000[14]
Mexico (2008/09)	222 800–282 500[15]
Greece (2009)	262 000[32]
India (2006/07)	247 283[16]
Ecuador (2009)	235 000[17]
Malaysia (2009)	226 000[31]
United Kingdom (2008)	212 900[8]
Turkey (2009)	170 000[18]
Canada (2008)	161 600[19]
Peru (2008)	145 000[20]
Republic of Korea (2008)	126 898[21]
Bangladesh (2007)	100 000–150 000[10]
Myanmar (2007)	100 000–150 000[10]
Russian Federation (2007)	100 000–150 000[10]
Colombia (2009)	100 000–120 000[10]
Honduras (2007)	75 000–100 000[10]
Spain (2007)	75 000–100 000[10]
Italy (2007)	68 750[22]
Australia (2008/09)	58 125[23]
Iran, Islamic Republic of (2007)	50 000–100 000[10]
France (2009)	44 400[24]
Denmark (2008)	43 500[25]
Venezuela, Bolivarian Republic of (2008)	37 580[26]
Germany (2007)	32 000[27]
Nicaragua (2009)	25 508[28]
Costa Rica (2007)	25 000–35 000[10]
Nigeria (2007)	20 000–30 000[10]
Ireland (2009)	20 000[29]
Argentina (2008)	3 901[30]
Total	**24.4 to 28.9 million tonnes**

[1]Wu (2009)/Miao Weimin (personal communication); [2]AAP (2009)/Best (2010a); [3]Dave Robb (personal communication); [4]Supis Thongrod (personal communication); [5]Ian Carr/Sigve Nordum (personal communication); [6]Niels Alsted (personal communication); [7]Aliro Borquez/Ian Carr (2008 data, personal communication); [8]Claudio Larraín estimates total salmonid aquafeed production as 575 000 tonnes in 2009 (personal communication); [9]Menghe Li/Kevin Fitzsimmons/Cheryl Shew (personal communication); [10]Estimate based, in part, on production values reported in Annex 2; [11]Sakashita (2009); [12]Shi-Yen Shiau (personal communication); [13]Rodrigo Carvalho/Silvio Coelho/Daniel Lemos (personal communication); [14]Abdel-Fattah El-Sayed (personal communication; [15]Jessica Montaño/Jesus Zendejas (personal communication); [16]Syed Ahamad Ali (personal communication); [17]Cesar Molina (personal communication); [18]Ozlem Guzel (personal communication); [19]Brad Hicks (personal communication); [20]Christian Berger (personal communication – includes shimp feed exports estimated at about 100 000 tonnes/annum). Peru aquaculture feed production in 2008 estimated at 46 800 tonnes (Carlos Mastrokalo Durand/Patricia Infante, personal communication) and 40 780 tonnes in 2009 (Fabricio Vargas Elias, personal communication); [21]Jeongdae Kim (personal communication); [22]Umberto Luzzana (personal communication); [23]Brett Glencross (personal communication); [24]Michel Autin (personal communication); [25]Hans Erik Bylling (personal communication); [26]José Duarte (personal communication); [27]Christian Lückstädt (personal communication); [28]Francisco Velasquez (personal communication); [29]Dave Jackson (personal communication); [30]Santiago Panné Huidobro (personal communication); [31]AAP (2010); [32]Iannis Zarkadis (personal communication).

At present, no precise statistical information exists on the total global production of farm-made aquafeeds (Tacon and Hasan, 2007), although production in 2006 has been tentatively estimated to be between 18.7 and 30.7 million tonnes (Tacon, 2008). This figure is in general agreement with total farm-made aquafeed production in Asia, which was reported at 19.3 million tonnes in 2004 (De Silva and Hasan, 2007). As expected, the largest farm-made aquafeed producers in 2006 were all countries from the Asian region and included China (10 to 20 million tonnes), India (6.5 to 7.5 million tonnes), Viet Nam (1 to 1.5 million tonnes), Japan (650 000 to 800 000 tonnes), and Thailand (700 000 to 750 000 tonnes; Tacon, 2008). According to Chinese researchers, the volume of farm-made feed production is not known in China (Weimin and Mangqing, 2007), although they estimate that farm-made feeds account for about 40 percent of the country's aquaculture production, natural feeds about 50 percent, and commercial feeds only 10 percent. They also report that 40 to 55 percent of farmed fish production in China are fed industrially compounded aquafeeds. These assumptions are similar to those made by Jin (2006), who estimated that only 20 percent of the aquatic animals that need to be fed on feed in China are fed formulated feeds. Clearly, more detailed studies and information are required concerning the use of forage feed fish in China and the extent and status of the on-farm and commercial aquafeed manufacturing sector.

The current widespread use of forage feed fish-based feeding regimes in the Asian region, particularly for the higher value carnivorous marine fish and crustacean species, is very similar to how the salmon farming industry started in Norway in the early 1970s (Talbot and Rosenlund, 2002): the first farmed Atlantic salmon (*Salmo salar*) were fed raw fish in the 1970s, and the industry then progressed to the development of semi-moist and dry pelleted feeds in the 1980s, to the use of high-energy extruded pelleted feeds in the 1990s and 2000s (Figure 7). Of particular importance is the fact that, as a result of these feed technology advancements (see also Kearns, 2005; Larraín, Leyton and Almendras, 2005), fish growth has increased and feed conversion ratios and fish production costs reduced for the farmer.

FIGURE 7
Historical development of feeds in the Norwegian salmon industry in relation to prevailing technologies and typical inclusion levels of crude proteins, digestible energy and digestible protein levels, 1960–2000



Note: CP = crude proteins; DE = digestible energy (MJ/kg); DP = digestible protein (g/kg).
Source: Talbot & Rosenlund (2002).

Notwithstanding the above discussion, it is important to highlight here the important role played by farm-made aquafeeds, particularly in the production of lower value (in marketing terms) freshwater fish species for home consumption (Tacon and Hasan, 2007); farm-made aquafeeds representing over 97 percent of the total carp feeds used by farmers in India (7.5 million tonnes in 2006/07) (Syed Ahamad Ali, Central Institute of Brackishwater Aquaculture, Chennai, India, personal communication, November 2009), and still providing the mainstay of feed inputs in many southeast Asian (Ng, Soe and Phone, 2007) and sub-Saharan countries (Hecht, 2007).

Moreover, despite the lack of official published information concerning the direct use of "low-value/trash fish" and other small pelagic forage fish species as aquaculture feed, it is estimated that the total use in aquaculture was between 5.6 and 8.8 million tonnes in 2006 (mean 7.2 million tonnes; Tacon and Metian, 2009a); China alone reportedly consumed 4 to 5 million tonnes in 2005 (Jin, 2006). However, estimates for 2008 concerning the direct use of low-value/trash fish as feed in China are currently 6 to 8 million tonnes, 4 to 5 million tonnes of marine trash fish, and 2 to 3 tonnes of freshwater fish, including live food fish (approximately 70 percent of this is used for feeding inland carnivorous aquaculture species and the remainder for marine finfish, Miao Weimin, personal communication).

Samples of commercially produced pellets for rainbow trout (Oncorhynchus mykiss) *in a trout farm, Ermstalfischerei, Germany. Rainbow trout are fed with commercially produced pellets throughout their farm production cycles.*

Courtesy of Jayanta Saha

3. Feed ingredient production and availability

The global production and market availability of feed ingredient sources commonly used in aquaculture feeds have been reviewed by Hasan *et al.* (2007). The review focuses on developing countries; these countries produced over 91.5 percent of total fed fish and crustacean production in 2007 (FAO, 2009a). In particular, the review includes a global overview (Tacon and Hasan, 2007), regional reviews covering Asia (De Silva and Hasan, 2007), Latin America (Flores-Nava, 2007) and sub-Saharan Africa (Hecht, 2007), and 13 individual country profiles (Bangladesh, Cameroon, China, Egypt, India, Indonesia, Kenya, Malawi, Nigeria, the Philippines, Viet Nam, Thailand and Uganda) concerning aquaculture feed production and ingredient usage (Hasan *et al.*, 2007).

For the purposes of this paper, feed ingredients are categorized into animal nutrient sources, plant nutrient sources and microbial nutrient sources.

3.1 ANIMAL NUTRIENT SOURCES

3.1.1 Aquatic animal protein meals and lipids

The major aquatic animal protein meals and lipids available in the marketplace can be listed as follows (in order of global production and current market availability):

- *fish/shellfish meals and oils*: produced from wild harvested whole fish and macroinvertebrate animals, including bycatch;
- *fish/shellfish by-product meals and oils*: produced from seafood and/or aquaculture processing wastes;
- *zooplankton meals and oils*: produced from wild harvested marine invertebrates;
- *fish/shellfish hydrolysates, silages and fermentation products*: produced from harvested whole fish, macroinvertebrates, zooplankton and/or seafood processing wastes; and
- *marine polychaete meals*: produced from wild harvested and/or cultured marine annelid worms.

Table 5 summarizes the available published information on the total reported global production of the above listed aquatic animal protein meals and lipids.

Fish/shellfish meals and oils

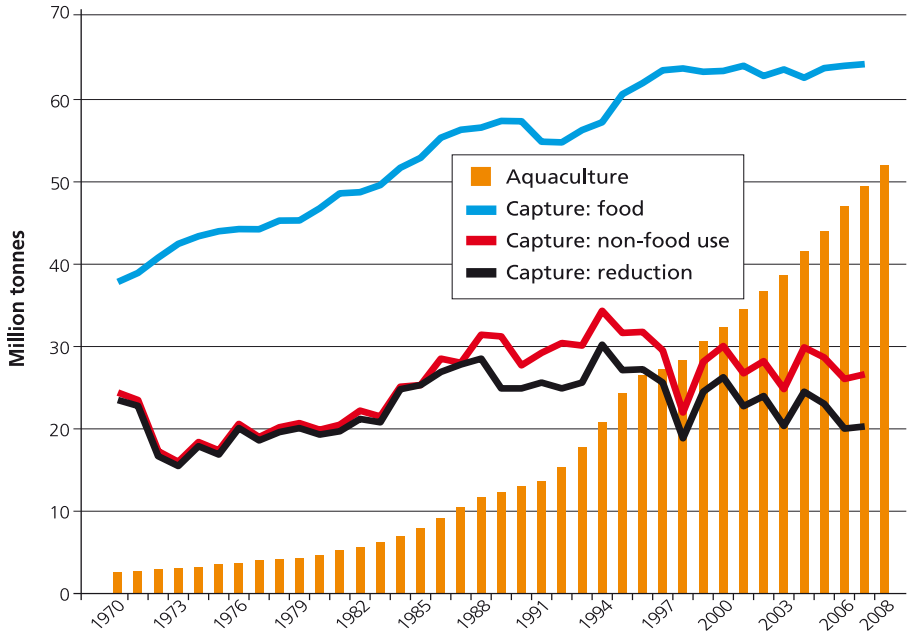
Fishmeals and oils derived from wild harvested whole fish currently constitute the major aquatic protein and lipid sources available within the animal feed marketplace. Despite this, the proportion of the global fisheries catch destined for reduction into fishmeal and fish oil has remained static with respect to the growth of the aquaculture sector (20.4 million tonnes in 2007; Figure 8), with global fishmeal and fish oil production decreasing at an average rate of –1.7 percent per year and –2.6 percent per year since 1995, respectively (Table 5). Moreover, according to FAO (2009a), only 15 percent of total global fishmeal production and 44 percent of total fish oil production was reported down to the species level in 2007. To a large extent this is due to the common practice by the industry (in some countries) of blending different batches and sources of meals and oils so as to attain an overall specific nutrient standard for sale to traders and buyers.

TABLE 5
Total reported production of aquatic animal protein meals and lipids

Ingredient	Global production, growth and market availability
Fish/shellfish meals and oils: produced from wild harvested whole fish and macroinvertebrate animals, including fishes (anchovy, capelin, crab, grenadier, hake, herring, mackerel, menhaden, pilchard, sandeel, sardine, sardinella, saury, shad, sprat, whiting); crustaceans (marine shrimps, squilla); and molluscs (clams, mussels, squid).	**Fishmeal global production:** 5 621 712 tonnes in 2007 (6 125 420 tonnes in 2008); down from reported lowest production in 1995 (6 851 899 tonnes) and reported highest production in 2000 (6 961 483 tonnes), APR decrease since 1995, -1.7%/year, 85.0% total production in 2007, non-species specific. **Fish oil global production:** 1 011 886 tonnes in 2007 (1 060 472 tonnes in 2008); down from lowest production in 1995 (1 378 599 tonnes) and highest production in 1986 (1 667 193 tonnes), APR decrease since 1995, -2.6%/year, 56.3% total production in 2007, non-species specific. **Fishmeal country production (2007):** Peru (24.9%); China (18.7%); Chile (12.5%); Thailand (7.6%); United States (4.5%); Japan (3.6%); Denmark (3.1%); Norway (3.0%); Iceland (2.3%); South Africa (1.6%); Ecuador (1.6%); Spain (1.3%); Mexico (1.3%) – total 86.0%. **Fish oil country production (2007):** Peru (30.6%); Chile (18.4%); Denmark (11.8%); United States (6.8%); Iceland (6.1%); Japan (5.9%); Norway (4.6%); Morocco (2.5%); Mexico (2.4%); Spain (1.6%); China (1.3%); United Kingdom (1.2%) – total 93.2%. **Fishmeal exports:** 3 116 570 tonnes in 2007; down from lowest export in 1995 (4 501 810 tonnes) and highest export in 1994 (4 905 692 tonnes), APR decrease since 1995, -3.1%/year; major exporters in 2007: Peru (41.0%); Chile (15.7%); Germany (5.8%); Denmark (4.6%); Iceland (3.9%); United States (3.4%); Thailand (3.0%); Ecuador (2.8%); Faroe Islands (1.8%); Norway (1.3%); Mexico (1.2%) – total 84.5%. **Fish oil exports:** 865 075 tonnes in 2007; down from lowest export in 1995 (941 808 tonnes) and highest export in 1994 (946 763 tonnes), APR decrease since 1995 -0.7%/year; major exporters in 2007: Peru (37.1%); Denmark (14.7%); Chile (8.3%); Iceland (7.1%); Norway (6.6%); United States (6.4%); Morocco (3.0%); France (2.4%); the Netherlands (2.1%) – total 85.6%. **Fishmeal imports:** 3 270 499 tonnes in 2007; down from lowest import in 1995 (4 571 860 tonnes) and highest import in 1994 (4 918 553 tonnes), APR decrease since 1995, -2.8%/year; major importers in 2007: China (29.6%); Japan (10.7%); Norway (6.8%); Germany (6.4%); Taiwan Province of China (4.7%); Denmark (5.4%); Viet Nam (3.5%); Greece (2.9%); United Kingdom (2.7%); Spain (2.1%); Russian Federation (1.8%); Italy (1.7%); Turkey (1.7%); Indonesia (1.7%) – total 81.7%. **Fish oil imports:** 896 850 tonnes in 2007; down from lowest import in 1995 (1 115 528 tonnes) and highest import in 1995 (1 115 528 tonnes), APR decrease since 1995, -1.8%/year; major importers in 2007: Norway (25.8%); Denmark (17.7%); Chile (10.2%); France (4.3%); Canada (3.9%); the Netherlands (3.6%); Japan (3.4%); China (3.4%); United States (2.8%); Taiwan Province of China (2.8%) – total 77.9%.
Fish/shellfish by-product meals and oils: produced from seafood and/or aquaculture processing wastes, including catfish, crab, crayfish, hake, pollock, lobster, salmon, shrimp, squid, tilapia, trout and tuna. **Zooplankton meals and oils:** produced from wild harvested marine invertebrates, including brine shrimp biomass, calanus and krill. **Fish/shellfish hydrolysates, silages and fermentation products:** produced from harvested whole fish, macroinvertebrates, zooplankton and/or seafood processing wastes. **Marine polychaete meals:** produced from wild harvested and/or cultured annelid worms.	Total **tuna meal** production reported as 36 054 tonnes in 2007: major reported country producers: Islamic Republic of Iran (38.7%); Seychelles (38.5%); Maldives (5.0%); Fiji Islands (1.1%). Total **shrimp meal** production reported as 26 290 tonnes in 2007: major reported country producers: Indonesia (98.6%); Iceland (1.4%). Total crustacean meal (no species given) production reported as 20 558 tonnes in 2007: major country producers: Chile (94.8%); El Salvador (5.2%). Total **squid oil** production reported as 280 tonnes in 2007: major country producer: Republic of Korea (100%). Hardy and Shepherd (2007) reported that 84 579 tonnes of fishmeal and 21 916 tonnes of fish oil was produced in Alaska from Alaskan pollack and cod processing wastes in 2006. Total **krill** landings reported as 118 124 tonnes in 2007, with higest production (430 765 tonnes) reported in 1987: major country producers: Norway (33.7%); Republic of Korea (28.0%); Japan 20.6%; India (11.5%); Poland (6.3%). Total **fish silage** (no species given) production reported as 1 220 tonnes in 2007: major country producer: Finland (100%).

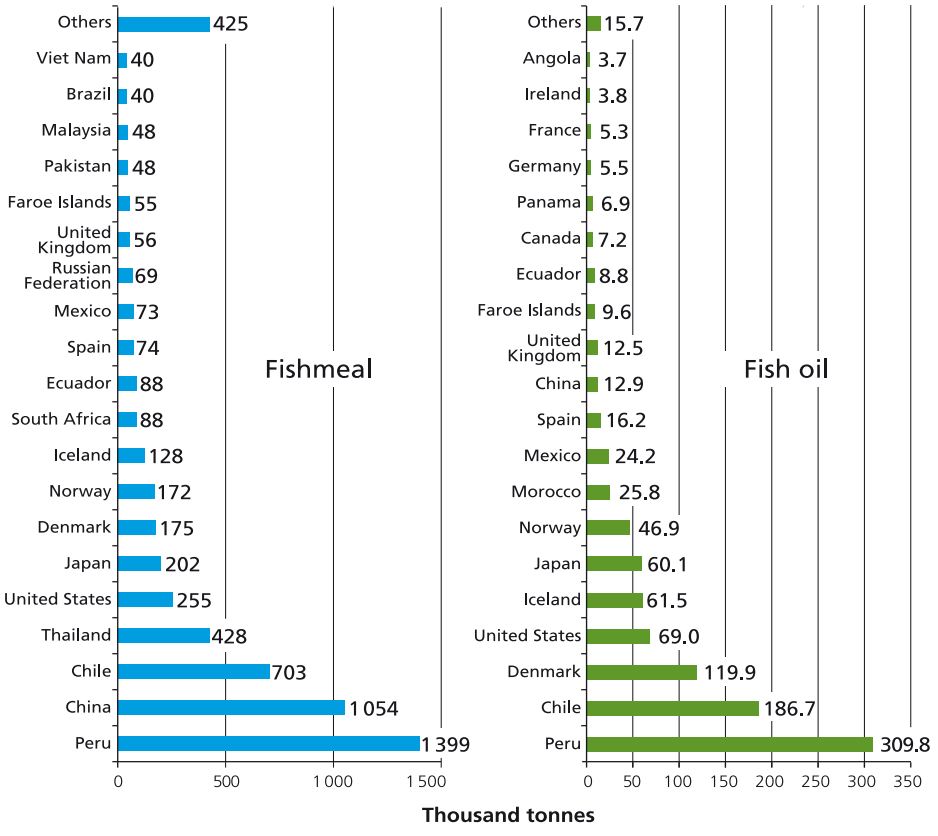
Source: FAO (2009a).

FIGURE 8
Total capture fisheries and aquaculture production and volume of the catch destined for reduction and other non-food uses, 1970–2008



Note: Capture and aquaculture production exclude mammals, reptiles and aquatic plants.
Source: FAO (2009a and 2010a).

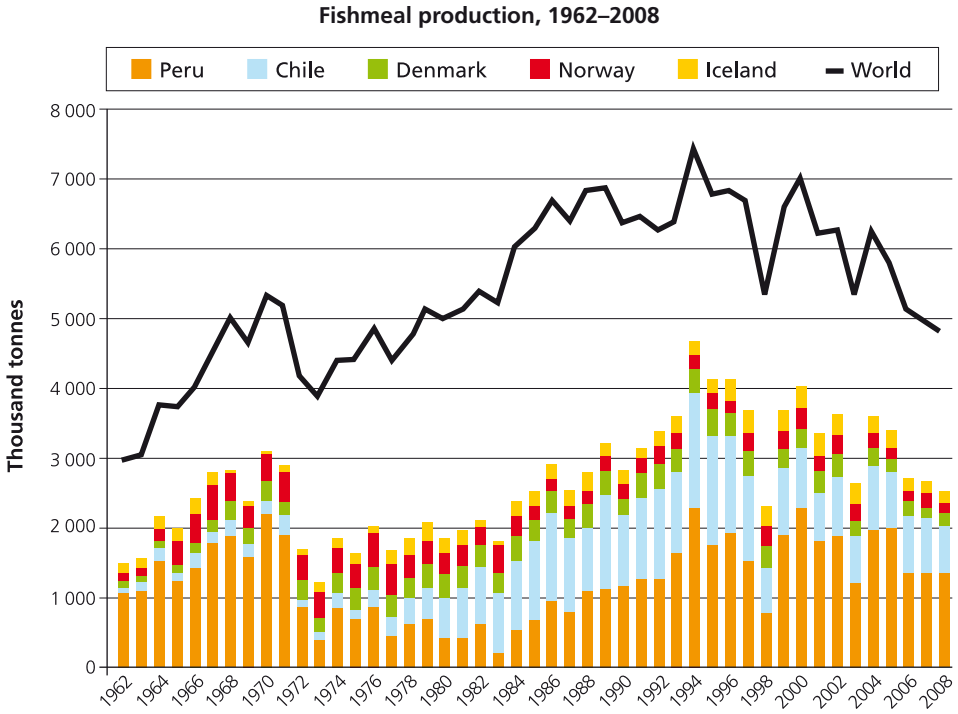
FIGURE 9
Major country producers of fishmeal and fish oil, 2007

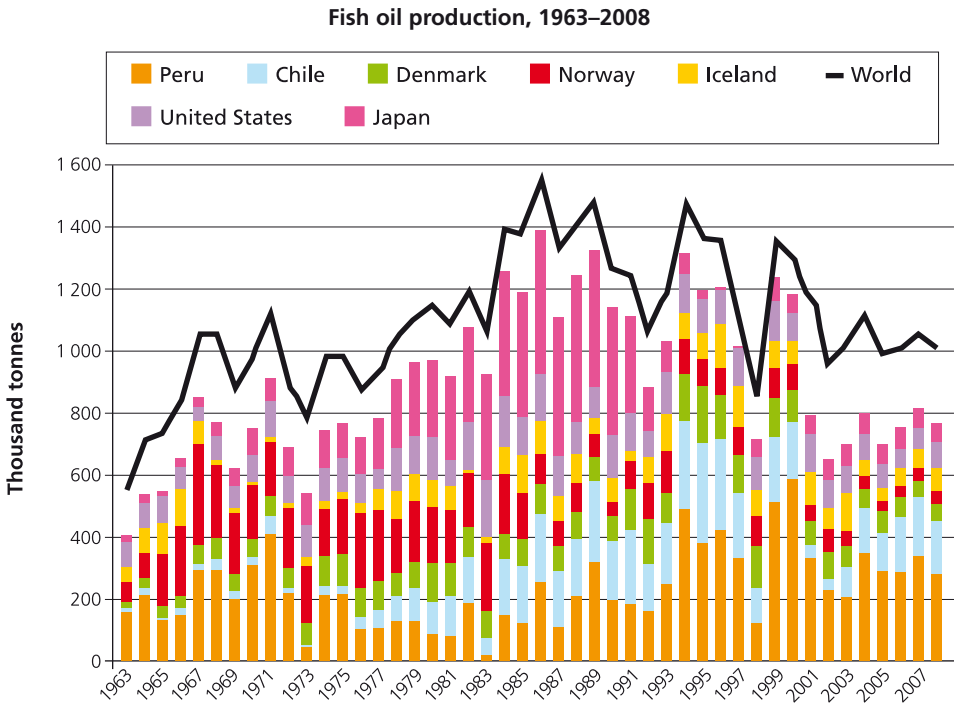


Source: FAO (2009a).

Figure 9 shows the major country producers of fishmeal and fish oil, with Peru producing the major share of both commodities. Figure 10 shows total fishmeal and fish oil production by country from 1962 to 2008, according to the latest estimates of the International Fishmeal and Fish Oil Organisation (IFFO) (Shepherd, 2009).

FIGURE 10
Historical production trend of fishmeal and fish oil, 1962–2008

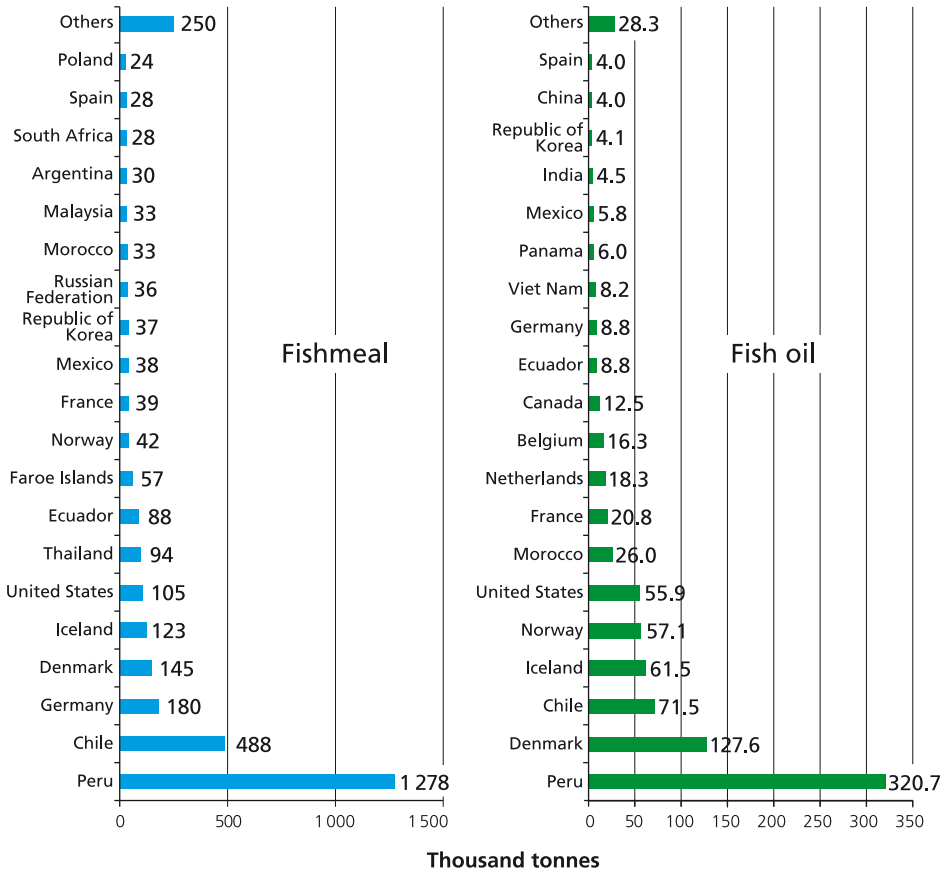




Source: Shepard (2009).

As with production, the largest exporter of fishmeal and fish oil in 2007 was Peru, exporting 41 percent and 30.6 percent of total world fishmeal and fish oil exports, respectively (Table 5; Figure 11; FAO, 2009a). As with total global production, fishmeal and fish oil exports decreased at an average annual rate of –3.1 percent and –0.7 percent from 1995, respectively (Table 5; Figure 11). Fishmeal and fish oil imports continue to be dominated by China and Norway, which imported 29.6 percent (969 832 tonnes) and 25.8 percent (231 264 tonnes) of total fishmeal and fish oil imports, respectively, in 2007 (Figure 12). Moreover, in line with global production and exports, the quantity of fishmeal and fish oil available for export decreased at an average annual rate of –2.8 percent and –1.8 percent since 1995 (Table 5; FAO, 2009a). However, recent data suggest that China's consumption continues to increase, with fishmeal imports increasing to 1 348 676 tonnes in 2008 (Peru 65.0 percent, Chile 17.7 percent, the United States of America 5.7 percent) and 1 225 295 tonnes for the first ten months of 2009 (Peru 58.7 percent, Chile 26.0 percent, the United States of America 5.5 percent) (Beckman, Xiping and Han, 2009).

FIGURE 11
Major exporters of fishmeal and fish oil, 2007



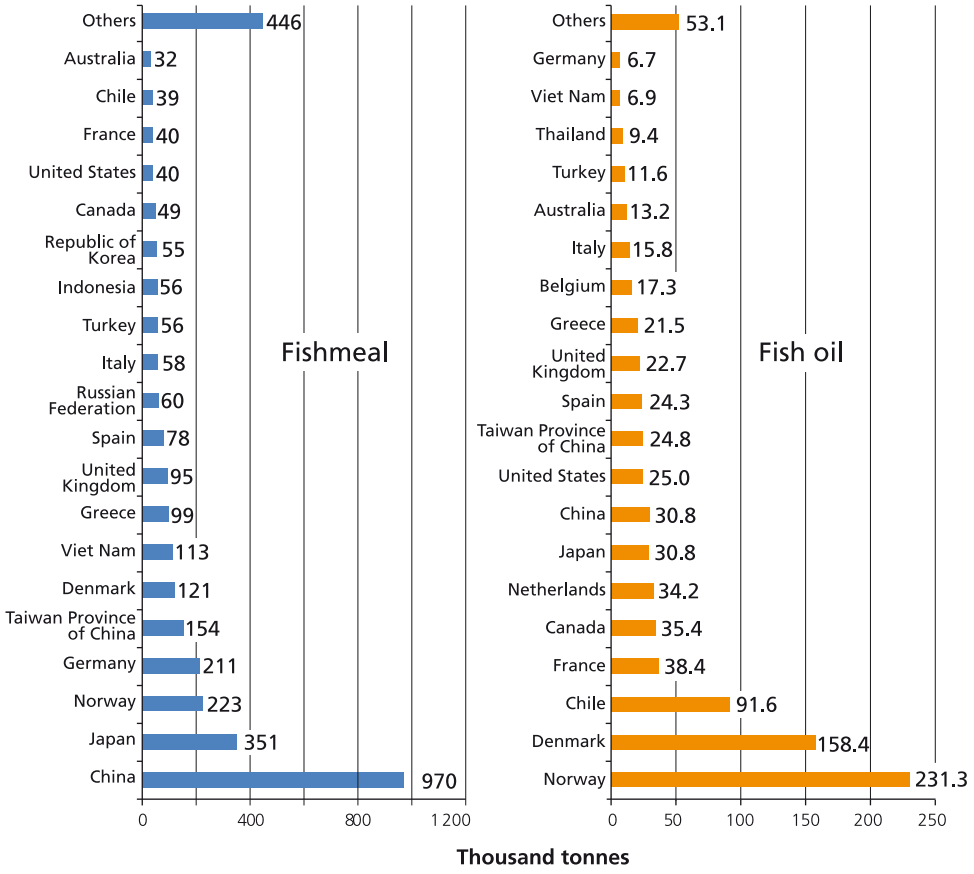
Source: FAO (2009a).

Fish/shellfish by-product meals and oils

Statistical information is not available from FAO on the total global production of fishmeal and fish oil from seafood and/or aquaculture processing wastes. However, it has been estimated that about 6 million tonnes of trimmings and rejects from food fish are currently used for fishmeal and fish oil production (SEAFISH, 2009a). For example, according to SEAFISH (2009b), 38 percent of the fishmeal consumed in the United Kingdom of Great Britain and Northern Ireland was produced from trimmings

in 2008 (trade estimates). The same authors quote 2006 trade estimates that 33 percent of the fishmeal produced within the European Union (EU) was manufactured from trimmings/offal from food fish processing plants, and that globally this figure was about 24 percent. Similarly, IFFO estimates that about 25 percent of the total global production of fishmeal is now derived from fisheries by-products (Table 6; Jackson, 2009). No information is available concerning the proportion of by-product fishmeals and oils produced from aquaculture processing waste.

FIGURE 12
Major importers of fishmeal and fish oil, 2007



Source: FAO (2009a).

Clearly, the data presented in Table 6 are not a true picture of the quantities of by-product meals available in the marketplace. For example, tuna meal production is reported by FAO (2009a) as 36 054 tonnes from only four countries (Fiji, Maldives, the Islamic Republic of Iran and Seychelles), whereas information is not reported on tuna fishmeal and tuna oil from other larger tuna producers, including China, Ecuador, France, Ghana, Indonesia, Japan, Mexico, Panama, Papua New Guinea, Spain, Sri Lanka, Taiwan Province of China, Thailand, the United States of America and Vanuatu. A similar situation exists for shrimp and crustacean meals (including crab meals) and squid meals and oils.

Moreover, at present, no information is available from FAO concerning the total global production of fishmeal and oils produced from aquaculture processing wastes, including those produced from farmed catfish, tilapia, trout, salmon and shrimp. For example, in Chile, it is estimated that the production of 600 000 tonnes of salmon yielded 270 000 tonnes of processing waste and farm mortalities, which in turn

TABLE 6

IFFO estimate of global fishmeal production derived from fisheries by-products, 2007

Country	Fishmeal (thousand tonnes)	By-product coefficient %*	By-product fishmeal production (thousand tonnes)
Angola	5.3	50.0	2.7
Argentina	30.0	60.0	18.0
Australia	14.0	50.0	7.0
Brazil	40.4	20.0	8.1
Cambodia	3.0	60.0	1.8
Canada	30.2	100.0	30.2
Chile	770.1	12.0	92.4
China	204.0	5.0	10.2
Denmark	166.0	20.0	33.2
Ecuador	40.7	14.0	5.8
Faroe Islands	54.6	5.0	2.7
Finland	3.6	70.0	2.5
France	13.7	100.0	13.7
Germany	19.0	100.0	19.0
Iceland	152.0	35.0	52.4
India	1.0	5.0	0.1
Indonesia	15.0	30.0	4.5
Iran, Islamic Republic of	25.1	30.0	7.5
Ireland	19.3	40.0	7.7
Italy	4.3	100.0	4.3
Côte d'Ivoire	1.0	60.0	0.6
Japan	200.5	92.0	184.4
Republic of Korea	50.0	20.0	10.0
Lithuania	30.0	20.0	6.0
Malaysia	48.2	40.0	19.3
Maldives	2.0	80.0	1.6
Mauritius	5.0	60.0	3.0
Mexico	73.0	50.0	36.5
Morocco	60.6	15.0	9.1
Namibia	12.5	100.0	12.5
New Zealand	30.0	10.0	3.0
Norway	172.0	22.0	37.8
Pakistan	56.0	20.0	11.2
Panama	45.7	10.0	4.6
Peru	1 407.0	2.0	28.1
Poland	22.1	40.0	8.8
Russian Federation	65.8	50.0	32.9
Senegal	4.3	100.0	4.3
Seychelles	20.0	70.0	14.0
South Africa	88.0	10.0	8.8
Spain	20.0	100.0	20.0
Sweden	23.3	50.0	11.7
Taiwan Province of China	18.2	70.0	12.7
Thailand	428.0	65.0	278.2
United Kingdom	44.2	68.0	30.1
United States	251.5	26.0	65.4
Viet Nam	52.4	50.0	26.2
Total 47 countries	4 842.6	-	1 204.7
Others	127.4	20.0	25.5
Total world	4 970.0	24.8	1 230.2

*% contribution of fisheries by-products to total country fishmeal production.

Source: Jackson (2009).

resulted in the production of 48 600 tonnes of salmon oil and 43 200 tonnes of salmon meal (Anon, 2006). As mentioned previously, this absence of information on these by-products is partly due to the common practice in some countries of blending different batches and sources of meals and oils so as to attain an overall specific nutrient standard for sale to traders and buyers.

Zooplankton meals and oils

Major marine zooplankton species that have potential, and/or have been considered for use as feed ingredients, include the Arctic amphipod *Themisto libellula*, the copepod *Calanus finmarchicus* and the Antarctic krill *Euphausia superba*. Of these, commercial operations only exist for the Antarctic krill, which total landing is reported as 118 124 tonnes in 2007 (Table 5; FAO, 2009a). As with other shrimp and crustacean meals, no information is available concerning the total global production and market availability of krill meal and krill oil. Nonetheless, krill meal and krill oil are available in the marketplace (www.akerbiomarine.com; www.aquaticeco.com/subcategories/1148/Krill-Meal).

Others

At present, little or no information is available on the global production and market availability of fish and shellfish hydrolysates, silages and fermentation products, nor of the production of wild harvested and cultured marine polychaete worms. However, as mentioned previously, numerous fish hydrolysates, fermentation products and wild harvested and cultured polychaetes are available in the marketplace (salmon protein hydrolysate [www.rossyew.co.uk/salmon_pro.htm]; farmed polychaetes and polychaete products [www.dragonfeeds.com]).

3.1.2 Land animal protein meals and lipids

The major land animal protein meals and lipids available in the marketplace can be listed as follows (in order of global production and current market availability):

- *meat by-product meals and fats:* produced from slaughtered farmed livestock (cattle, pig, sheep, etc.), and includes meat and bone meal, meat meal, meat solubles and lard/tallow;
- *poultry by-product meals and fats:* produced from slaughtered farmed poultry, and includes poultry by-product meal, turkey meal, feather meal, chick hatchery waste and poultry fat;
- *blood by-product meals:* produced from slaughtered farmed livestock (ruminant and monogastric), and includes blood meal, haemoglobin meal and dried plasma products; and
- *miscellaneous invertebrate terrestrial products:* produced from wild harvested and/or cultured annelid worms, insect larvae/pupae, gastropods – golden apple snail, etc.

Table 7 summarizes the available published information on the total reported global production and trade of the above listed terrestrial animal protein meals and fats.

Global production and major country producers, exporters and importers

Although no published statistical information exists concerning the individual global production of the above-mentioned animal by-product meals, it has been estimated that the global combined production of rendered animal protein meals and fats in 2008 was about 13.0 and 10.2 million tonnes, respectively (Swisher, 2009a); global production of these animal protein meals being over twice that reported for fishmeal in 2008 (Figure 10). Currently, these terrestrial animal protein meals and fats represent the largest source of animal protein and fats available to the animal feed compounder.

The largest reported producer of rendered animal protein meals and fats in 2008 was the United States of America at 4 094 237 tonnes and 4 576 429 tonnes (total 8 670 666 tonnes), respectively; followed by the EU-18 at 3 870 000 tonnes and 2 687 000 tonnes (total 6 557 000 tonnes); South America at 3 970 578 tonnes and 2 278 379 tonnes (total 6 248 957 tonnes); Australia at 650 000 tonnes and 470 000 tonnes (total 1 120 000 tonnes); New Zealand at 214 300 tonnes and 140 000 tonnes (total 354 300 tonnes); and Turkey at 185 600 tonnes and 84 179 tonnes (total 269 779 tonnes), respectively. However, these global estimates are low as they exclude most Asian countries from the analysis.

Total exports of rendered animal protein meals in 2008 was 1 338 954 tonnes, or 10.3 percent of total global production; the largest reported country exporters being the EU-27 (340 153 tonnes), followed by the United States of America (298 257 tonnes), Australia (259 903 tonnes), New Zealand (149 405 tonnes), Argentina (73 309 tonnes), Brazil (62 903 tonnes), Uruguay (52 081 tonnes), and Canada (25 709 tonnes) (Swisher, 2009a). The largest importers of rendered animal protein meals in 2008 was Indonesia (309 679 tonnes), followed by Thailand (149 490 tonnes), Viet Nam (114 379 tonnes), Mexico (107 187 tonnes), the United States of America (89 675 tonnes), China (62 905 tonnes), Egypt (62 276 tonnes), Chile (53 141 tonnes), Bangladesh (50 315 tonnes), the Philippines (50 054 tonnes), Taiwan Province of China (42 190 tonnes), Russian Federation (38 610 tonnes), and South Africa (35 919 tonnes) (Swisher, 2009a).

TABLE 7
Total reported production of terrestrial animal protein meals and lipids, 2008

Ingredient	Global production, growth and market availability
Meat by-product meals and fats: produced from slaughtered farmed livestock (cattle, pig, sheep), and includes meat and bone meal, meat meal, meat soluble, tallows and greases. Poultry by-product meals and fats: produced from slaughtered farmed poultry, and includes poultry by-product meal, turkey meal, feather meal, chick hatchery waste and poultry fat. Blood by-product meals: produced from slaughtered farmed livestock (cattle, poultry, pig), and includes blood meal, haemoglobin meal and dried plasma products.	Total global production of rendered animal protein meals in 2008: 12 984 715 tonnes, major producers including: the United States 31.5%, South America 30.6%, EU-18 29.8%, Australia 5.0%, New Zealand 1.6%, Turkey 1.4%. Total global production of rendered fats and greases in 2008: 10 235 987 tonnes, major producers including: United States 44.7%, EU-18 26.2%, South America 22.2%, Australia 4.6%, New Zealand 1.4%, Turkey 0.8%. Total global exports of rendered animal protein meals: exports increasing by 57.8% from 848 656 tonnes in 2004 to 1 338 954 tonnes in 2008; major exporters in 2008 included: EU-27 25.4%, United States 22.3%, Australia 19.4%, New Zealand 11.1%, Argentina 5.5%, Brazil 4.7%, Uruguay 3.9%, Canada 1.9%, data exclude intra-EU trade. Total global imports of rendered animal protein meals: imports increasing by 57.8% from 848 656 tonnes in 2004 to 1 338 954 tonnes in 2008; major importers in 2008 included: Indonesia 23.1%, Thailand 11.2%, Viet Nam 8.5%, Mexico 8.0%, United States 6.7%, China 4.7%, Egypt 4.6%, Chile 4.0%, Bangladesh 3.7%, Philippines 3.7%, Taiwan Province of China 3.1%, Russian Federation 2.9%, South Africa 2.7%. Total global tallow exports: exports increasing by 1.5% from 1 850 973 tonnes in 2002 to 1 878 661 tonnes in 2008; major exporters in 2008 included: United States 55.4%, Australia 19.8%, Canada 9.8%, New Zealand 7.9%, Uruguay 3.3%, EU-27 1.8%, Brazil 1.3%. Total global tallow imports: imports increasing by 1.5% from 1 850 973 tonnes in 2002 to 1 878 661 tonnes in 2008; major importers in 2008 included: Mexico 27.5%, China 19.4%, Nigeria 6.6%, Turkey 6.4%, CAR* 6.2%, Republic of Korea 5.6%, Pakistan 3.4%, Japan 3.1%.

*Central Asian Republics include Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.

Source: Swisher (2009a).

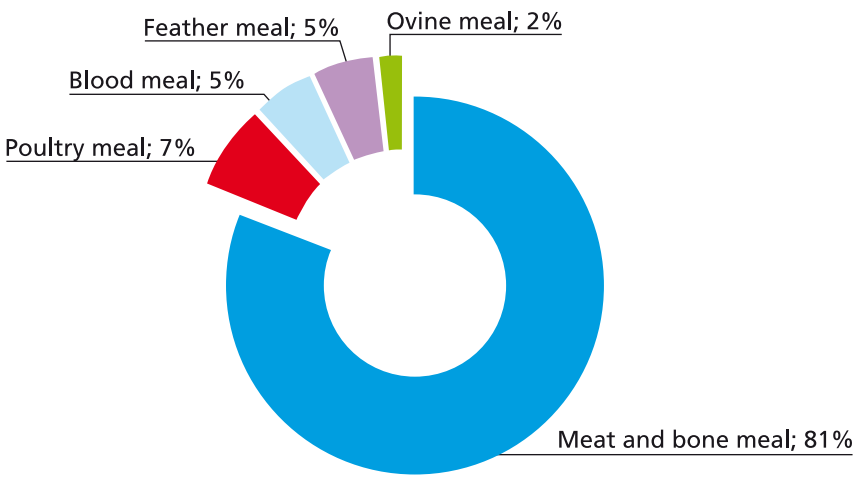
Data for global rendered fats and greases are currently only available for tallows, with total global tallow exports and imports reported at 1 878 661 tonnes in 2008. The major tallow exporters were the United States of America (1 040 926 tonnes), Australia (372 532 tonnes), Canada (183 765 tonnes) and New Zealand (148 405 tonnes); and the major tallow importers in 2008 were Mexico (516 266 tonnes), China (365 351 tonnes) and Nigeria (123 567 tonnes) (Swisher, 2009a).

More detailed production data are available for Australia (Palmer, 2009) and the United States of America (Swisher, 2009b). For example, in the case of Australia, total rendered animal protein meal production in 2008 has been estimated at 650 000 tonnes, with meat and bone meals representing 81 percent of total meal production, followed by poultry meal, feather meal, blood meal and ovine (sheep) meal, respectively (Figure 13).

Similarly, in the case of the United States of America (the largest global producer and exporter of rendered animal protein meals), the bulk of production in 2008 was in the form of meat and bone meals (2 339 500 tonnes, or 56.8 percent total protein meal production), followed by poultry by-product meal (1 176 500 tonnes, or 28.5 percent), and feather meal (603 900 tonnes, or 14.6 percent (Swisher, 2009b). In the case of animal fats and greases, the bulk of production was in the form of inedible tallow (1 604 800 tonnes, or 35.6 percent); greases (1 215 100 tonnes, or 27.0 percent); edible tallow (807 300 tonnes, or 17.9 percent); poultry fat (656 800 tonnes, or 14.6 percent); and lard (220 300 tonnes, or 4.9 percent) (Swisher, 2009b). Moreover, total protein meal and fat/grease production increased by 12 percent and 6 percent, from 3 675 300 tonnes in 2003 to 4 119 900 tonnes (meals) and 4 243 400 tonnes to 4 504 300 tonnes (fats) in 2008, respectively (Swisher, 2009b; Figures 14 and 15).

The United States exports of all rendered products were estimated at 1 895 000 tonnes in 2008, including 1 503 500 tonnes of fats and greases and 371 500 tonnes of animal protein meals; the latter includes 298 300 tonnes of animal protein meals (mammalian meat and bone meal and poultry by-product meal) and 73 300 tonnes of feather meal (Swisher, 2009b). The largest importers of the United States of America animal protein meals and feather meal in 2008 were primarily in Asia. Importing countries included Indonesia (173 822 tonnes, or 46.8 percent total exports), Mexico (107 164 tonnes, or 28.8 percent), Canada (35 234 tonnes, or 9.5 percent), Viet Nam (22 160 tonnes, or 6.0 percent), Ecuador (7 405 tonnes, or 2.0 percent), Thailand (6 825 tonnes, or 1.8 percent), the Philippines (5 736 tonnes), China (5 249 tonnes), Bangladesh (1 546 tonnes), Honduras (1 449 tonnes), Taiwan Province of China (1 154 tonnes), Malaysia (860 tonnes), the Netherlands (787 tonnes), and Switzerland (291 tonnes) (Swisher, 2009b).

FIGURE 13
Composition of rendered animal protein by meal type in Australia, 2008

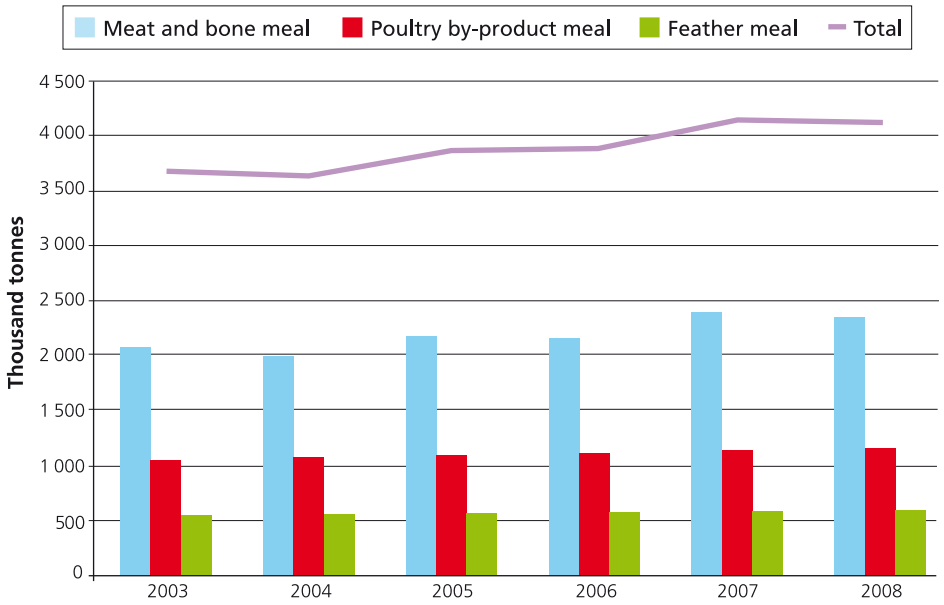


Source: Palmer (2009).

Miscellaneous invertebrate terrestrial products

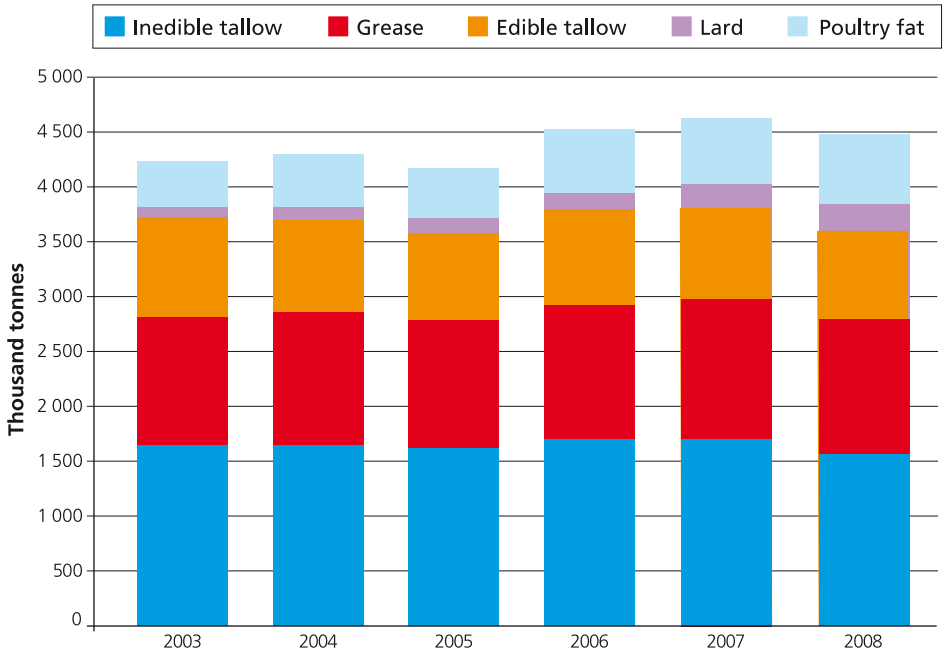
No statistical information is available concerning the total global production of terrestrial invertebrate animal products, the majority being highly localized and serving as supplementary feed items or for use within farm-made aquafeeds (Hasan *et al.*, 2007).

FIGURE 14
Annual production of animal protein meals in the United States, 2003–2008



Source: Swisher (2009b).

FIGURE 15
Annual production of animal fats and grease in the United States, 2003–2008



Source: Swisher (2009b).

3.2 PLANT NUTRIENT SOURCES

The major plant dietary nutrient sources, including meals and oils, available in the marketplace can be listed as follows (in order of global production and current market availability):

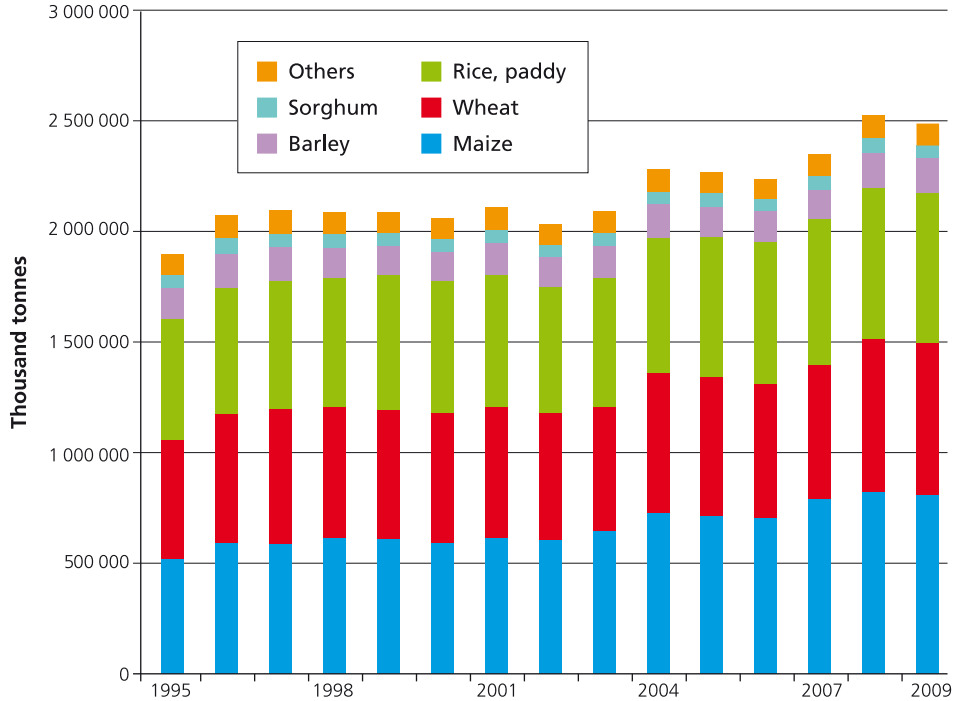
- *cereals, including by-product meals and oils:* includes milled/processed cereals (maize/corn, wheat, rice, barley, sorghum, oats, rye, millet, triticale, etc.); by-product meals (corn/maize gluten, wheat gluten, dried distillers grains with solubles, rice protein concentrate, rice bran, wheat bran); and extracted oils (corn/maize, rice);
- *oilseed meals and oils:* includes full-fat (soybean) and solvent extracted oilseed meals (soybean, rapeseed, cotton, groundnut/peanut, sunflower, palm kernel, copra); by-product meals (soybean protein concentrates, rapeseed/canola protein concentrate); and extracted oils (palm, soybean, rapeseed, sunflower, linseed, cottonseed, olive); and
- *pulses and protein concentrate meals:* includes milled/processed pulses (peas, lupins) and by-product meals (pea protein concentrate, lupin protein concentrate).

Table 8 summarizes the total reported global production and trade of the major traded cereals, oilseeds, pulses and grain legume meals, and by-products and oils available to the animal feed compounder, including for the manufacture of aquaculture feeds.

Cereals and by-products

Total global cereal production was 2 489 million tonnes in 2009, up by 31.2 percent from 1 898 million tonnes in 1995, with production growing at an average annual rate of 2.2 percent per year (Figure 16); maize totalling 817.1 million tonnes, or 32.8 percent of the total cereal crop in 2009, followed by wheat at 681.9 million tonnes (27.4 percent), rice paddy at 678.7 million tonnes (27.3 percent), barley at 150.3 million tonnes (6.0 percent), and sorghum at 62.1 million tonnes (2.5 percent; Figure 17). Maize remains the fastest growing cereal crop, with global production up by 57.9 percent since 1995 and growing at an annual percent rate of 3.3 percent per year (Figure 16; FAO, 2010c).

FIGURE 16
Total global production of cereals by commodity, 1995–2009



Source: FAO (2010c).

TABLE 8
Estimated global production and trade of major agricultural food/feed commodities, 2008/09 (values given in million tonnes and presented in order of production by weight)

Production		Exports		Imports	
Cereals					
Maize/corn	**817.1 (2009)[1]**	**Export total**	**84.0 (2008/09)[1]**	**Import total**	**84.1 (2008/09)[1]**
United States	333.0	United States	46.1	Japan	16.4
China	163.1	Argentina	12.1	Mexico	7.9
European Union	57.8	Brazil	6.9	Republic of Korea	7.5
Brazil	51.2	Ukraine	5.5	Egypt	5.2
Mexico	20.2	South Africa	2.3	China	4.2
Indonesia	17.6	European Union	1.7	Taiwan Province of China	4.1
India	17.3	India	1.5	European Union	3.0
Argentina	13.1	Russian Federation	1.3	Islamic Republic of Iran	3.0
South Africa	12.1	Serbia	1.2	Colombia	2.8
Ukraine	10.5	Thailand	0.7	Malaysia	2.6
Wheat	**681.9 (2009)[1]**	**Export total**	**139.1(2008/09)[1]**	**Import total**	**136.1 (2008/09)[1]**
European Union	138.7	United States	26.9	Egypt	9.9
China	115.0	European Union	24.7	Islamic Republic of Iran	8.5
India	80.7	Russian Federation	18.7	European Union	7.9
Russian Federation	61.7	Canada	17.8	Brazil	6.7
United States	60.3	Australia	13.5	Algeria	6.4
Canada	26.5	Ukraine	12.6	Indonesia	5.3
Pakistan	24.0	Argentina	8.1	Japan	5.4
Australia	21.7	Kazakhstan	5.8	Morocco	3.7
Ukraine	20.9	Turkey	2.3	Nigeria	3.6
Turkey	20.6	Pakistan	2.0	Iraq	3.6
Rice (milled equivalent)	**678.7 (2009)[1]**	**Export total**	**30.4 (2009)[1]**	**Import total**	**30.4 (2009)[1]**
China	197.3	Thailand	8.6	Nigeria	1.8
India	131.3	Viet Nam	6.3	Philippines	1.8
Indonesia	64.4	United States	3.1	Islamic Republic of Iran	1.3
Bangladesh	45.1	Pakistan	2.8	European Union	1.2
Viet Nam	38.9	India	2.5	Iraq	1.1
Thailand	31.5	China	0.9	Saudi Arabia	1.0
Philippines	16.3	Myanmar	0.8	Malaysia	0.9
Brazil	12.6	Uruguay	0.8	Côte d'Ivoire	0.9
Japan	10.6	Brazil	0.7	Senegal	0.9
Pakistan	10.3	Egypt/Argentina	0.5	South Africa	0.9

TABLE 8, continued

Estimated global production and trade of major agricultural food/feed commodities, 2008/09 (values given in million tonnes and presented in order of production by weight)

	Production		Exports		Imports	
Barley	**150.3 (2009)[1]**	**Export total**	**19.7 (2008/09)[1]**	**Import total**	**20.1 (2008/09)[1]**
European Union	62.4	Ukraine	6.3	Saudi Arabia	7.3
Russian Federation	17.9	European Union	3.5	Islamic Republic of Iran	2.0
Ukraine	11.8	Russian Federation	3.5	Syrian Arab Republic	1.7
Canada	9.5	Australia	3.3	China	1.4
Australia	8.1	Canada	1.4	Japan	1.4
Turkey	7.3	Argentina	0.9	Tunisia	0.6
United States	4.9	Kazakhstan	0.3	United States	0.6
Poland	4.0	United States	0.3	Algeria	0.4
Islamic Republic of Iran	3.4			Morocco	0.4
China	3.4			Libya	0.4
Sorghum	**62.1 (2009)[1]**	**Export total**	**6.9 (2008/09)[1]**	**Import total**	**6.0 (2008/09)[1]**
United States	9.7	United States	3.8	Mexico	2.3
India	7.2	Australia	1.4	Japan	1.3
Mexico	6.2	Argentina	0.9	European Union	0.4
Sudan	4.2	Sudan	0.3	Sudan	0.3
Ethiopia	2.8	Burkina Faso	0.1	China	0.1
Australia	2.7	Nigeria	0.1	Ethiopia	0.1
China	2.3				
Brazil	1.8				
Argentina	1.8				
Mali	1.5				
Oilseed crops, by-products and olis					
Soybeans	**210.9 (08/09)[3]**	**Export total**	**76.7 (2008/09)[3]**	**Import total**	**76.5 (2008/09)[3]**
United States	80.7	United States	34.9	China	41.1
Brazil	57.0	Brazil	30.0	European Union-27	13.3
Argentina	32.0	Argentina	5.6	Japan	3.4
China	15.5	Paraguay	2.4	Mexico	3.3
India	9.1	Canada	2.0	Taiwan Province of China	2.1
Paraguay	3.9	Others	1.8	Thailand	1.5
Canada	3.3			Indonesia	1.2
Others	9.3			Egypt	1.2
				Republic of Korea	1.2
				Turkey	1.0
				Others	7.1

TABLE 8, continued

Estimated global production and trade of major agricultural food/feed commodities, 2008/09 (values given in million tonnes and presented in order of production by weight)

	Production		Exports		Imports	
Soybean meal	**151.6 (08/09)[3]**	**Export total**	**52.10 (08/09)[3]**	**Import total**	**51.39 (08/09)[3]**
United States	35.47	Argentina	23.99	European Union-27	21.50
China	32.47	Brazil	13.00	Indonesia	2.45
Argentina	24.95	United States	7.72	Viet Nam	2.30
Brazil	24.33	India	3.16	Thailand	2.16
European Union-27	10.11	Plurinational State of Bolivia	1.04	Republic of Korea	1.81
India	5.98	Others	3.19	Japan	1.81
Mexico	2.73			Mexico	1.50
Others	15.50			Philippines	1.31
				Canada	1.27
				Bolivarian Republic of Venezuela	1.05
				Others	14.21
Rapeseed	**58.24 (08/09)[3]**	**Export total**	**12.40 (08/09)[3]**	**Import total**	**12.26 (08/09)[3]**
European Union-27	19.04	Canada	7.90	European Union-27	3.34
Canada	12.64	Others	4.50	China	3.03
China	12.10			Japan	2.12
India	7.00			Others	3.76
Ukraine	2.87[2]				
Australia	1.61[2]				
Russian Federation	0.75[2]				
United States	0.66[2]				
Others	1.56				
Palm oil	**42.40 (08/09)[3]**	**Export total**	**34.23 (08/09)[3]**	**Import total**	**34.07 (08/09)[3]**
Indonesia	19.50	Malaysia	16.0	India	6.87
Malaysia	17.26	Indonesia	14.65	China	6.12
Thailand	1.20	Benin	0.47	European Union-27	4.90
Nigeria	0.82	Papua New Guinea	0.40	Pakistan	2.20
Colombia	0.75	United Arab Emirates	0.35	United States	1.04
Others	2.87	Others	2.36	Egypt	0.85
				Bangladesh	0.75
				Malaysia	0.70
				Islamic Republic of Iran	0.57
				Japan	0.53
				Others	9.54

TABLE 8, continued

Estimated global production and trade of major agricultural food/feed commodities, 2008/09 (values given in million tonnes and presented in order of production by weight)

	Production		Exports		Imports	
Soybean oil	**35.76 (08/09)[3]**	**Export total**	**9.05 (08/09)[3]**	**Import total**	**8.86 (08/09)[3]**
United States	8.50	Argentina	4.71	China	2.49
China	7.31	Brazil	1.91	India	1.06
Argentina	6.12	United States	0.99	European Union-27	0.82
Brazil	6.02	European Union-27	0.40	Algeria	0.32
European Union-27	2.31	Paraguay	0.24	Bolivarian Republic of Venezuela	0.32
India	1.34	Bolivia	0.18	Egypt	0.31
Mexico	0.61	Russian Federation	0.13	Morocco	0.28
Others	3.54	Others	0.48	Islamic Republic of Iran	0.27
				Republic of Korea	0.27
				Bangladesh	0.25
				Others	2.46
Sunflower	**33.05 (08/09)[3]**	**Export total**	**2.08 (08/09)[3]**	**Import total**	**1.86 (08/09)[3]**
Russian Federation	7.35	Ukraine	0.77	European Union-27	0.59
Ukraine	7.00	European Union-27	0.30	Turkey	0.44
European Union-27	6.96	Russian Federation	0.16	Argentina	0.11
Argentina	2.90	Argentina	0.06	Others	0.71
China	1.85[2]	Others	0.78		
United States	1.55[2]				
India	1.11[2]				
South Africa	0.88[2]				
Turkey	0.83				
Others	2.62				
Rapeseed meal	**30.76 (08/09)[3]**	**Export total**	**3.45 (08/09)[3]**	**Import total**	**3.54 (08/09)[3]**
European Union-27	11.69	Canada	1.89	China	0.26
China	8.32	India	0.70	European Union-27	0.16
India	3.26	China	0.27	Japan	0.11
Canada	2.49	European Union-27	0.16	Others	3.00
Japan	1.25	Others	0.45		
Others	3.75				
Rapeseed oil	**20.39 (08/09)[3]**	**Export total**	**2.37 (08/09)[3]**	**Import total**	**2.44 (08/09)[3]**
European Union-27	8.43	Canada	1.53	European Union-27	0.45
China	4.70	European Union-27	0.14	China	0.45
India	2.06	Others	0.70	Canada	0.11
Canada	1.78			Others	1.41
Japan	0.88				
Others	2.53				

TABLE 8, continued

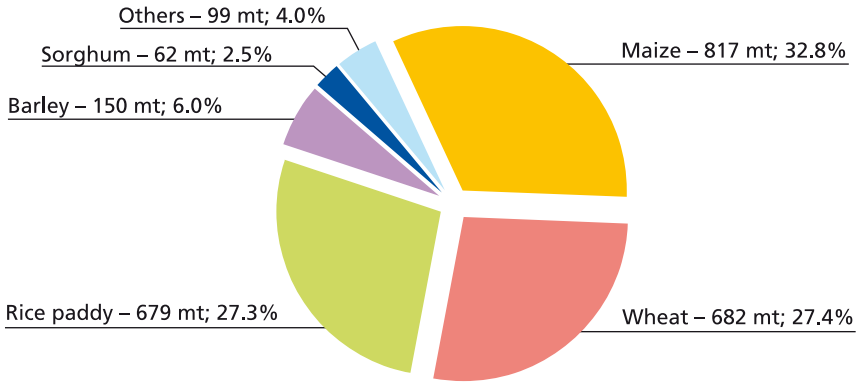
Estimated global production and trade of major agricultural food/feed commodities, 2008/09 (values given in million tonnes and presented in order of production by weight)

	Production	Exports		Imports	
Sunflower meal	**12.59 (08/09)[3]**	**Export total**	**4.21 (08/09)[3]**	**Import total**	**4.11 (08/09)[3]**
European Union-27	3.21	Ukraine	2.21	European Union-27	2.35
Ukraine	2.59	Russian Federation	0.96	Turkey	0.31
Russian Federation	2.31	Argentina	0.80	Others	1.45
Argentina	1.47	European Union-27	0.08		
Turkey	0.45	Others	0.16		
Others	2.56				
Sunflower oil	**11.74 (08/09)[3]**	**Export total**	**4.49 (08/09)[3]**	**Import total**	**4.04 (08/09)[3]**
Ukraine	2.63	Ukraine	2.10	European Union-27	1.05
Russian Federation	2.56	Argentina	1.00	Turkey	0.43
European Union-27	2.33	Russian Federation	0.80	Others	2.55
Argentina	1.44	Turkey	0.13		
Turkey	0.51	European Union-27	0.13		
Others	2.26	Others	0.33		
Peanut oil	**4.97 (08/09)[3]**	**Export total**	**0.19 (08/09)[3]**	**Import total**	**0.16 (08/09)[3]**
China	2.17	India	30 000 tonnes	India	96 000 tonnes
India	1.54	China	10 000 tonnes	United States	24 000 tonnes
United States	0.06	United States	4 000 tonnes	China	20 000 tonnes
Others	1.19	European Union-27	2 000 tonnes	Others	21 000 tonnes
		Others	148 000 tonnes		
Cottonseed oil	**4.84(08/09)[3]**	**Export total**	**0.19 (08/09)[3]**	**Import total**	**0.19 (08/09)[3]**
China	1.60	United States	87 000 tonnes	India	5 000 tonnes
India	1.03	China	5 000 tonnes	United States	5 000 tonnes
United States	0.30	Others	98 000 tonnes	Turkey	4 000 tonnes
Turkey	0.12			Others	61 000 tonnes
European Union-27	47 000 tonnes				
Others	1.74				
Olive oil	**2.97 (08/09)[3]**	**Export total**	**0.68 (08/09)[3]**	**Import total**	**0.59 (08/09)[3]**
European Union-27	2.25	European Union-27	0.41	United States	0.28
Turkey	0.17	Turkey	42 000 tonnes	European Union-27	0.15
Others	0.54	Others	0.22	Others	0.17

[1]FAO (2010b); [2]FAO (2010c); [3]USDA (2010a).

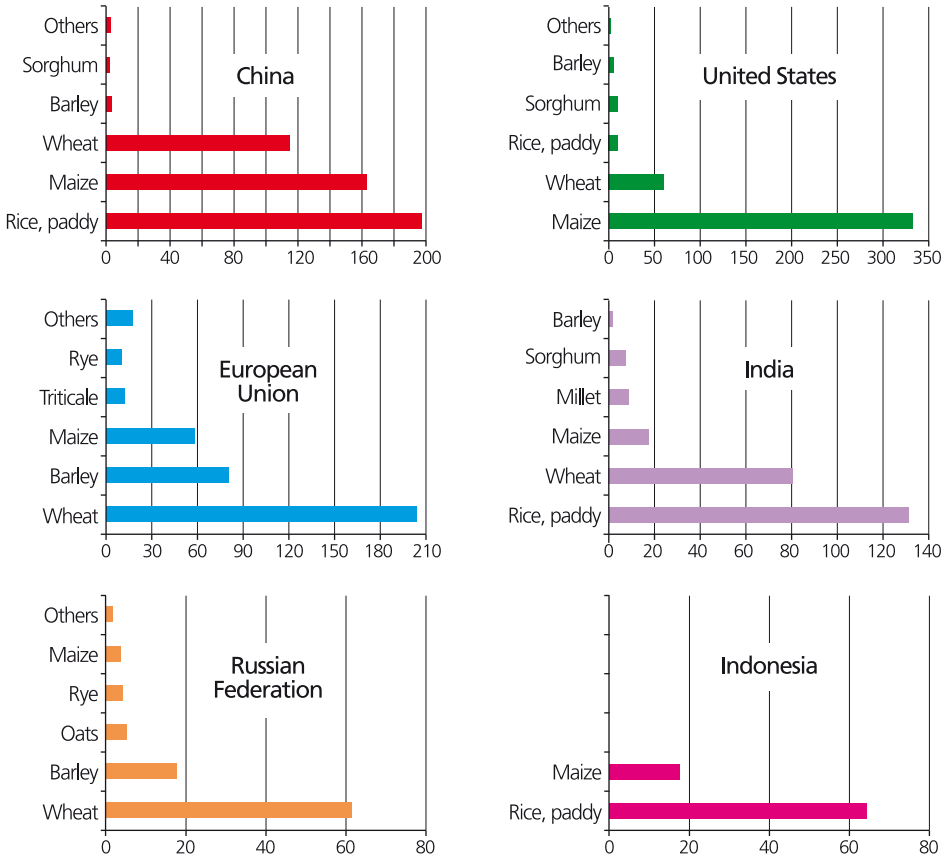
The largest producer of maize in 2009 was the United States of America at 333 million tonnes, or 40.8 percent of global production, followed by China (163.1 million tonnes, or 20.0 percent), and the EU (57.8 million tonnes, or 7.1 percent; Figure 18).

FIGURE 17
Composition of commodities in global production of cereals, 2009
Total global production of cereals in 2009 – 2 489 million tonnes



Note: mt = million tonnes.
Source: FAO (2010c).

FIGURE 18
Top cereal producer countries by commodity, 2009



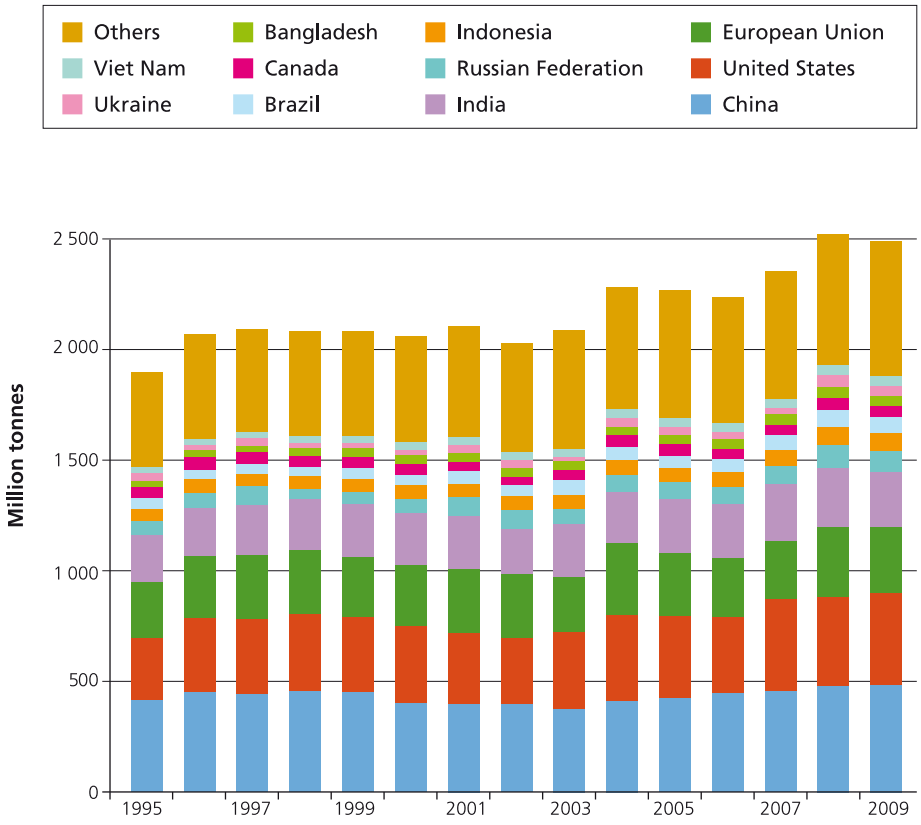
Source: FAO (2010c).

Asia remains the largest global producer of cereals at 1 193 million tonnes, or 47.9 percent of global production, in 2009 (with rice paddy being the main cereal crop at 51.3 percent); followed by the Americas at 633.9 million tonnes, or 25.5 percent (with maize being the main cereal crop at 67.8 percent); Europe at 504.4 million tonnes, or 20.0 percent (with wheat being the main cereal crop at 49.2 percent); Africa at 160.8 million tonnes, or 6.5 percent (with maize being the main cereal crop at 35.2 percent); and Oceania at 36.1 million tonnes, or 1.4 percent (with wheat being the main cereal crop at 61.1 percent; FAO, 2010c).

By country, China maintains its position as the world's top cereal producer at 484 million tonnes (19.4 percent of global production in 2009), followed by the United States of America (419.8 million tonnes, or 16.9 percent), the EU (298 million tonnes, or 12.0 percent), India (246.8 million tonnes, or 9.9 percent), the Russian Federation (95.1 million tonnes), and Indonesia (82.0 million tonnes); these countries account for over 65.3 percent of total global cereal production in 2009 (Figure 19) (FAO, 2010c).

In marked contrast to cereal production, non-Asian countries dominate the cereal export market. For example, the top cereal exporters in 2008/09 included the United States of America at 80.3 million tonnes (only includes the major traded cereal exports listed in Table 8), followed by the EU (30.2 million tonnes), Ukraine (24.5 million tonnes), the Russian Federation (23.6 million tonnes), Argentina (22.5 million tonnes), Canada (21.5 million tonnes) and Australia (18.5 million tonnes); the largest cereal exporters, mostly rice, in Asia are Thailand (9.4 million tonnes) and Viet Nam (6.3 million tonnes; Figure 20).

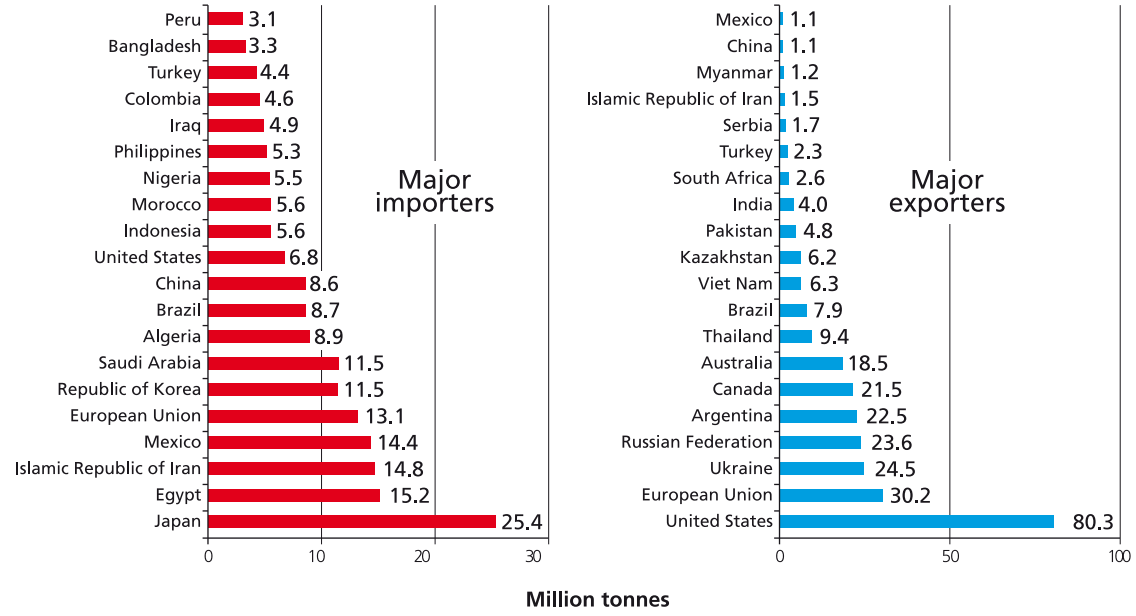
FIGURE 19
Total global production of cereals by country, 1995–2009



Source: FAO (2010c).

Japan continues to be the world's largest cereal importer at over 25.4 million tonnes in 2008/09, followed by Egypt (15.2 million tonnes), the Islamic Republic of Iran (14.8 million tonnes), Mexico (14.4 million tonnes), EU (13.1 million tonnes), Republic of Korea (11.5 million tonnes), Saudi Arabia (11.5 million tonnes), Algeria (8.9 million tonnes), Brazil (8.7 million tonnes), China (8.6 million tonnes), the United States of America (6.8 million tonnes), Indonesia (5.6 million tonnes), Morocco (5.6 million tonnes) and Nigeria (5.5 million tonnes) (Figure 20).

FIGURE 20
Top cereal importers and exporters, 2008/09



Source: FAO (2009b).

In addition to the above global market overview, the FAO FAOSTAT Agriculture database on trade also reports the country imports and exports of specifically traded cereal by-product meals and oils, including:

- brans of cereals (buckwheat, barley, fonio, maize, millet, oats, rice, rye, sorghum, wheat);
- cakes of cereals (maize, rice bran);
- flours of cereals (buckwheat, maize, millet, rye, sorghum, wheat);
- germ of cereals (maize, wheat);
- gluten feed and meal (no cereal specified); and
- oils of cereals (maize, rice bran).

Apart from the absence of statistical information on the total global production of cereal by-product meals and oils, the list currently excludes major wheat by-products (wheat middlings/wheat pollard) and by-products from corn ethanol production.

According to the Renewable Fuels Association, ethanol biorefineries within the United States of America reportedly produced nearly 27 million tonnes of corn cereal by-products for use as animal feed in 2008, including 23 million tonnes of distillers grains (production up tenfold from 2.3 million tonnes in 1999), 3 million tonnes of corn gluten feed, and 600 000 tonnes of corn gluten meal (Figure 21). The association also reported that the estimated market value of feed co-products from ethanol production in 2007/08 was US$3 billion, with an estimated additional US$1.7 billion from the sales of corn oil produced from wet-mill ethanol refineries (Renewable Fuels Association: www.ethanolrfa.org/pages/industry-resources-coproducts; Renewable Fuels Association, 2008; Deutscher, 2009).

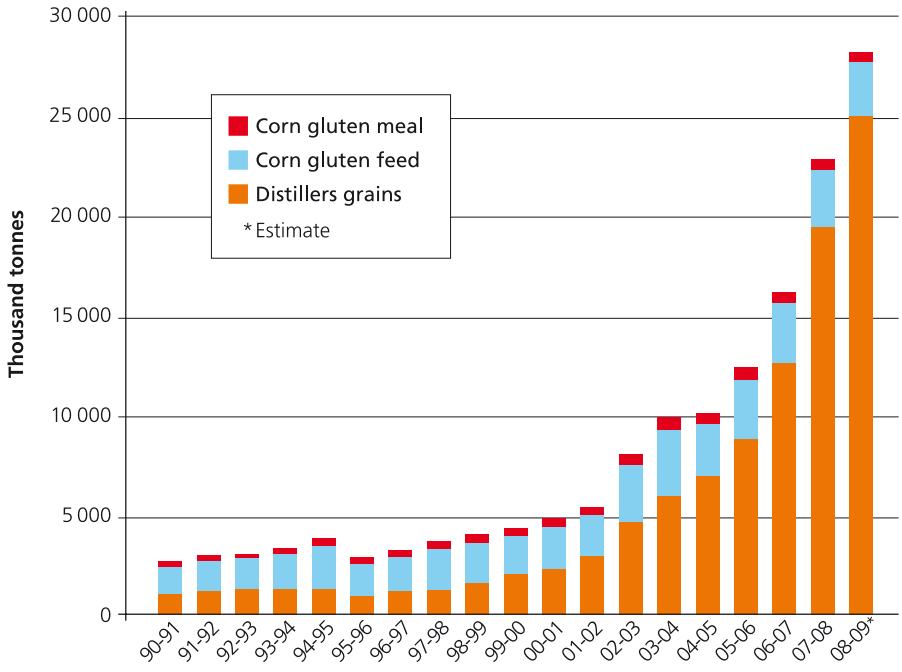
In 2009, distillers grains production was expected to reach 31.5 million tonnes, with exports expected to reach 6.6 million tonnes over the next ten years (Deutscher, 2009). According to the United States Grains Council, the United States of America exported over 4.5 million tonnes of dried distillers grains with solubles in 2008; the largest export markets in 2008 were Mexico (1.2 million tonnes, or 26.3 percent total exports), followed by Canada (772 000 tonnes, or 17.1 percent), Japan (198 000 tonnes, or 4.4 percent), Taiwan Province of China (189 000 tonnes, or 4.2 percent), and Republic of Korea (185 000 tonnes, or 4.1 percent) (Chen, 2009).

Oilseed crops, by-product meals and oils

According to FAO (2010c), the total global production of oilseeds in 2009 was 415 million tonnes, with production up by 56.4 percent since 1995 and growing at an average annual rate of 3.24 percent per year (Table 9; Figure 22); soybean represented 53.6 percent of the total oilseed crop in 2009, followed by rapeseed (14.9 percent), cottonseed (9.9 percent), groundnut (8.6 percent), sunflower seed (7.7 percent), and palm kernel (2.9 percent) (Figure 23).

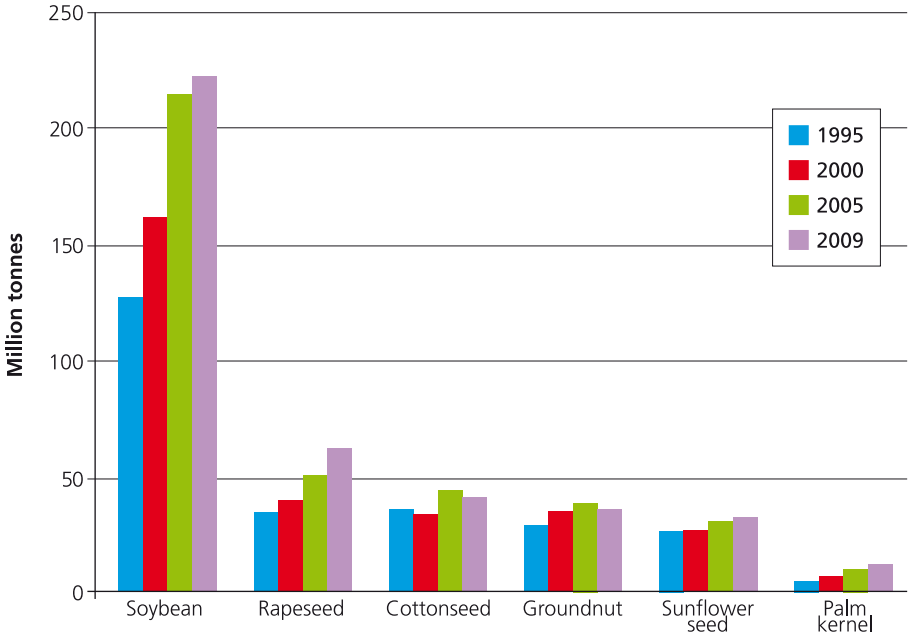
Soybean production continues to be the largest and one of the fastest growing oilseed crops, with global production up by 75.1 percent to 222.3 million tonnes since 1995 and growing at an annual percent rate of 4.1 percent per year (Figure 24, Table 9). The largest producer of soybean in 2009 was the United States of America at 91.4 million tonnes (41.1 percent total oilseed production), followed by Brazil (57.0 million tonnes, or 25.6 percent), Argentina (31.0 million tonnes, or 13.9 percent), China (14.5 million tonnes, or 6.5 percent) and India (10.2 million tonnes, or 4.6 percent) (Figure 25; FAO, 2010c). Other major oilseeds produced in 2009 are listed in Table 9 and include rapeseed (61.6 million tonnes), cottonseed (40.9 million tonnes), groundnut (35.5 million tonnes), sunflower seed (32.0 million tonnes) and palm kernel (11.9 million tonnes).

FIGURE 21
Production of corn feed by-products from alcohol biorefineries in the United States, 1990/91 to 2008/09



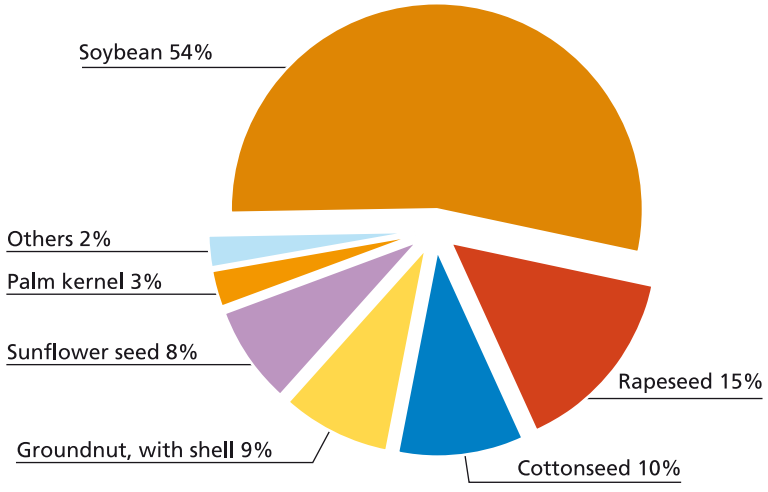
Source: Renewable Fuels Association: www.ethanolrfa.org/pages/industry–resources–coproducts.

FIGURE 22
Global production of major plant oilseed crops, 1995–2009



Source: FAO (2010c).

FIGURE 23
Composition of commodities in global production of oilseed crops, 2009
Total global oilseed crop production in 2009 – 415 million tonnes



Source: FAO (2010c).

The total global production and trade of oilseeds and extracted oilseed meals and oils is shown in Table 9. The data are based on the recent oilseed review of the United States Department of Agriculture (USDA) (2010a) and covers the period of 2008/09 and 2009/10; current FAO estimates for oilseed trade within FAOSTAT are only available up to 2007 (FAO, 2009c), at the time of writing this report. In terms of the total global supply of oilseed protein meals, these follow global oil crop production, with the largest supply by far being for soybean meal at 151.55 million tonnes in 2008/09 (Figures 26 and 27); the largest country producers of soybean meal in 2008/09 were the United States of America (35.47 million tonnes, or 23.4 percent), China (32.47 million tonnes,

TABLE 9
Global production (tonnes) and growth of major oilseed crops, 1995–2009

Oilseed	1995	2000	2005	2009	% increase (1995–2009)	APR % (1995–2009)
Soybean	126 950 271	161 290 903	214 462 151	222 268 904	75.1	4.1
Rapeseed	34 185 574	39 517 577	50 014 339	61 630 798	80.3	4.3
Cottonseed	35 562 917	33 251 468	43 517 078	40 869 553	14.9	1.0
Groundnuts, with shell	28 599 004	34 721 018	38 325 794	35 520 257	24.2	1.6
Sunflower seed	26 297 585	26 454 517	30 549 976	32 002 190	21.7	1.4
Palm kernel	4 759 764	6 478 254	9 889 639	11 932 886	150.7	6.8
Sesame seed	2 530 393	2 786 267	3 373 202	3 511 042	38.8	2.4
Oilseeds, nes	1 719 041	1 918 741	2 271 990	2 373 606	38.1	2.3
Linseed	2 525 094	2 060 823	2 781 281	2 206 288	(–12.6)	–1.0
Melonseed	552,100	595 128	705 405	757 803	37.3	2.3
Mustard seed	487 449	487 048	562 611	661 326	35.7	2.2
Safflower seed	844 467	624 610	582 043	653 791	(–22.6)	–1.8
Poppy seed	70 237	42 175	75 671	96 333	37.2	2.3
Hempseed	30 306	34 591	49 541	56 523	86.5	4.6
Total	265 114 202	310 263 120	397 160 721	414 541 300	56.4	3.2

Note: nes = not elsewhere specified.
Source: FAO (2010c).

or 21.4 percent), Argentina (24.95 tonnes, or 16.5 percent), Brazil (24.33 million tonnes, or 16.0 percent), EU-27 (10.11 million tonnes, or 6.7 percent), India (5.98 million tonnes, or 3.9 percent), and Mexico (2.73 million tonnes, or 1.8 percent (Table 8).

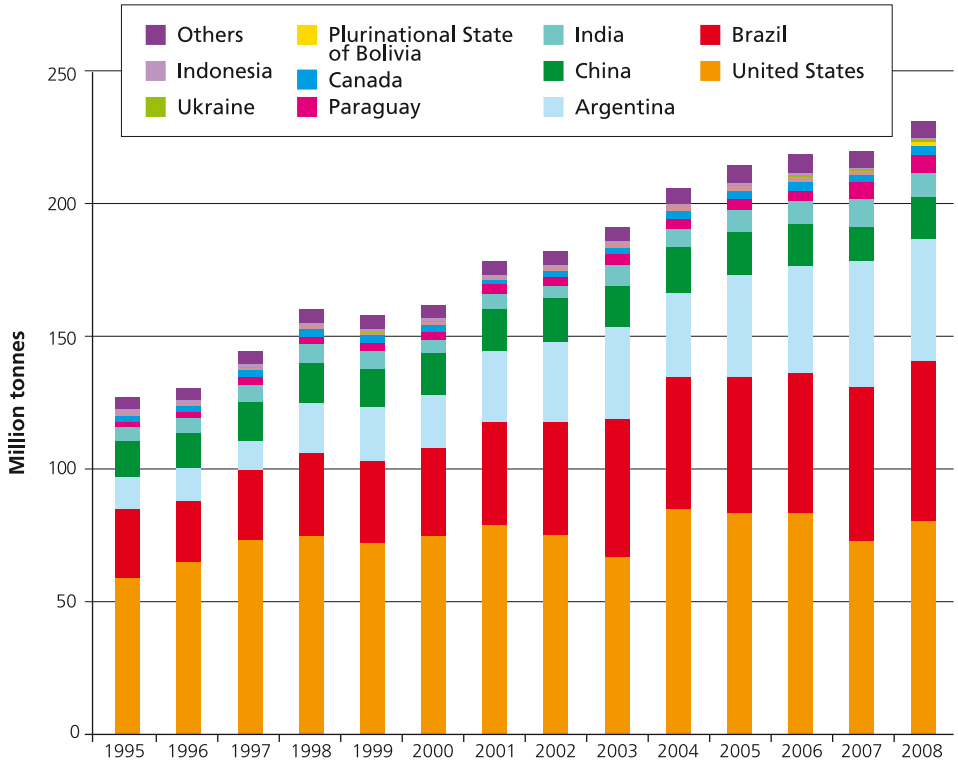
Other major oilseed protein meals produced in 2008/09, ranked in order of production volume, included: rapeseed meal (30.76 million tonnes), cottonseed meal (14.44 million tonnes), sunflower seed meal (12.59 million tonnes), palm kernel meal (6.2 million tonnes), groundnut/peanut meal (6.02 million tonnes), and copra/coconut meal (1.90 million tonnes) (Figures 26 and 27). However, no published information is currently available concerning the global production of oilseed protein concentrate meals, including soybean protein concentrate, rapeseed/canola protein concentrate, cottonseed protein concentrate or sunflower seed protein concentrate meals.

In terms of oil supply, palm oil was the top extracted oil produced in 2008/09 at 42.40 million tonnes (Figure 28), the largest country producers being Indonesia (19.5 million tonnes, or 46.0 percent) and Malaysia (17.26 million tonnes, or 40.7 percent; Figure 29). The second-largest volume of extracted oil was soybean oil at 35.76 million tonnes, with the major producers being the United States of America 8.50 million tonnes; China 7.31 million tonnes; Argentina 6.12 million tonnes; Brazil 6.02 million tonnes; EU-27 2.31 million tonnes; India 1.34 million tonnes; and Mexico 0.61 million tonnes (Figure 30). Other major oilseed oils produced in 2008/09, ranked in order of production volume, included rapeseed oil (20.39 million tonnes); sunflower seed oil (11.74 million tonnes); palm kernel oil (5.13 million tonnes); peanut/groundnut oil (4.97 million tonnes); cottonseed oil (4.84 million tonnes); copra oil (3.63 million tonnes); and olive oil (2.97 million tonnes; Figure 28).

As with the cereals, corn/maize and wheat, more than 85 percent of global oilcrop exports originate from within the Americas (FAO, 2009b), including the United States of America (45.5 percent and 14.8 percent global soybean and soybean meal exports, respectively); Brazil (39.1 percent, 25.0 percent and 21.0 percent of global soybean, soybean meal and soybean oil exports, respectively); Canada (63.7 percent, 54.8 percent and 64.5 percent of global rapeseed, rapeseed meal and rapeseed oil

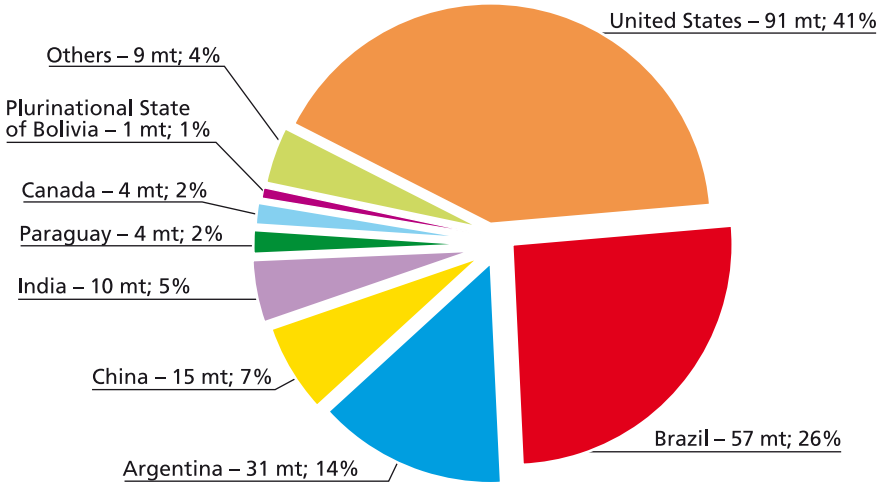
exports, respectively); and Argentina (7.3 percent, 46.0 percent and 52.0 percent total soybean, soybean meal and soybean oil exports (Table 8). The major role played by the United States of America in the global supply and exports of agricultural products, including cereals and oilseeds, is shown in Figure 31.

FIGURE 24
Global production of soybean oilseed crop by country, 1995–2009



Source: FAO (2010c).

FIGURE 25
Global production of soybean oilseed crop by country, 2009

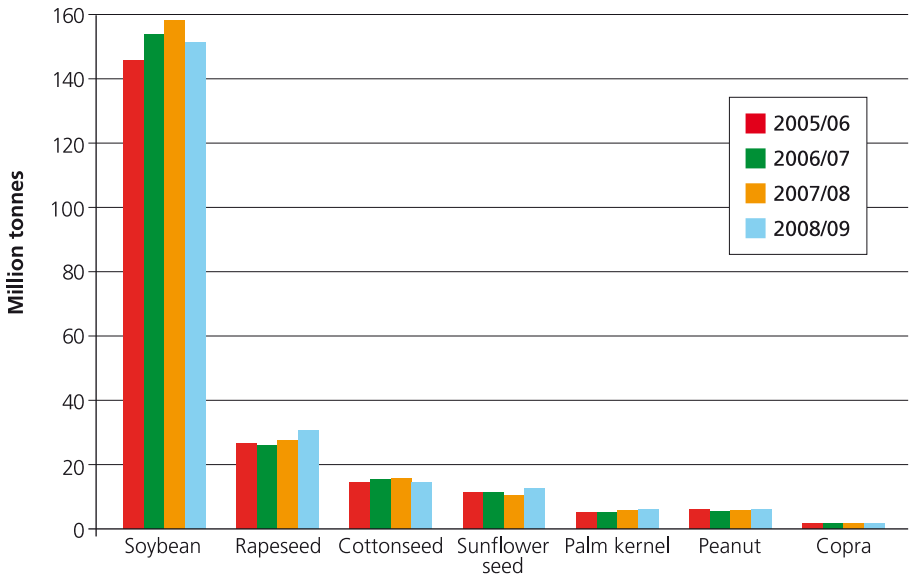


Note: mt = million tonnes.
Source: FAO (2010c).

In marked contrast, China continues to be the world's largest importer of oilseeds (46.6 million tonnes, or 48.0 percent of global oilseed imports in 2008/09 (FAO, 2009b), including 53.7 percent of global soybean imports, 28.1 percent soybean oil imports, 24.7 percent global rapeseed imports, 18.4 percent global rapeseed oil imports, and 18.0 percent global palm oil imports (Table 8; Figure 32).

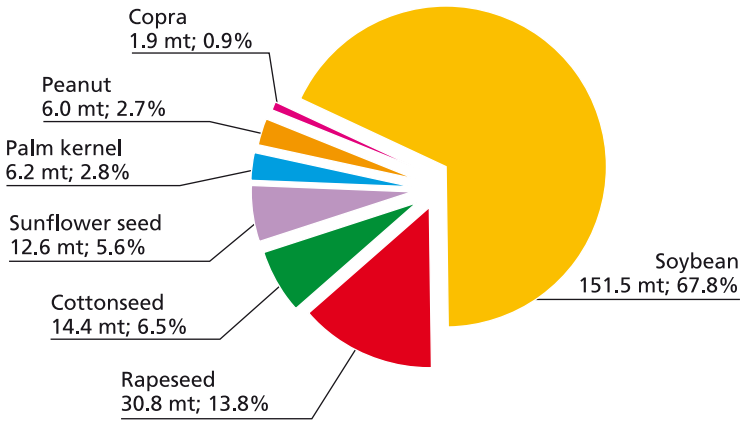
The second largest importer of oilseeds was the EU (18.6 million tonnes, or 19.1 percent global oilcrop imports in 2008/09 (FAO, 2009b), including 57.2 percent global sunflower seed meal imports, 41.9 percent global soybean meal imports, 31.7 percent sunflower seed imports, 27.2 percent global rapeseed imports, 26.0 percent global sunflower seed oil imports, 18.4 percent rapeseed oil imports (Figure 33).

FIGURE 26
Global production of major oilseed meals, 2005/06 to 2008/09



Source: USDA (2010a).

FIGURE 27
Global production of major oilseed meals by commodity, 2008/09
Total global production of major oilseed meals in 2008/09 – 223.5 million tonnes



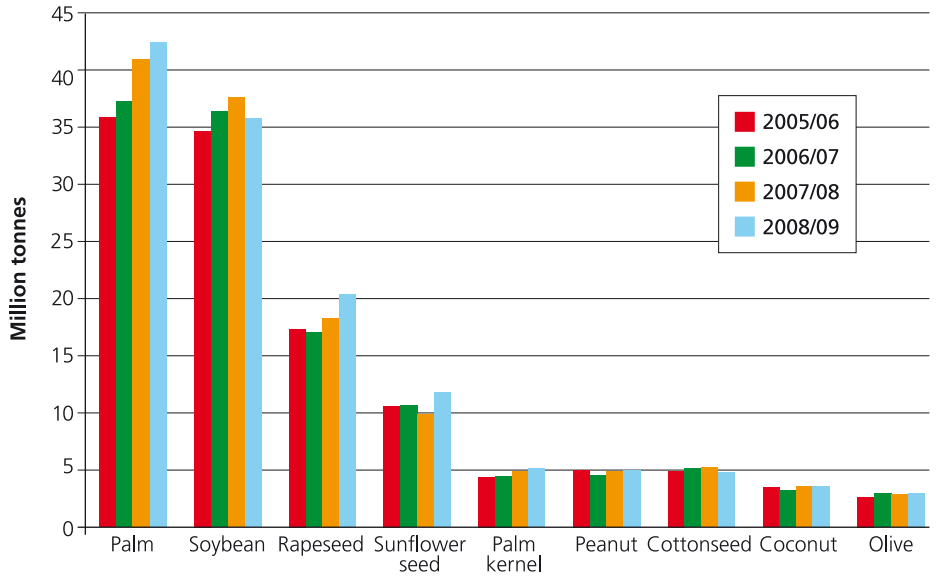
Note: mt = million tonnes.
Source: USDA (2010a).

Pulses and protein concentrate meals

For the purposes of this paper only peas and lupins will be considered, as their protein concentrate meals are commercially available for use within compounded animal feeds, including aquaculture feeds.

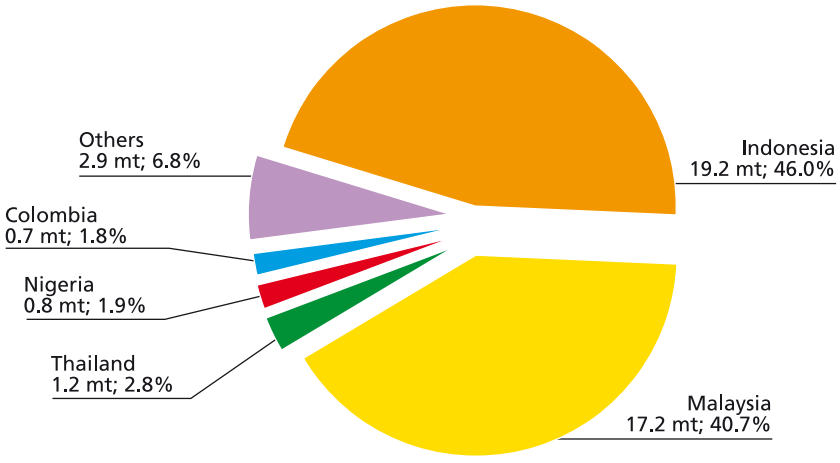
The total global production of dry peas was 10.5 million tonnes in 2009, with production down by 8.7 percent from 1995; the major country producers in 2009 include Canada (3.38 million tonnes or 32.2 percent of global production), followed by the Russian Federation (1.35 million tonnes or 12.9 percent of global production),

FIGURE 28
Global production of major oilseed oils, 2005/06 to 2008/09



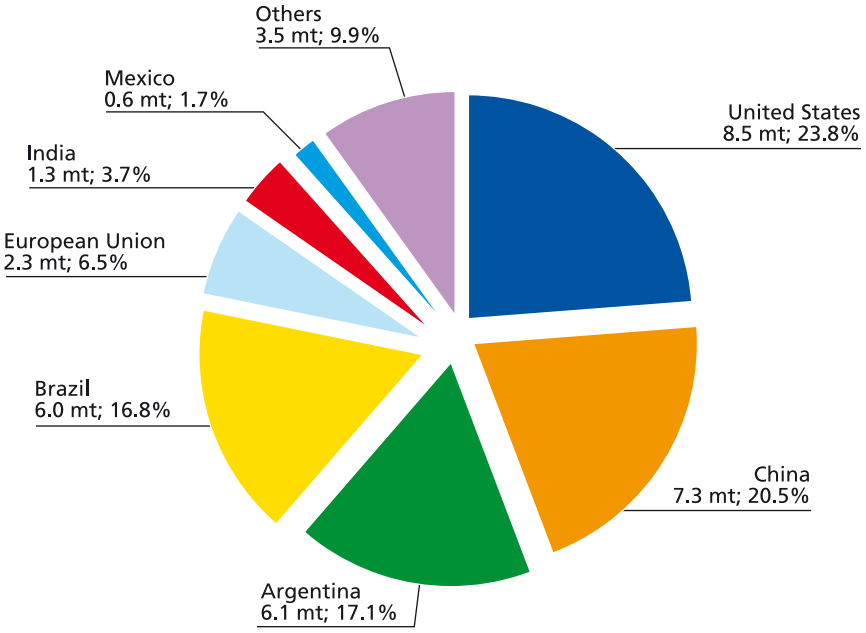
Source: USDA (2010a).

FIGURE 29
Global production of palm oil by country, 2008/09



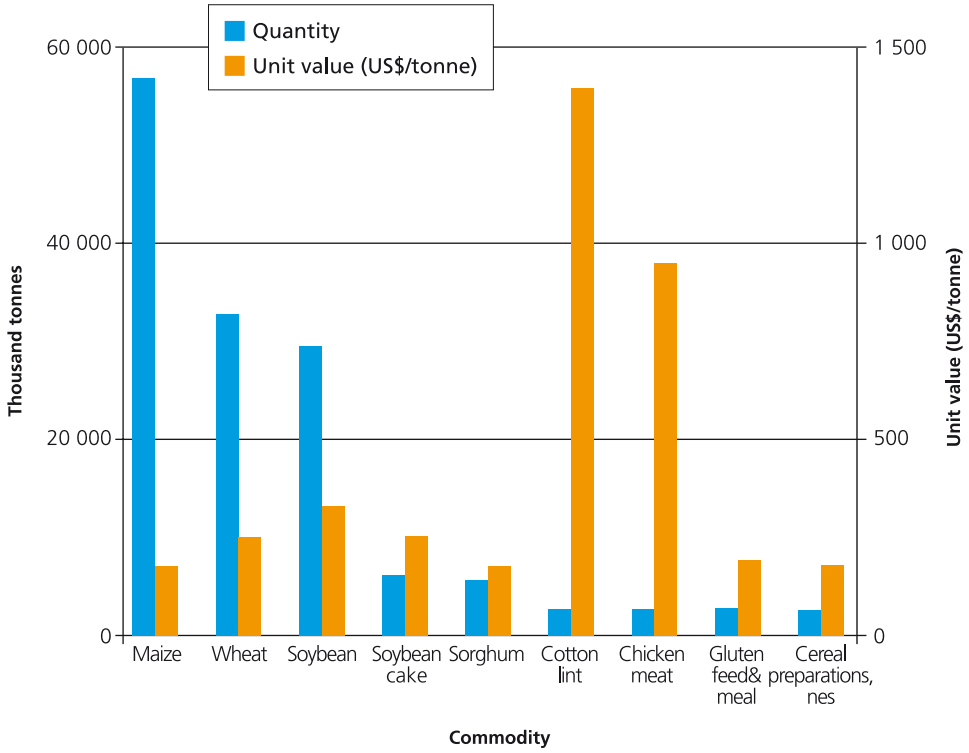
Note: mt = million tonnes.
Source: USDA (2010a).

FIGURE 30
Global production of soybean oil by country, 2008/09



Note: mt = million tonnes.
Source: USDA (2010a).

FIGURE 31
Top agricultural exports by quantity from the United States, 2007



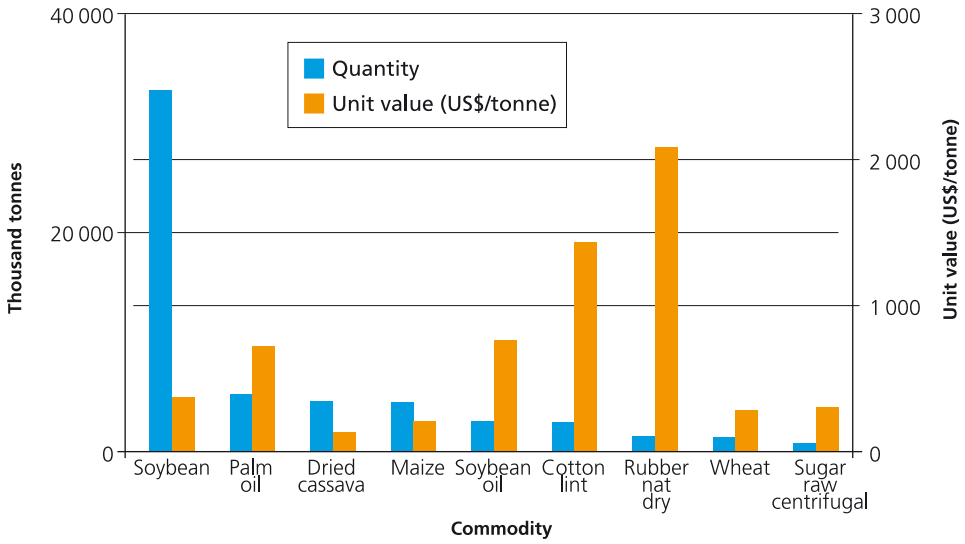
Note: nes = not elsewhere specified.
Source: FAO (2009b).

China (960 000 tonnes), the United States of America (777 320 tonnes), India (754 459 tonnes), France (546 846 tonnes), Ukraine (493 600 tonnes), Australia (356 000 tonnes), Ethiopia (235 872 tonnes) and Germany (165 907 tonnes) (Figure 34).

The total global production of lupins was 925 412 tonnes in 2009, with production down by 46.0 percent from 1995; the major country producers in 2009 include Australia (614 000 tonnes or 66.3 percent global production), followed by Belarus (73 708 tonnes), Germany (59 627 tonnes), Poland (57 000 tonnes), Ukraine (26 800 tonnes), South Africa (20 654 tonnes), Chile (12 311 tonnes), Lithuania (10 600 tonnes), Peru (9 907 tonnes), and the Russian Federation (9 290 tonnes) (Figure 35).

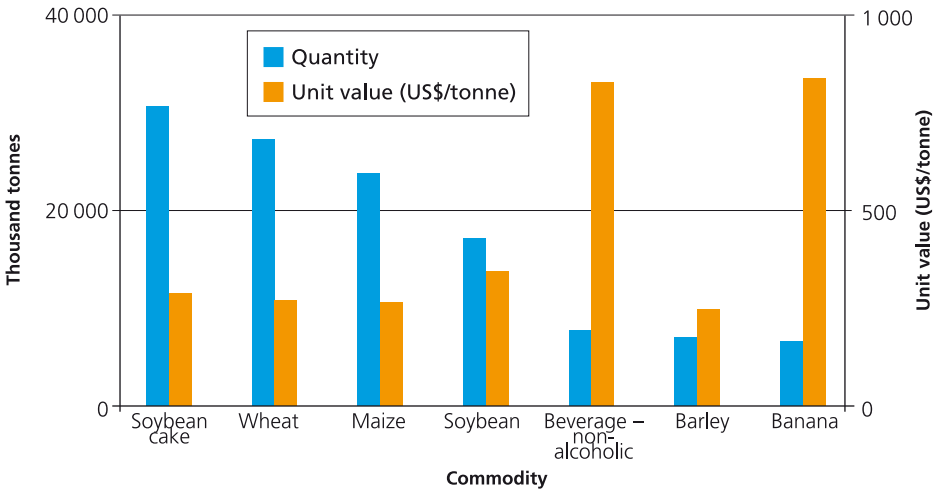
At present, no information is available concerning the global production of pea and/or lupin protein concentrates.

FIGURE 32
Top agricultural imports by quantity in China, 2007



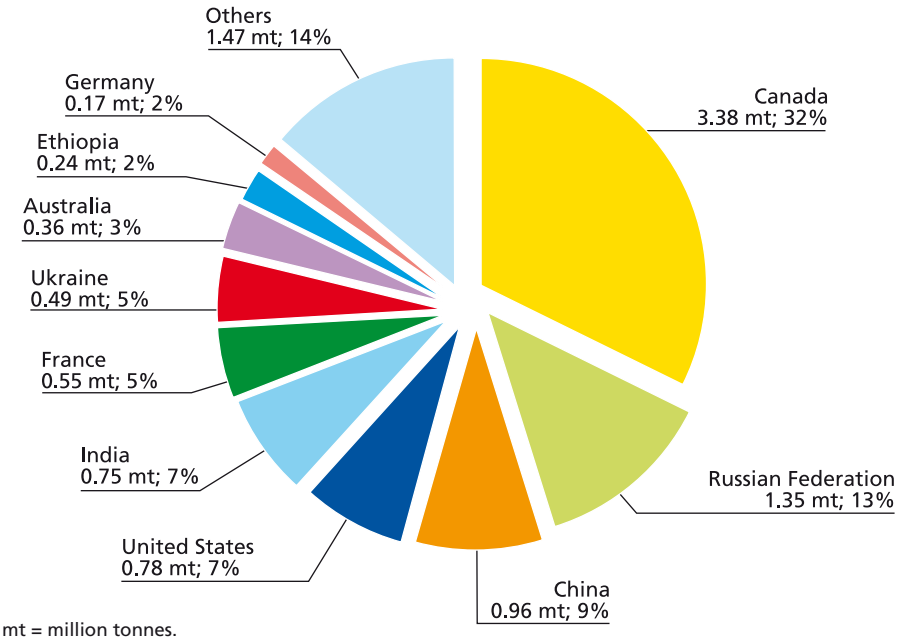
Source: FAO (2009b).

FIGURE 33
Top agricultural imports by quantity in the European Union, 2007



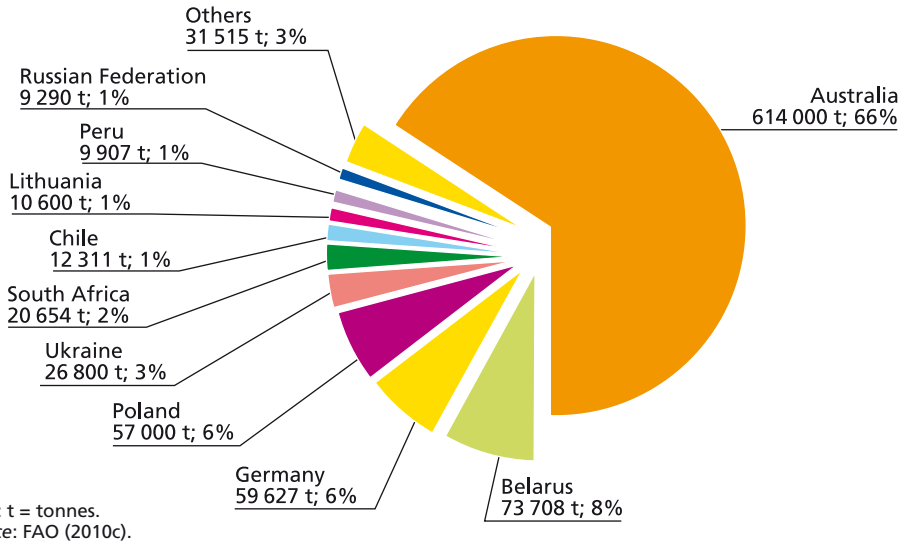
Source: FAO (2009b).

FIGURE 34
Global production of dry peas by country, 2009



Note: mt = million tonnes.
Source: FAO (2010c).

FIGURE 35
Global production of lupins by country, 2009



Note: t = tonnes.
Source: FAO (2010c).

3.3 MICROBIAL INGREDIENT SOURCES

Microbial derived feed ingredient sources include the use of mass-produced harvested/extracted algae, thraustochytrids, yeasts, fungi, bacteria and/or mixed bacterial/microbial single cell protein (SCP) sources. Apart from the limited market availability of algal and thraustochytrid products, the only microbial ingredient sources currently available in commercial quantities globally are yeast-derived products, including brewer's yeast and extracted fermented yeast products (Tacon, Metian and Hasan, 2009). No information, however, is available concerning the total global production and market availability of these products.

Harvest of Indian major carps in Andhra Pradesh, India. Major carps are fed with feeds ranging from supplementary feed, farm-made aquafeed and commercially produced industrial aquafeed in India.

Courtesy of FAO/R. Ramakrishna

4. Current levels of feed ingredient usage and constraints

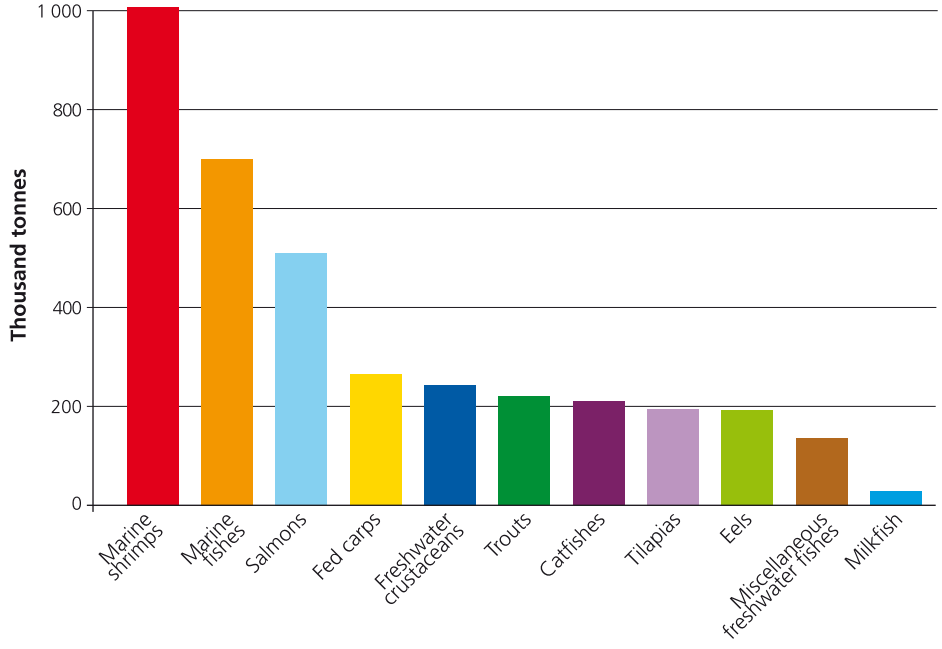
Table 10 shows the feed ingredients currently used in compound aquafeeds for the major cultivated finfish and crustacean species. The results are based on the responses received from commercial feed manufacturers and/or nutritionists to an electronic survey conducted for this study. Although by no means complete, the results show some significant findings, as detailed below.

4.1 CONTINUED USE OF FISHMEAL AND FISH OIL AS MAJOR DIETARY ANIMAL PROTEIN AND LIPID SOURCES

Fishmeal (FM) and fish oil (FO) are continued to be used as the major sources of dietary protein and lipid within compound aquafeeds for the higher trophic level fish and crustacean species, e.g. eels (FM 55–65 percent, FO 3–18 percent, total of FM and FO 58–83 percent); marine finfishes (FM 20–65 percent, FO 5–20 percent, total 25–85 percent); salmons (FM 25–40 percent, FO 10–25 percent, total 35–65 percent); trouts (FM 18–40, FO 5–25 percent, total 23–65 percent); marine shrimps (FM 5–40 percent, 1-9 percent, total 6–49 percent); and freshwater prawns (FM 20–65 percent, FO 0–7 percent, total 20–72 percent) (Table 10).

However, in total usage terms, the largest consumers of fishmeal in 2008 (average species levels based partly on the results of the current survey and shown in Table 11) were shrimps (27.2 percent of total fishmeal used in compound aquafeeds), followed by marine fishes (18.8 percent), salmons (13.7 percent), carps (7.4 percent), freshwater crustaceans (6.4 percent), trouts (5.9 percent), catfishes (5.5 percent), tilapias (5.3 percent),

FIGURE 36
Estimated global consumption of fishmeal by major aquaculture species group, 2008

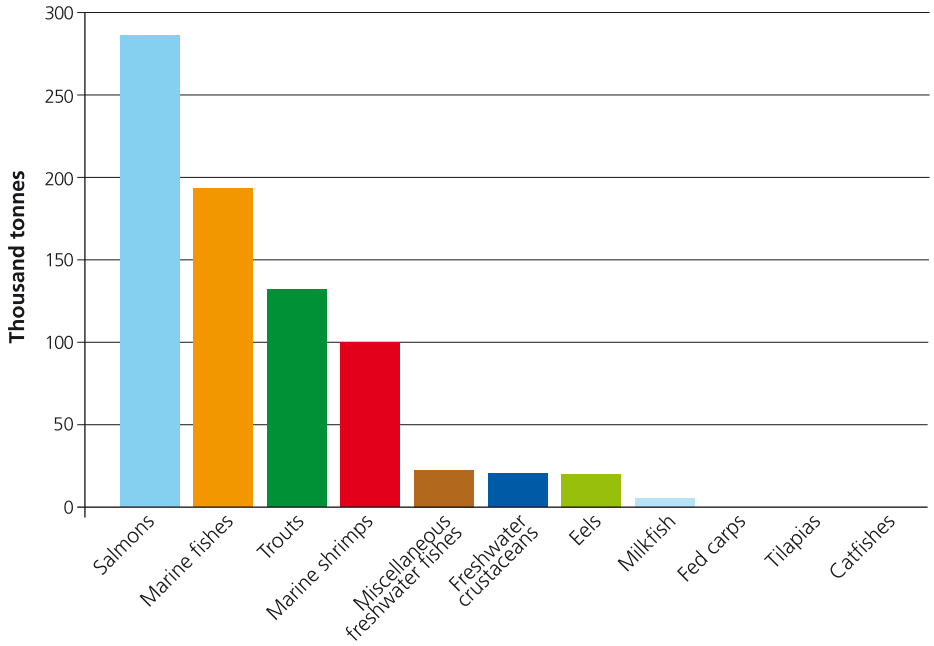


Source: Based on data from Table 11.

eels (5.2 percent), miscellaneous freshwater fishes (3.9 percent) and milkfish (0.8 percent) (Figure 36). On a global basis, it is estimated that the aquaculture sector consumed 3 723 000 tonnes of fishmeal (60.8 percent of global fishmeal production; FAO, 2011b) in 2008 (Table 11). In 2007, the aquaculture sector consumed 3 844 000 tonnes of fishmeal, or about 68.4 percent, of total reported global fishmeal production for that year.

Similarly, in total usage terms the largest consumers of fish oil in 2008 were salmons (36.6 percent total fish oil used in compound aquafeeds), followed by marine fishes (24.7 percent), trouts (16.9 percent), marine shrimps (12.9 percent), miscellaneous freshwater fishes (3.1 percent), freshwater crustaceans (2.6 percent), eels (2.6 percent), and milkfish (0.7 percent; Table 11) (Figure 37). On a global basis, it is estimated that the aquaculture sector consumed 782 000 tonnes of fish oil (73.8 percent of global fish oil production; FAO, 2011b) in 2008 (Table 11). In 2007, the aquaculture sector consumed 823 000 tonnes of fish oil or about 81.3 percent of total reported global fish oil production for that year.

FIGURE 37
Estimated global consumption of fish oil by major aquaculture species group, 2008



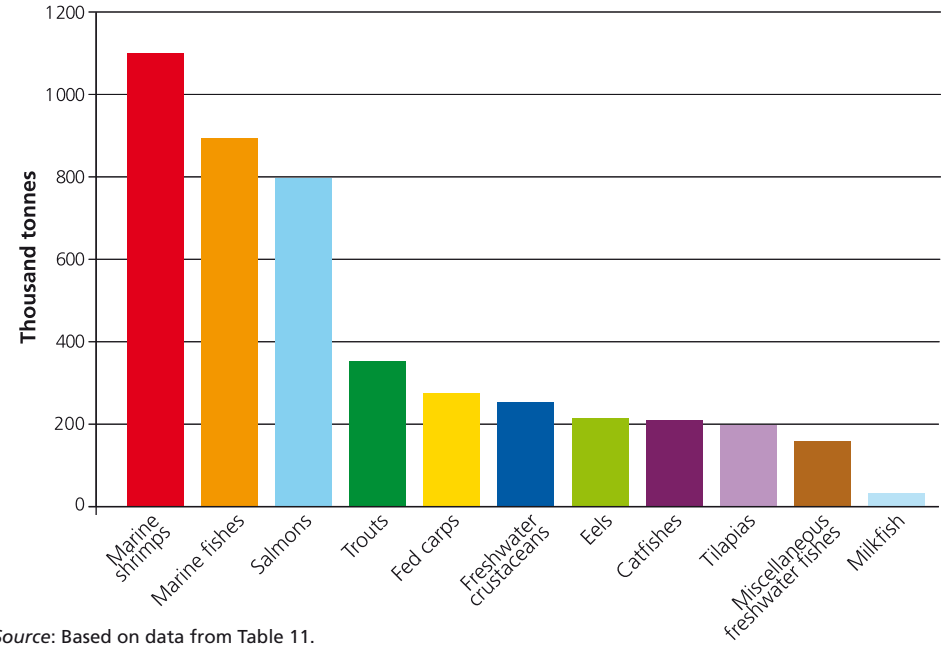
Source: Based on data from Table 11.

Although there has been a gradual reduction of combined fishmeal and fish oil use in aquaculture since 2006, the aquaculture sector has continued to remain the largest user of fishmeal and fish oil. The sector consumed over 4 667 000 tonnes of fishmeal and fish oil, or about 70.3 percent, of the total global production of these two ingredients in 2007. In 2008, the sector consumed about 4 506 000 tonnes of fishmeal and fish oil, or about 62.7 percent, of the global production of these two ingredients for that year. However, there is a wide variation in fishmeal and fish oil usage between major producing countries for species/species groups with shrimp, marine fish and salmon being the largest users of fishmeal and fish oil (Figure 38).

Overall, this variation reflects the differences in the selection and use by countries of fishmeal and fish oil replacers and the differences between countries in cost and availability of ingredients. One other factor is the increased use of land animal proteins and fats within feeds for high trophic level fish species and crustaceans within the Americas and Australia.

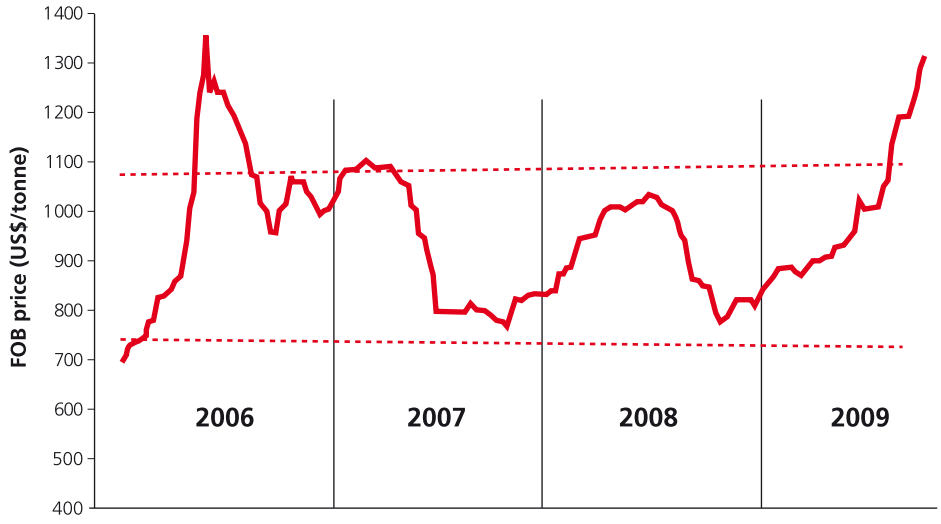
In total usage terms, it is expected that the total use of fishmeal by the aquaculture sector will decrease in the long term, decreasing from 4.23 million tonnes in 2005 to 3.72 million tonnes in 2008 (or 12.8 percent of total aquafeeds by weight), and expected to decrease further to 3.49 million tonnes by 2020 (or 4.9 percent of total aquafeeds for that year) (Table 11). The reasons for this decrease are the increasing market demand and prices (Figure 39), decreased supplies from tighter quota setting and more controls on unregulated fishing, and increased use of more cost-effective dietary fishmeal replacers (Davis and Sookying, 2009; Hardy, 2009; Manomaitis, 2009; Nates *et al.*, 2009; Quintero *et al.*, 2010; Wang, 2009).

FIGURE 38
Estimated total global consumption of fishmeal and fish oil by major aquaculture species group, 2008



Source: Based on data from Table 11.

FIGURE 39
Variation in price of fair average quality (FAQ) Peru fishmeal, January 2006 to October 2009



Note: FOB = free on board.
Source: Mittaine (2009).

On the contrary, it is expected that the use of fish oil by the aquaculture sector will continue to increase in the long run albeit slowly; total usage will increase by over 16 percent by volume, from 782 000 tonnes (2.7 percent of total feeds by weight) in 2008 to the estimated 908 000 tonnes (1.3 percent of total aquafeeds for that year) by 2020 (Table 11). The reasons for the increased use in global terms are believed to be the rising demand for these resources by the rapidly growing marine finfish and crustacean aquaculture sector and the absence of cost-effective alternative sources of dietary lipids that are rich in long-chain, highly unsaturated fatty acids, including eicosapentaenoic acid (EPA; 20:5n-3) and docosahexaenoic acid (DHA; 22:6n-3) (Hole, 2009; Turchini, Torstensen and Ng, 2009; Wang, 2009).

4.2 INCREASED USE OF TERRESTRIAL ANIMAL PROTEIN MEALS AND OILS AS DIETARY NUTRIENT SOURCES

The use (within non-European countries) of terrestrial animal protein meals and lipids is increasing within compound aquafeeds, for both high and low trophic level species, and concern specifically the following species groups (Table 10):

- *salmons* – poultry by-product meal (10–30 percent); hydrolysed feather meal (5–12 percent); blood meal (1–8 percent); meat meal (10–30 percent); poultry oil (1–15 percent);
- *trouts* – poultry by-product meal (5–30 percent); hydrolysed feather meal (5–20 percent); blood meal (1–8 percent); meat meal (10–30 percent); poultry oil (1–15 percent);
- *marine finfishes* – poultry by-product meal (10–30 percent); blood meal (1–10 percent); meat meal (10–30 percent) (1–10 percent);
- *marine shrimps* – poultry by-product meal (2–30 percent); hydrolysed feather meal (5–10 percent); meat meal (2–30 percent);
- *catfishes* – poultry by-product meal (2–4 percent);
- *tilapia* – meat and bone meal (5–10 percent); poultry oil (2–4 percent);
- *freshwater crayfishes* – meat meal (10–30 percent); meat and bone meal (10–30 percent);
- *carps* – meat and bone meal (5–10 percent); and
- *grey mullets* – meat and bone meal (5–10 percent).

The fact that non-European feed manufacturers are able to utilize this largely untapped dietary nutrient source allows them to be less reliant on the use of fishmeal and fish oil as dietary nutrient sources and, by virtue of their greater availability and lower cost, makes them more economically competitive than their European counterparts. For example, salmon feeds in Chile currently contain about 10–20 percent terrestrial animal by-products and only 20–25 percent fishmeal and 12–15 percent fish oil, whereas in the United Kingdom of Great Britain and Northern Ireland, salmon feeds contain 35 percent fishmeal, 25 percent fish oil and 0 percent terrestrial animal by-products (Table 10). Despite this, it is estimated that the total direct usage of terrestrial animal by-product meals and oils within compound aquafeeds is, at present, only between 150 000 tonnes and 300 000 tonnes (Table 10), or less than 1 percent of total global compound aquafeed feed production. Clearly, there is considerable room for further growth and expansion (Nates *et al.*, 2009).

According to the European Commission, the only animal by-products (ABP) that can be used within aquafeeds are Category 3 ABP (for review, see Woodgate, 2010; European Commission Regulation No. 1774/2002 and No. 999/2001). These are animal by-products or parts of slaughtered animals that are fit for human consumption in accordance with Community legislation but are not intended for human consumption for commercial reasons. These include:

TABLE 10
Country responses regarding feed ingredient usage for major cultivated species groups (percentage values represent country ranges and/or means)

Country	Year	FM	FO	R/CO	SBM	WH	WGM	SSM	CGM	R/CM	LKM	FPM	FBM	KM	PO	PBM	HFM	BM	MM
Salmons – Atlantic salmon, coho salmon, chinook salmon																			
Australia	2008/09	25–40	10–25	-	-	10–20	2–10	-	-	-	5–15	-	-	5–10	0–10	10–30	-	1–5	10–30
Canada	2008	25–35	15–25	-	3–10	12–18	-	-	10–40	3–10	-	-	-	-	10-15	15-25	5-12	6-8	-
Chile	2008	25	12	12 (20:80 rape:soya oil); 20 (plant: SBM <12, RSM <6, LKM <6, CGM <10, SPC <8, CSM <12); 17 (poultry by-products: HFM <12, PBM <8, BM <7)															
Chile	2010	20–25	15	15	Plant protein sources: 25									-	-	Animal by-products: 10-20			
Norway	2008	26–30	17–19	11–13	8–12	10–14	3–4	7–9	-	-	-	-	-	+[1]	-	-	-	-	-
Norway	2010	25	15	15	12	12	Other plant protein sources: 20									-	-	-	-
United Kingdom	2008	35	25	5	10	10	-	5	-	5	-	3	5	-	-	-	-	-	-
United Kingdom	2010	35	25	+	+	12	No other information given												
Trouts – rainbow trout, sea trout																			
Argentina	2009	18–40	5–20	-	10–35	15	-	-	3–8	-	-	-	-	-	-	-	10–20	-	-
Australia	2008/09	20–40	10–20	-	-	10–20	2–10	-	-	-	5–15	5–10	-	-	0–10	10–30	-	1–5	10–30
Canada	2008	25–35	15–25	-	3–10	12–18	-	-	10–40	3–10	-	-	-	-	10–15	15–25	5–12	6–8	-
Chile	2008	25	12	12 (20:80 rape: soya oil); 20 (plant: SBM <12, RSM <6, LKM <6, CGM <10, SPC <8, CSM <12); 17 (poultry by-products: FM <12, PBM <8, BM <7).															
Chile	2010	20–25	15	15	Plant protein sources: 25											Animal by-products: 10–20			
Denmark	2008	32	20	-	12	12	-	-	-	-	-	-	No other details given						
Ecuador	2009	>30	10–15	-	<15	Corn <15; No other details given													
France	2009	20–30	10–15	5–8	10–15	5–10	3–5	5–8	5–8	-	-	5–10	Pea protein meal 5–10; soybean protein concentrate 5–10%						
Greece	2009	20–40	7–15	-	10–35	5–15	5–12	5–10	5–12	5–10	-	5–10							
Mexico	2009	15–25	10–15	-	20–35	Corn <10; Soy lecithin 2-3			4–5	2–5	-	-	-	-	-	5-10	Hog and blood meal <10		
Norway	2008	28–32	16–19	10–12	8–12	10–14	3–4	7–9	-	-	-	-	-	-	-	-	-	-	-
Norway	2010	25	15	15	12	12	Other vegetable proteins: 20												
United Kingdom	2008	30	20	-	15	10	-	8	-	5	-	3	8	-	-	-	-	-	-

TABLE 10, continued

Country responses regarding feed ingredient usage for major cultivated species groups (percentage values represent country ranges and/or means)

Country	Year	FM	FO	R/CO	SBM	WH	WGM	SSM	CGM	R/CM	LKM	FPM	FBM	KM	PO	PBM	HFM	BM	MM
Marine shrimps – whiteleg shrimp, giant tiger prawn																			
Australia	2008/09	20–40	2–5	-	-	10–30	-	2–10	-	-	5–15	-	-	5–15	-	10–30	-	-	10–30
China	2008	20–30	-	-	10–25	Wheat and wheat by-products 15–25				0–20	-	-	-	-	-	-	-	-	-
China	2008	30	1–2	Other ingredients listed include soybean meal, peanut cake/meal, rapeseed cake/meal, corn, wheat flour – no levels given															
Ecuador	2009	5–20	-	<5	>30	<15	Other ingredients listed: corn <20; cassava <20; polished rice 15; broken rice 15%;												
India	2006/07	20–30	2–3	3	20–25	Wheat and other cereals 20–25; groundnut meal 15–20;							1–2	Squid meal and acetes shrimp 3–10					
Mexico	2009	12–20	3–6	1–2	15–40	12–22	3–6	Corn by-products 2–4		3–8	-	-	1–4	-	-	2–4	-	-	2–4
Nicaragua	2009	12.5	3	-	15	20	Rice bran 19; sorghum 15; peanut/groundnut meal 4;									3			
Venezuela (Bolivarian Republic of)	2008	22	4	-	25	10	25	Broken rice 5; rice meal 5;					1	-	-	-	-	-	-
United States	2009	30–40	5–9	5–10	5–15	Wheat, wheat flour, wheat middlings 10–25; squid oil 1–5; imported special fishmeals 10-15											5–10		
Marine fishes – barramundi, cobia, cods, groupers, halibuts, seabass, seabreams, tunas, yellowtail																			
Australia	2008/09	20–40	5–20	-	-	10–20	2–10	Other ingredients: lupin kernel meal 5–15, field pea 25						-	0-10	10-30	-	1-5	10-30
China	2008	20–50	5	-	10–25	Wheat and wheat by-products 15–25				0–20	Others listed: soybean meal, peanut meal/cake, rapeseed cake/meal, corn, wheat								
France	2009	20–30	5–10	-	15–25	5–10	3–5	5–8	10–18	Others listed: rapeseed oil 3–5, peas 5–10, pea protein 5–10, soy protein concentrate 5–10									
Greece	2009	20-40	7–15	-	10–35	5–15	5–12	5–10	5–12	5–10	Pea meal 5–10								
Norway	2010	50	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spain	2009	45–64	7–12	6		1–5	9–13	-	4	7	10	Other ingredients: soybean concentrate 5–19, pea meal 5–10							
Taiwan Province of China	2007	50–65	6-8	3–5	15–25	10–15	-	-	-	-	-	-	-	-	-	-	-	-	-
United Kingdom	2008	60	15	-	15	10	Other ingredients listed: beans 5, others 5												
United States	2009	20–40	5–20	-	10–15	5–15	-	-	5–10	-	5–10	2–4	10–15	-	-	-	-	5–10	-

TABLE 10, continued

Country responses regarding feed ingredient usage for major cultivated species groups (percentage values represent country ranges and/or means)

Country	Year	FM	FO	SO	SBM	WH	WB	MA	CGM	R/CM	CSM	FPM	SL	KM	PO	PBM	HFM	BM	RB
Carps – grass carp, common carp, crucian carp, catla, rohu																			
China	2008	0–3	-	-	0–25	0–25		0–25	-	20–40	Spirit-based distillers grains 0–8%								
Egypt	2008	4–12	-	-	20–25	-	10–25	10–25	-	-	Other ingredients listed: yellow corn 30–40, local meat and bone meal 5–10								
India	2006/07	-	-	-	5	-	50	50	-	-	Other ingredients listed: groundnut/peanut cake 30, mustard cake 10								
Catfishes – channel catfish, pangasiid catfishes																			
India	2006/07	5–10	-	-	10	15–20					Other ingredients listed: groundnut/peanut cake 30, mustard cake 10								
Mexico	2009	10–15	3–6	1–4	30	15–20		15-20	-	5–10	-	-	1–4	-	-	2–4	-	-	-
United States	2008	-	-	-	20–50	10–20		30–45		-	10–20	-	-	-	-	-	-	-	-
Viet Nam	2008	0–10			30–60	-	-	-	-	Other ingredients listed: cassava 20–35					20–30	-	-	-	-
Tilapias																			
China	2008	0–3	-	-	0–25	0–25		0–15		20–40	0–25	Spirit based distillers grains 0–8							
Ecuador	2009	<10	-	-	>40	-	-	20–30	Other ingredients listed: sorghum <25, rice polishing 15, broken rice 15										
Egypt	2008	4–12	-	-	20–25	-	10–25	30–40	-	-	-		-	-	-	-	5–10	-	10–25
Mexico	2009	10–15	3–6	1–4	30	15–20	15–20	-	5–10	-	-	1–4	-	-	2–4	-	-	-	-
Peru	2008	20	-	-	40	-	-	30	-	-	-	-	-	-	-	-	-	-	-
Taiwan Province of China	2007	20–25	3–5	5–8	30–35	15–20		-	-	-	-	-	-	-	-	-	-	-	10–25
United States	2008	2–5	1	-	30–35	Other ingredients reported: corn, sorghum and wheat products													
Venezuela (Bolivarian Republic of)	2008	16	-	2	23	34	22	-	6	-	-	Broken/milled rice 7, sorghum grain meal 20							
Viet Nam	2008	5	-	-	30–60	-	-	-	Other ingredients listed: cassava 20–35										20–30
Eels																			
Denmark	2008	55	18	-	10	15	-	-	-	-	-	-	-	-	-	-	-	-	-
Taiwan Province of China	2007	60–65	3–5	6–8	8–10	Starch 15–20													

TABLE 10, continued

Country responses regarding feed ingredient usage for major cultivated species groups (percentage values represent country ranges and/or means)

Country	Year	FM	FO	SO	SBM	WH	WB	MA	CGM	R/CM	CSM	FPM	SL	KM	PO	PBM	HFM	BM	RB
Freshwater prawns																			
China	2008	20–30	0–1	-	-	-	5–10	Other ingredients listed: soybean meal, peanut meal/cake, rapeseed cake/meal, corn, and wheat flour											5–10
India	2006/07	20–30	2–3	-	20–25	20–25		Other marine prote ins: squid, acetes				3–10	1–2	Other: groundnut cake 15–20, mustard cake 15–20					
Taiwan Province of China	2007	20–65	5–7	4–5	15–20	10–15	-	-	-	-	-	-	-	-	-	-	-	-	-
Milkfish																			
Taiwan Province of China	2007	5–10	3–5	5–8	35–40	15–20		-	-	-	-	-	-	-	-	-	-	-	15–20
Cachama																			
Venezuela (Bolivarian Republic of)	2008	7–18	-	2	13	46	25	-	6	Other ingredients listed: sorghum gain meal 20, broken rice/meal 7									
Freshwater crayfishes																			
Australia	2008/09	5–10	0–5	-	-	20–40	2–10	Other ingredients: lupin kerneal meal 5–30						-	-	-	-	1–5	10–30
Grey mullets																			
Egypt	2008	4–12	-	-	20–25	-	10–25	10–25	Other ingredients: yellow corn 30–40										5–10

Note: BM = blood meal; CGM = corn gluten meal; CPC = canola protein concentrate; CSM = cottonseed meal; FPM = field pea meal; FBM = faba bean meal; FM = fishmeal; FO = fish oil; G/PM = groundnut/peanut meal; HFM = hydrolysed feather meal; KM = krill meal; LKM = lupin kernel meal; MA = maize/corn; MBM = meat and bone meal; MC = mustard seed cake; MM = meat meal (hog/ovine); PBM = poultry by-product meal; PO = poultry oil; R/CM = rapeseed/canola meal; RB = rice bran; R/CO = rapeseed/canola oil; SL = soy lecithin; SO = soybean oil; SBM = soybean meal; SSM =sunflower seed meal; WH = wheat; WGM = wheat gluten meal; SM = squid meal; WF = wheat flour; WB = wheat bran; WM = wheat middlings.

[1]5–10 percent krill meal used in specialty diets, including starter feeds and broodstock feeds.

TABLE 11
Estimated global use and demand for fishmeal and fish oil (thousand tonnes), 1995-2020

Year	Total feeds use[1]	Mean % FM[2]	Mean % FO[2]	Total FM use	Total FO use
Fed carps					
1995	2 062	10	0	206	0
2000	5 556	9	0	500	0
2005	7 371	8	0	590	0
2007	8 303	3	0	249	0
2008	9 145	3	0	274	0
2010	10 503	2	0	210	0
2015	13 275	1	0	133	0
2020	15 801	1	0	158	0
Tilapias					
1995	985	10	0	99	0
2000	1 696	9	0	153	0
2005	2 852	8	0	228	0
2007	3 493	5	0	175	0
2008	3 948	5	0	197	0
2010	4 893	3	0	147	0
2015	7 852	2	0	157	0
2020	12 178	1	0	122	0
Catfishes					
1995	586	5	0	29	0
2000	772	8	0	62	0
2005	1 747	12	0	210	0
2007	2 448	8	0	196	0
2008	2 935	7	0	205	0
2010	4 240	5	0	212	0
2015	7 829	3	0	235	0
2020	12 488	2	0	250	0
Miscellaneous freshwater fishes					
1995	15	55	8	8	1
2000	56	50	6	28	3
2005	250	45	5	113	13
2007	360	36	5	130	18
2008	480	30	5	144	24
2010	718	24	4	172	29
2015	1 581	12	3	190	47
2020	3 055	8	2	244	61
Salmons					
1995	806	45	25	363	202
2000	1 327	40	23	531	305
2005	1 796	35	21	629	377
2007	2 029	28	16	568	325
2008	2 045	25	14	511	286
2010	2 255	22	12	496	271
2015	2 877	16	10	460	288
2020	3 672	12	8	441	294
Trouts					
1995	588	40	20	235	118
2000	666	36	17	240	113
2005	743	34	16	253	119
2007	903	28	15	253	135
2008	880	25	15	220	132

TABLE 11, continued
Estimated global use and demand for fishmeal and fish oil (thousand tonnes), 1995-2020

Year	Total feeds use[1]	Mean % FM[2]	Mean % FO[2]	Total FM use	Total FO use
Trouts, continued					
2010	970	22	12	213	116
2015	1 238	16	10	198	124
2020	1 581	12	8	190	126
Milkfish					
1995	220	15	3	33	7
2000	318	10	2	32	6
2005	464	5	1	23	5
2007	547	5	1	27	5
2008	568	5	1	28	6
2010	671	4	1	27	7
2015	856	3	1	26	9
2020	1 068	2	1	21	11
Eels					
1995	338	65	8	220	27
2000	351	62	6	218	21
2005	327	60	5	196	16
2007	416	50	5	208	21
2008	403	48	5	193	20
2010	397	46	4	183	16
2015	447	38	3	170	13
2020	504	30	2	151	10
Marine fishes					
1995	533	50	15	267	80
2000	1 139	44	10	501	114
2005	2 050	38	8	779	164
2007	2 533	32	8	811	203
2008	2 416	29	8	701	193
2010	2 964	26	6	771	178
2015	4 239	18	5	763	212
2020	6 643	12	4	797	266
Marine shrimps					
1995	1 387	28	2	388	28
2000	1 857	25	2	464	37
2005	4 268	24	2	1024	85
2007	4 821	20	2	964	96
2008	5 058	20	2	1012	101
2010	6 251	16	2	1000	125
Marine shrimps					
2015	8 793	12	1.5	1055	132
2020	11 322	8	1	906	113
Freshwater crustaceans					
1995	91	25	2	23	2
2000	412	23	2	95	8
2005	904	20	1.5	181	14
2007	1 320	20	1.5	264	20
2008	1 315	18	1.5	237	20
2010	1 510	16	1.5	242	23
2015	2 015	12	1	242	20
2020	2 657	8	1	213	27

TABLE 11, continued
Estimated global use and demand for fishmeal and fish oil (thousand tonnes), 1995-2020

Year	Total fed production	Total feeds used	Total fishmeal used	Total fish oil used
Summary totals for fed species and aquafeed production and fishmeal and fish oil use				
1995	4 028	7 612	1 870	463
2000	7 684	14 150	2 823	608
2005	13 048	22 585	4 225	792
2007	16 126	26 950	3 844	823
2008	17 476	29 194	3 728	782
2010	21 201	35 371	3 670	764
2015	32 315	51 002	3 626	845
2020	46 917	70 969	3 490	908

[1, 2] Data taken from Table 3; mean % fishmeal and fish oil use for species/species groups has been adapted from Tacon and Metian (2008a).

- fishmeal (with restrictions – intraspecies recycling is prohibited, see Regulation (EC 999/2001);
- dicalcium phosphate and tricalcium phosphate of animal origin (with restrictions);
- non-ruminant blood meal and blood products (with restrictions);
- milk, milk-based products and colostrums (without restriction);
- eggs and egg products (without restriction);
- hydrolysed protein from ruminant hides/skin (without restriction);
- hydrolysed protein from non-ruminants (without restriction);
- gelatine from non-ruminants (without restriction);
- animal fats (without restriction); and
- collagen from non-ruminants (without restriction).

4.3 CONTINUED AND INCREASED USE OF PLANT PROTEIN MEALS AND OILS AS DIETARY NUTRIENT SOURCES

Plant proteins represent the major dietary protein source used within feeds for lower trophic level fish species (tilapias, carps, catfishes) and the second major source of dietary protein and lipid source after fishmeal and fish oil for shrimps and European high trophic level fish species (Table 10), for example:

- *tilapias* – soybean meal (20–60 percent), corn gluten meal (5–10 percent); rapeseed/canola meal (20–40 percent); cottonseed meal (1–25 percent); soybean oil (1–8 percent);
- *carps* – soybean meal (5–25 percent); rapeseed/canola meal (20–40 percent); groundnut/peanut meal (30 percent); mustard seed cake (10 percent),
- *marine shrimps* – soybean meal (5–40 percent); wheat gluten meal (2–10 percent); corn gluten meal (2–4 percent); rapeseed/canola meal (3–20 percent); lupin kernel meal (5–15 percent);
- *marine fishes* – soybean meal (10–25 percent); soybean oil (3–6 percent); wheat gluten meal (2–13 percent); corn gluten meal (4–18 percent); sunflower seed meal (5–8 percent); rapeseed/canola meal (7–20 percent); canola protein concentrate (10–15 percent);
- *trouts* – soybean meal (3–35 percent); wheat gluten meal (2–10 percent); sunflower seed meal (5–9 percent); corn gluten meal (3–40 percent); rapeseed/canola meal (2–10 percent); lupin kernel meal (5–15 percent); faba bean meal (8 percent); field pea meal (3–10 percent); rapeseed/canola oil (5–15 percent); soybean oil (5–10 percent);
- *salmons* – soybean meal (3–12 percent); wheat gluten meal (2–10 percent); sunflower seed meal (5–9 percent); corn gluten meal (10–40 percent); rapeseed/

canola meal (3–10 percent); lupin kernel meal (5–15 percent); faba bean meal (5 percent); field pea meal (3 percent); rapeseed/canola oil (5–15 percent); soybean oil (5–10 percent);
- *milkfish* – soybean meal (35–40 percent);
- *grey mullets* – soybean meal (20–25 percent);
- *freshwater prawns* – soybean meal (15–25 percent);
- *cachama* – soybean meal (13 percent); corn gluten meal (6 percent);
- *freshwater crayfishes* – wheat gluten meal (2–10 percent); lupin kernel meal (5–30 percent); and
- *eels* – soybean meal (8–10 percent).

Soybean meal is the most common source of plant protein used in compound aquafeeds and the most prominent protein ingredient substitute for fishmeal in aquaculture feeds (Manomaitis, 2009), with feeds for herbivorous and omnivorous fish species and crustaceans usually containing (depending upon species, country, price and availability) from 15 to 45 percent soybean meal, with a mean of 25 percent in 2008 (Table 10). In global usage terms, and based on a total compound aquafeed production of 29.3 million tonnes in 2008 (Table 3), it is estimated that the aquaculture feed sector is consuming about 6.8 million tonnes of soybean meal; China alone is currently consuming an estimated 6.0 million tonnes of soybean meal within compound aquafeeds (Mike Cremer, American Soybean Association, personal communication, December 2009).

At present, plant protein/oil choice and selection are based upon a combination of local market availability and cost (Figure 40), and the nutritional profile (including antinutrient content and level) of the protein meal and/or plant oil in question (Davis and Sookying, 2009; Gatlin *et al.*, 2007; Krogdahl *et al.*, 2010). With the continued rise in the price of fishmeal, plant protein concentrates will gain more and more prominence over regular plant protein meals within aquafeeds for high trophic level cultured species and crustaceans (includes soybean protein concentrate, canola protein concentrate, pea protein concentrate and corn/wheat gluten meals; for review see Tacon, Metian and Hasan, 2009). For example, according to Manomaitis (2009), the forecast demand for soybean protein concentrates within aquafeeds is over 2.8 million tonnes by 2020.

4.4 INGREDIENT COMPETITION WITH OTHER USERS

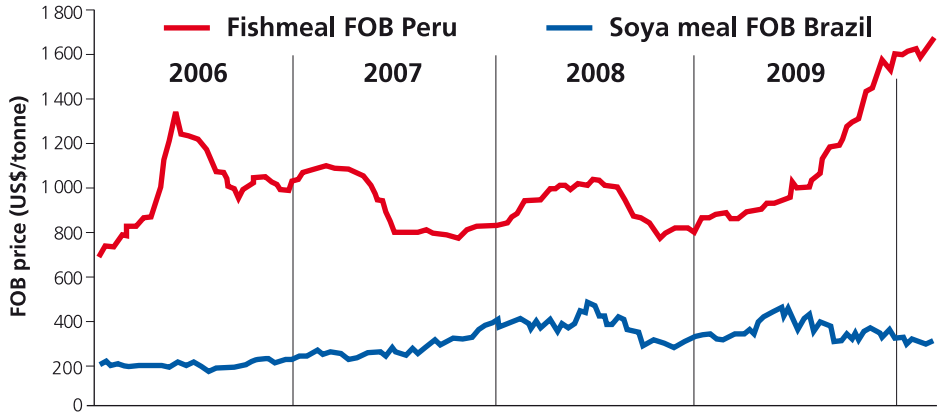
Aquaculture, like any other animal production system, has to compete with other users for nutrient inputs, including specific feed ingredients and fresh food items.

4.4.1 Competition with livestock

Livestock are an integral part of the agricultural food production process within all of the countries where aquaculture is practised. They are also a major consumer of feed ingredients and feeds: total global livestock and animal feed production is estimated at 708 million tonnes in 2009 (poultry 41.5 percent; pig 30.0 percent; ruminant 25 percent) (Peter Best, personal communication, March 2010); total global feed production increased by 20 percent since 1995, growing at an average annual compound rate of 1.3 percent (Best, 2010b).

Although contribution of aquafeed to global animal feed production is currently less than 4 percent by volume, aquaculture has emerged as a major competitor and consumer for several key ingredient sources, including fishmeal and fish oil. It is estimated that the aquaculture sector consumed over 4.5 million tonnes of fishmeal and fish oil in 2008, or about 70.3 percent of the total global production of these commodities (Table 11; Figure 38). Despite this, in China (the world's largest producer of pigs and aquaculture products), the largest consumer of fishmeal remains the livestock and poultry sector (52 percent of total Chinese fishmeal demand in 2008); the

FIGURE 40
Variation in price (US$/tonne) of FAQ fishmeal and soybean meal, January 2006 to March 2010



Note: FOB = free on board.
Source: J. F. Mittaine (International Fishmeal and Fish Oil Organization, personal communication, 2009).

estimated demand for fishmeal within pig starter/piglet diets alone is 612 000 tonnes (Wang, 2009). For example, according to the same author, animal feed production in China during the first half of 2009 was reported as follows: total national feed production 64.63 million tonnes (down by 5.4 percent from the previous year); pig feed 23.3 million tonnes (up 1.8 percent); poultry feed (meat) 18.5 million tonnes (down 12 percent); poultry feed (egg) 11.123 million tonnes (down 15.8 percent); aquatic feed 7.85 million tonnes (up 17.3 percent); ruminant feed 2.15 million tonnes (down 24.6 percent); and others 1.6 million tonnes (up 5.7 percent; Wang, 2009). According to Shepherd (2009), the major consumers of fishmeal in 2008 were aquaculture 58.8 percent, pig 30.9 percent, poultry 9.1 percent; and of fish oil (2010 estimate), aquaculture 80 percent, refined edible 12 percent, and industrial 7 percent. Aquaculture currently uses 760 000 tonnes of fishmeal, equivalent to 76 percent of Europe's fishmeal consumption (Thomsen, 2009).

4.4.2 Competition with pet food

The pet food industry represents a relatively new and rapidly growing non-food animal sector, with dog and cat feed sales totalling US$49 billion in 2008 (Gianni Carniglia, personal communication, December 2009). Despite this, the dog and cat feed sector is one of the largest consumer of terrestrial animal protein meals and fats, including poultry by-product meal and meat and bone meal; the pet-food industry representing 45 percent of the processed animal protein outlets in the EU (Nielsen, 2009) and 9 percent of rendered meal usage in Australia (Palmer, 2009). Moreover, compared with the other conventional animal feed sectors (including the aquaculture sector), the high-value and lucrative pet food sector is willing to pay top price for "pet food grade" low-ash poultry by-product meals, which results in many of these products being out of the economic grasp of other users, including aquatic feed producers (for review, see Aldrich, 2006). A similar situation exists for the competition for fresh fish and aquaculture by-product meals for use within tinned cat foods and dog foods (De Silva and Turchini, 2008).

4.4.3 Competition with biofuels

Increasing petroleum costs and concern for the climate and the need to reduce greenhouse gas emissions have placed renewed efforts to identify alternative renewable sources of energy, including the use of conventional food grains and oilseeds, plant

and animal oils and by-products, and/or low-value cellulosic wastes as substrates for the production of biofuels, including ethanol and biodiesel. Notwithstanding the ecological, environmental, economic and/or ethical merits or not of biofuel production, it is suffice to say that many countries/governments have now adopted biofuel production as a national priority, with the sector in some countries enjoying a variety of government subsidies and incentives (for review, see FAO, 2008a).

On the negative side of the biofuel production is the diversion of potential existing food grains and crops (including the land and other resources used to produce them) from direct human consumption to more profitable (owing to government subsidies and incentives) biofuel production for use as a "greener" petroleum substitute; the latter leading to less grains and crops being available for direct human consumption and increased demand for these commodities and consequent increased food prices.

For example, Figure 41 shows the rapid growth and development of biodiesel production (based on the use of vegetable oil and animal fat as organic carbon inputs and typically made by chemically reacting these lipids with an alcohol) by the world's two top producers – the EU and the United States of America – with a total combined production of 8 million tonnes out of a world total of about 13 million tonnes (Swisher, 2009b). The majority of feedstock used is soybean oil, rapeseed oil and palm oil, but the use of animal fats and greases from the rendering industry is gaining ground, accounting for over 20 percent of the total raw materials used for biodiesel production in the United States of America in 2008. Rendered fats and oils also accounted for approximately 15 percent in Brazil, 67 percent in Paraguay, 60 percent in Uruguay, and for the majority of raw material used in Canada (Swisher, 2009b).

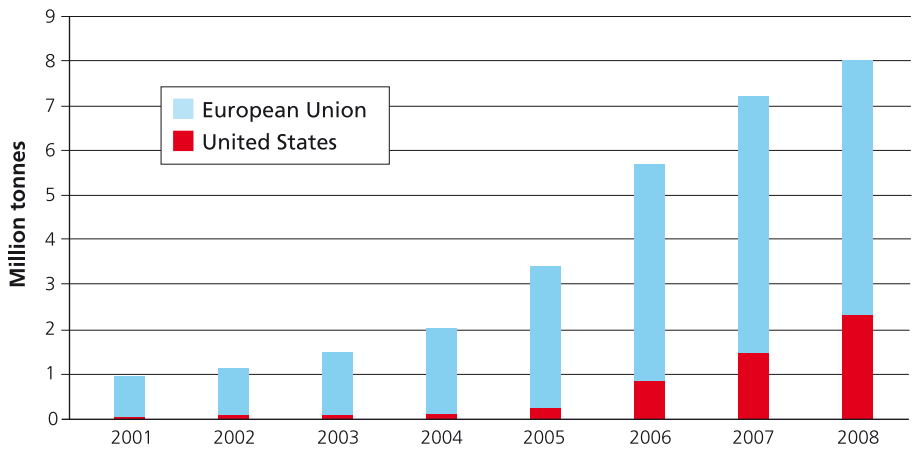
In the case of the other major biofuels, ethanol or bioethanol, they are usually produced through the microbial fermentation of sugars or starches present in food crops such as corn, wheat, sugar beets, sugar cane and molasses. Table 12 shows the total global production of biofuels according to FAO (2008a). Figure 42 shows the proportion of the United States of America corn crop destined for biofuel production.

On the positive side, as mentioned previously, a variety of new feed by-product meals will be produced and be available from ethanol biorefineries, including distillers grains, corn gluten feed and corn gluten meal (Figures 21 and 42).

4.4.4 Competition with humans

Last but not least, there is the direct competition between aquaculture and humans for fish, either in the form of fresh/frozen fish used as a direct feed source (estimated usage

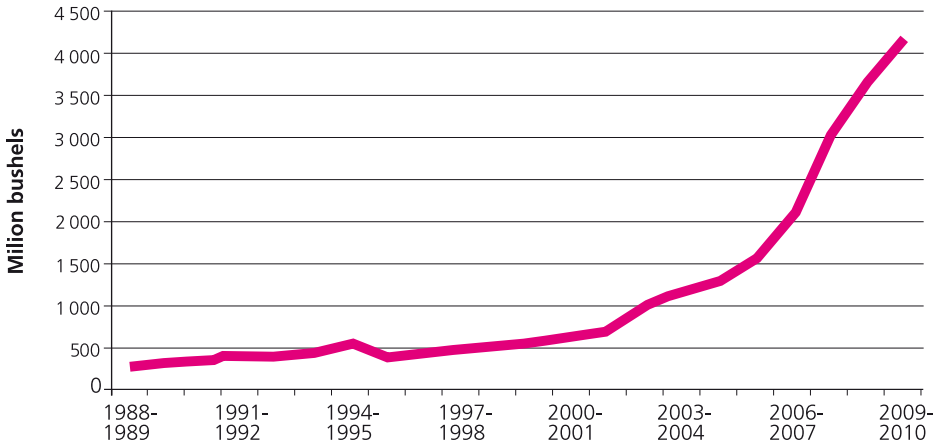
FIGURE 41
United States and European Union production of biodiesel, 2001–2008



Source: Swisher (2009b).

by aquaculture in China being between 6 and 8 million tonnes in 2008), or indirectly in the form of fishmeal and fish oil produced from whole fish suitable for direct human consumption (for review, see FAO, 2008b; FAO, 2011a; Funge-Smith, Lindebo and Staples, 2005; Hasan and Halwart, 2009; Tacon and Metian, 2008a, 2009a, 2009b).

FIGURE 42
United States corn destined for ethanol production, 1988/89 to 2009/10



Note: 1 bushel = 25.4 kg.
Source: USDA (2010b).

TABLE 12
Biofuel production by country, 2007

Country/country grouping	Ethanol		Biodiesel		Total	
	Million litres	Mtoe*	Million litres	Mtoe*	Million litres	Mtoe*
Brazil	19 000	10.44	227	0.17	19 227	10.60
Canada	1 000	0.55	97	0.07	1 097	0.62
China	1 840	1.01	114	0.08	1 954	1.09
India	400	0.22	45	0.03	445	0.25
Indonesia	0	0.00	409	0.30	409	0.30
Malaysia	0	0.00	330	0.24	330	0.24
European Union	2 253	1.24	6 109	4.52	8 362	5.76
Others	1 017	0.56	1 186	0.88	2 203	1.44
World	52 009	28.57	10 204	7.56	62 213	36.12

* Mtoe = million tonnes of oil equivalent.
Source: FAO (2008a).

4.5 GROWING IMPORTANCE OF FEED AND FOOD SAFETY

Reported food safety risks associated with the use of aquaculture feeds may result from the possible presence of contaminants, either within the feed ingredients used or from the external contamination of the finished feed on prolonged storage. For example, major animal feed contaminants reported to date have included salmonellae, mycotoxins, veterinary drug residues, persistent organic pollutants, agricultural and other chemicals (solvent residues, melamine), heavy metals (mercury, lead, cadmium) and excess mineral salts (arsenic, hexavalent chromium, selenium, fluorine), and possible transmissible spongiform encephalopathies. Apart from the direct negative effect of these possible contaminants on the health of the cultured target species, there is also a risk that some of these feed contaminants may be passed along the food chain via contaminated aquaculture produce to consumers.

Public concern regarding food safety has increased as a consequence of the increasing prevalence of antibiotic residues, persistent organic pollutants and chemicals in farmed seafood (for review, see Berntssen and Lundebye, 2008; Karunasagar, 2009; Lie, 2008; Lightner *et al.*, 2009; Tacon and Metian, 2008b).

Harvest of striped catfish (Pangasianodon hypophthalmus), *Mekong Delta, Viet Nam. Striped catfish are fed both farm-made and commercial aquafeeds in Viet Nam.*

Courtesy of FAO/Nguyen Thanh Phuong

5. Recommended approaches to feed ingredient selection and use

5.1 REDUCE COUNTRY DEPENDENCE UPON IMPORTED FEED INGREDIENT SOURCES

On the basis of the results obtained from the feed ingredient survey conducted for this report, it is clear that many aquaculture producing countries are highly dependent upon imports for sourcing the feed ingredients used in their aquaculture feeds. The results of this survey should be treated with caution as they are based on the best guesses of individual country respondents rather than official government statistics (and comparative advantage could very well favour importation over domestic production). All in all they do indicate some significant findings, as follows:

- Countries that reportedly import less than 25 percent of their feed ingredients used in compound aquafeeds: Argentina (0–10 percent), Brazil (0–10 percent), the United States of America (5–10 percent).
- Countries that reportedly import 25–50 percent of their feed ingredients used in compound aquafeeds: Australia (25–35 percent), Canada (40 percent), Denmark (30 percent), India (0–44 percent), Mexico (20–45 percent). In the case of India, feed ingredient imports can vary from 0 percent for freshwater Indian major carp feeds using locally available feed ingredient sources to as high as 44 percent for shrimp feeds.
- Countries and territories that reportedly import 50–75 percent of their feed ingredients used in compound aquafeeds: Chile (30–80 percent), China (>50 percent), Ecuador (60–70 percent), Egypt (54–75 percent), France (50–78 percent), Italy (70–75 percent), Turkey (70 percent), the United Kingdom of Great Britain and Northern Ireland (60–90 percent), Viet Nam (30–70 percent).
- Countries and areas that reportedly import 75–100 percent of their feed ingredients used in compound aquafeeds: Greece (90 percent), Republic of Korea (90–100 percent), Norway (80–90 percent), Peru (70–90 percent), Taiwan Province of China (50–100 percent), Tahiti (100 percent), the United Kingdom of Great Britain and Northern Ireland (60–90 percent).
- According to a recent statistic concerning the animal feed manufacturing sector in Mexico (CONAFAB, 2008), Mexico was ranked fourth in the world in terms of total animal feed production (26.2 million tonnes in 2008 – with aquaculture representing less than 1 percent of total feed production, or 230 000 tonnes), with the country importing over 55 percent of all the ingredients used within the animal feed sector, including over 90 percent of all plant oilseeds.
- Although no information was forthcoming from several other major aquaculture producers in Asia (including Bangladesh, Indonesia, Japan, the Philippines and Thailand), published information suggests that in the Philippines 40–60 percent and 85–95 percent of the feed ingredients used for fish feeds and shrimp feeds are imported, respectively (Sevilla, 2007). A similar situation to the Philippines is expected to exist in Indonesia, Malaysia and Thailand (see SES, 2009a, 2009b, 2009c).
- The current dependence of aquaculture producing countries upon the importation of major protein ingredient sources and lipids (i.e. fishmeal, soybean meal, fish oil)

is strongest within those countries where production is focused on exports and/or the production of high trophic level fish and shrimp (SES, 2009a).
- In general, the demand for imported feed ingredient sources is highest within those developing countries with a strong commercial animal feed manufacturing sector and dominated by larger integrated farms and larger independent farms (SES, 2009c).
- In-country feed ingredient availability and usage within most developing countries is usually biased toward energy-rich rather than protein-rich ingredient sources, with greatest usage of local non-imported ingredients being within compound feeds intended for the production of freshwater and brackishwater fish feeds targeted for domestic consumption (SES, 2009a, 2009b) and within farm-made aquafeeds produced by smallholder farmers (SES, 2009c).
- The active promotion by many governments to reduce the current dependency of their national animal feed manufacturing industries upon imported feed ingredient sources by developing more competitive protein and energy sources from locally available agricultural products, including cassava, rice, oil palm and copra (SES, 2009a, 2009b, 2009c, 2009d).

5.2 SELECT FEED INGREDIENTS THAT CAN BE SUSTAINABLY PRODUCED AND GROW WITH THE SECTOR

As mentioned at the outset, for finfish and crustacean fed aquaculture production to maintain its current average annual growth rate of 8 to 10 percent to 2025, the external supply of nutrients and, therefore, feed ingredient sources will have to keep pace. Included within these ingredient sources are:

- fishery by-products and aquaculture by-product meals and oils;
- invertebrate fishery by-product meals and oils;
- terrestrial animal by-product meals and fats;
- cereals, including by-product meals and oils;
- oilseed meals and oils;
- pulses and protein concentrate meals; and
- microbial ingredient sources.

Ingredient choice should be based, therefore, not only on nutrient level, digestibility, and cost, but also upon other criteria such as sustainability and environmental impact of production, and fish-in fish-out ratio (Jackson, 2010; Kaushik and Troell, 2010; Naylor *et al.*, 2009).

The limited supply of fishmeal and fish oil from wild fisheries and the continued strong demand for these products have led to concerns about the long-term sustainability of the fisheries and the level of responsible management of the fisheries. It is, therefore, important that care is taken to ensure that any fishmeal and fish oil made from wild fish comes from fisheries that have been managed according to the FAO Code of Conduct for Responsible Fisheries (FAO, 1995), and that countries follow the guidelines on the use of wild fish as feed in aquaculture (FAO, 2011a) that have been developed in support of Article 7 (Responsible fisheries management) and Article 9 (Aquaculture development) of the FAO *Code of Conduct for Responsible Fisheries*.

5.3 MINIMIZE ENVIRONMENTAL AND ECOSYSTEM IMPACT OF FEEDS AND FEEDING REGIMES

As mentioned earlier, one of major criteria for ingredient selection is nutrient density and nutrient digestibility. It follows, therefore, that the higher the nutrient digestibility of a particular ingredient (or complete feed containing the ingredient), the higher its nutrient utilization efficiency and resultant growth of the target species. Moreover, by using highly digestible feed ingredient sources and feeds, nutrient loss and feed wastage are kept to a minimum, thereby minimizing possible negative environmental and ecosystem impacts.

In addition to the direct selection of highly digestible feed ingredient sources, nutrient loss and nutrient impacts from feeds can also be negated by integrating production with other cultured species that can benefit from these nutrient waste streams (Duarte *et al.,* 2009; Soto, 2009) or by culturing the species under closed biofloc-based zero-water exchange culture conditions (Avnimelech, 2009).

Of particular note is the ability of biofloc-based zero-exchange production systems to essentially change the nutrition of the target species (usually either marine shrimps or tilapias) from a purely monogastric animal dependent upon the external supply of a nutritionally complete diet to an animal cultured within a nutrient-rich microbial soup capable of supplying nutrients to the cultured species (both shrimps and tilapias are able to filter out these microbial flocs) in addition to the diet being fed, with consequent cost-feed savings and ability to better utilize ingredient sources with inherent nutrient deficiencies or imbalances (Tacon *et al.,* 2002; Tacon, Nates and McNeil, 2006).

5.4 GIVE SPECIAL ATTENTION TO SMALL-SCALE FARMERS USING FARM-MADE/SEMI-COMMERCIAL AQUAFEEDS

Small-scale farmers still form the backbone of Asian aquaculture; they produce much of the cultured freshwater fish species for domestic consumption. One hallmark of this sector is the use of farm-made/semi-commercial aquafeeds. However, apart from the general absence of statistical information on the size and extent of this sector, little or no guidance and attention is given to better help small-scale farmers formulate and manage their feeds. To a large extent this has been due to the thrust by government agencies and feed manufacturers to move the sector away from the use of farm-made feeds to the purchase of commercially manufactured aquafeeds.

Merits and demerits aside of using farm-made aquafeeds (New, Tacon and Csavas, 1995; Hasan *et al.,* 2007), there is an urgent need to assist and train the resource-poor farmers using farm-made aquafeeds not only for improving feed formulation and minimizing the use of unnecessary feed additives and chemicals (including antibiotics), but also for improving feed management techniques (FAO, 2010d). The economic benefit is better returns from higher efficiency. The environmental benefit is less pollution from reduced wastage. There is also need for support services to build the capacity of small-scale aquafeed producers to improve their production processes as many small-scale farmers purchase feed from them.

References

AAP (Aquaculture Asia Pacific Magazine). 2009. Industry squeezed and high feed costs to remain. *Aquaculture Asia Pacific Magazine*, 5(1): 10–15.

AAP (Aquaculture Asia Pacific Magazine). 2010. Managing costs and improving feed performance. *Aquaculture Asia Pacific Magazine*, 6(1): 12–15.

Aldrich, G. 2006. Rendered products in pet food. *In* D.L. Meeker, ed., *Essential Rendering*, pp. 159–178. Arlington, USA, National Renderers Association, Kirby Lithographic Company Inc.

Anon. 2006. Alimentacion de peces en la salmonicultura Chilena: tasas de conversion. *Temas del Salmón*, 1 (1): 7.

Avnimelech, Y. 2009. *Biofloc Technology – A Practical Guide Book.* Baton Rouge, USA, World Aquaculture Society. 181 pp.

Ayinla, O.A. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Nigeria. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 453–470. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Ayyappan, S. & Ahamad Ali, S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in India. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development,* pp. 191–219. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Barman, B.K. & Karim, M. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Bangladesh. *In* M.R. Hasan, T. Hecht, S.S. De Silva & 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.

Beckman, C., Xiping, W. & Han, A. 2009. *Fishery products annual report*. GAIN (Global Agricultural Information Network) Report, USDA Foreign Agricultural Service, GAIN Report Number: CH9137, 12/22/2009.

Berntssen, M.H.G. & Lundebye, A.-K. 2008. Environmental contaminants in farmed fish and potential consequences for seafood safety. pp. 39–70. *In* Ø. Lie, ed. *Improving farmed fish quality and safety*. Cambridge, UK, Woodhead Publishing Limited. 500 pp.

Best, P. 2010a. Credit crunch triggers increased consolidation in Viet Nam. *Feed International*, 31(1): 24–25.

Best, P. 2010b. World feed panorama: China leads a late recovery. *Feed International*, 31(1): 12–13.

Cardia, F. & Lovatelli, A. 2007. A review of cage aquaculture: Mediterranean Sea. *In* M. Halwart, D. Soto & J.R. Arthur, eds. *Cage aquaculture – Regional reviews and global overview,* pp. 156–187. FAO Fisheries Technical Paper No, 498. Rome, FAO. 241 pp.

Chen, J., Guang, C., Xu C., Chen, H., Xu, Z. Yan, P., Wang, Y. & Liu, J. 2007. A review of cage and pen aquaculture: China. *In* M. Halwart, D. Soto & J.R. Arthur, eds. *Cage aquaculture – Regional reviews and global overview*, pp. 50–68. FAO Fisheries Technical Paper No, 498. Rome, FAO. 241 pp.

Chen, K. 2009. *U.S. DDGS dashes for China – Mostly to the feed mills of Guangdong*. Global Agricultural Information Network. USDA Foreign Agricultural Service, United States Department of Agriculture, GAIN Report Number: CH9611, July 16, 2009. 12 pp.

CONAFAB. 2008. *Conejo Nacional de Fabricanates de Alimentos Balanceados y de la Nutricion Animal A.C.,* (Mexican Feed Manufacturers Association), La Industria Alimenticia Animal en Mexico 2008, Mexico D.F. 80 pp.

D'Abramo, L.R., Oha, C.L, Hanson, T.R. & Montanez, J.L. 2002**.** *Production of the red swamp crayfish in earthen ponds without planted forage: management practices and economics.* Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, Bulletin 1115, 18 pp.

Davis, D.A. & Sookying, D. 2009. Strategies for reducing and/or replacing fishmeal in production diets for the Pacific white shrimp, *Litopenaeus vannamei*, pp.108–114. *In* C.L. Browdy & D.E. Jory, eds. *The Rising Tide, Proceedings of the Special Session on Sustainable Shrimp Farming*. World Aquaculture 2009. Baton Rouge, USA, World Aquaculture Society.

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 & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 19–47. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

De Silva, S.S. & Phillips, M.J. 2007. A review of cage aquaculture: Asia (excluding China). *In* M. Halwart, D. Soto & J.R. Arthur, eds. *Cage aquaculture – Regional reviews and global overview*, pp. 18–48. FAO Fisheries Technical Paper No, 498. Rome, FAO. 241 pp.

De Silva, S.S. & Turchini, G.M. 2008. Towards understanding the impacts of the pet food industry on world fish and seafood supplies. *Journal of Agricultural and Environmental Ethics*, 21: 459–467.

Deutscher, H. 2009. The economics of distillers grains. E*thanol Producer Magazine*, June 2009, 3 pp. (available at www.ethanolproducer.com/articles/5653/the-economics-of-distillers-grains).

Duarte, C.M., Holmer, M., Olsen, Y., Soto, D., Marba. N, Guiu, J., Black, K. & Karakassis, I. 2009. Will the oceans feed humanity? *BioScience*, 59(11): 967–976.

El-Sayed, A-F.M. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Egypt. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 410-422. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

FAO. 1995. *Code of Conduct for Responsible Fisheries*. Rome. 41 pp. (also available at: ftp://ftp.fao.org/docrep/fao/005/v9878e/v9878e00.pdf).

FAO. 2008a. *The State of Food and Agriculture 2008*. Rome. 128 pp.

FAO. 2008b. *Report of the FAO expert workshop on the use of wild fish and/or other aquatic species as feed in aquaculture and its implication to food security and poverty alleviation, Kochi, India, 16–18 November 2007*. FAO Fisheries Report No. 867. Rome. 29 pp. (also available at: www.fao.org/docrep/fao/011/i0263e/i0263e.pdf).

FAO. 2009a. FishStat Plus: Universal software for fishery statistical time series. *Aquaculture production: Quantities 1950–2007; Aquaculture production: Values 1984–2007; Capture production: 1950–2007; Commodities production and trade: 1950–2007; Total production: 1970–2007*. Version 2.30. FAO Fisheries Department. Fishery Information, Data and Statistics Unit. (available at www.fao.org/fi/statist/FISOFT/FISHPLUS.asp).

FAO. 2009b. *Food Outlook – Global Market Analysis. The Global Information and Early Warning System on Food and Agriculture*. December 2009, Rome. 103 pp. (also available at www.fao.org/worldfoodsituation).

FAO. 2009c. FAOSTAT Agriculture Database. (available at http://faostat.fao.org/site/567/default.aspx#ancor).

FAO. 2009d. *The State of Food Insecurity in the World*. FAO. 56 pp.

FAO. 2010a. FishStat Plus: Universal software for fishery statistical time series. *Aquaculture production: quantities 1950–2008; Aquaculture production: values 1984–2008; Capture production: 1950–2008; Commodities production and trade: 1950–2008; Total production: 1970–2008*. Version 2.30. FAO Fisheries and Aquaculture Department, Fishery Information, Data and Statistics Unit (available at www.fao.org/fi/statist/FISOFT/FISHPLUS.asp). (Accessed December 2010).

FAO. 2010b. *Food Outlook – Global Market Analysis. The Global Information and Early Warning System on Food and Agriculture*. November 2010, Rome. 116 pp. (also available at http://www.fao.org/docrep/013/al969e/al969e00.pdf).

FAO. 2010c. FAOSTAT Agriculture Database (available at http://faostat.fao.org/site/567/default.aspx#ancor).

FAO. 2010d. *Report of the FAO Expert Workshop on On-farm feeding and feed management in aquaculture, Manila, the Philippines, 13–15 September 2010*. FAO Fisheries Report No. 949. Rome. 37 pp. (also available at www.fao.org/docrep/013/i1915e/i1915e00.pdf).

FAO. 2011a. *Aquaculture development. 5. Use of wild fish as feed in aquaculture.* FAO Technical Guidelines for Responsible Fisheries No. 5, Suppl. 5. Rome. 79 pp. (also available at www.fao.org/docrep/014/i1917e/i1917e00.pdf).

FAO. 2011b. FishStat Plus: Universal software for fishery statistical time series. *Commodities production and trade: 1950–2008; Total production: 1970–2008*. Version 2.30. FAO Fisheries and Aquaculture Department, Fishery Information, Data and Statistics Unit (available at www.fao.org/fi/statist/FISOFT/FISHPLUS.asp).

Flores-Nava, A. 2007. Feeds and feeding for sustainable aquaculture development: a regional review for Latin America. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 49–75. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Funge-Smith, S., Lindebo, E. & Staples, D. 2005. *Asian fisheries today: The production and use of low value/trash fish from marine fisheries in the Asia-Pacific region*. FAO Regional Office for Asia and the Pacific (RAP). Bangkok, RAP Publication 2005/16. 38 pp.

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

Gill, C. 2007. World feed panorama: bigger cities, more feed. *Feed International*, 28: 5–9.

Gomes, L.C., Chagas, E.C., Martins-Junior, H., Roubach, R., Ono, E.A., Lourenco, J.N.P. 2006. Cage culture of tambaqui (*Colossoma macropomum*) in a central Amazon floodplain lake. *Aquaculture*, 253: 374–384.

Grottum, J.A. & Beveridge, M. 2007. A review of cage aquaculture: northern Europe. *In* M. Halwart, D. Soto & J.R. Arthur, eds. *Cage aquaculture – Regional reviews and global overview*, pp. 126–154. FAO Fisheries Technical Paper No, 498. Rome, FAO. 241 pp.

Gupta, M.V. & Abdur Rab, M. 1994. *Adoption and economics of silver barb (Puntius gonionotus) culture in seasonal waters in Bangladesh*. ICLARM Technical Report 41. 39 pp.

Hardy, R. 2009. Protein sources for marine shrimp aquafeeds: perspectives and problems. *In* C.L. Browdy & D.E. Jory, eds. *The Rising Tide, Proceedings of the Special Session on Sustainable Shrimp Farming*, pp. 115–125. World Aquaculture 2009. Baton Rouge, USA, World Aquaculture Society.

Hardy, R.W. & Shepherd, J. 2007. Sustainable marine resources for organic aquafeeds. *National Organic Standards Board Organic Aquaculture Symposium*, November 27, 2007. Arlington, Virginia.

Hasan, M.R. & Halwart, M., eds. 2009. *Fish as feed inputs for aquaculture: practices, sustainability and implications,* pp. 129–157. Fisheries and Aquaculture Technical Paper, No. 518. Rome, FAO. 407 pp.

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.

Hecht, T. 2007. Feeds and feeding for sustainable aquaculture development in sub-Saharan Africa. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 77–109. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Heinsbroek, L.T.N. 2008. A review of eel culture in Japan and Europe. *Aquaculture Research,* 22(1): 57–72.

Hempel, E. 2009. Integrated techno-savvy farm aims to boost Malaysian tilapia production. *INFOFISH International*, 3/2009, pp. 9–13.

Hole, R. 2009. Excess demand for fish oil – farmed fish still a healthy food product in 2025. *7th Euro Fed Lipid Congress*, 18–21 October 2009, Graz, Austria. European Federation for the Science and Technology of Lipids (available at www.eurofedlipid.org/meetings/archive/graz/index.htm).

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 & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 331–361. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Hung, L.T., Truc, L.T.T. & Huy, H.P.V. 2007. Development of the aquafeed industry in Viet Nam. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 363–377. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Jackson, A. 2009. The continuing demand for sustainable fishmeal and fish oil in aquaculture diets. *International Aquafeed*, 12(5): 32–36.

Jackson, A. 2010. Fishmeal, fish oil: prime ingredients not limiting factors for responsible aquaculture. *Global Aquaculture Advocate*, January/February 2010: 16–19.

Jin, W. 2006. Fishmeal as a dietary ingredient in China – first impressions. *International Fishmeal and Fish Oil Organization 2006 Annual Conference*, October 23–26, 2006, Barcelona, Spain.

Karunasagar, I. 2009. Melamine in fish feed and implications for safety of aquaculture products. *FAO Aquaculture Newsletter*, 42: 29–31.

Kaushik, S. & Troell, M. 2010. Taking the fish-in fish-out ratio a step further. *Aquaculture Europe*, 35(1): 15–17.

Kearns, J.P. 2005. Current production methods for the production of salmon feeds. *International Aquafeed,* 8(1): 28–33.

Krogdahl, A., Penn. M., Thorsen, J., Refstie, S. & Bakke, A.M. 2010. Important antinutrients in plant feedstuffs for aquaculture: an update on recent findings regarding responses in salmonids. *Aquaculture Research*, 41: 333–344

Larraín, C., Leyton, P. & Almendras, F. 2005. Aquafeed country profile – Chile and salmon farming. *International Aquafeed*, 8(1): 22–27.

Liao, I.C., Huang, T-S., Tsai., W-S., Hsueh, C-M. , Chang, S-L. & Leano, E.M. 2004. Cobia culture in Taiwan: current status and problems. *Aquaculture*, 237: 155–165.

Lie, Ø., ed. 2008. *Improving farmed fish quality and safety*. Cambridge, UK, Woodhead Publishing Limited. 500 pp.

Lightner, D. V., Redman., R.M., Pantoja, C.R., Navarro, S.A., Tang-Nelson, K.F.J., Noble, B.L. & Nunan, L.M. 2009. Emerging non-viral infectious and non-infectious diseases of farmed penaeid shrimp and other decapods. *In* C.L. Browdy & D.E. Jory, eds. *The Rising Tide, Proceedings of the Special Session on Sustainable Shrimp Farming*, pp. 46–52. World Aquaculture 2009. Baton Rouge, USA, World Aquaculture Society.

Manomaitis, L. 2009. Improving Southeast Asian aquaculture through feeds and technology. *17th Annual ASAIM SEA Feed Technology and Nutrition Workshop*. Imperial Hotel, Hue, Viet Nam, June 15–19, 2009 (also available at www.asaimsea.com/download_doc.php?file=FTNW09-Lukas.pdf).

Merican, Z. 2009. Industry analyses tra and other catfish farming. *Aqua Culture Asia Pacific*, 5(3): 20–28.

Mittaine, J-F. 2009. Are key commodity markets for Aquaculture in a bullish trend. *15th DSM Aquaculture Conference Asia Pacific*. Bangkok, November 19, 2009.

Nakada, M. 2008. Capture-based aquaculture of yellowtail. *In* A. Lovatelli & P.F. Holthus, eds. *Capture-based aquaculture. Global overview*, pp. 199–215. FAO Fisheries Technical Paper No. 508. Rome, FAO. 298 pp.

Nam, Y.K., Cho, H.J., Im, J.H., Park, I-S., Choi, G.C. & Kim, D.S. 2001. Production of all-female diploid and triploid far eastern catfish, *Silurus asotus* (Linnaeus): survival and growth performance. *Aquaculture Research*, 32(12): 991–997.

Nates, S.F., Bureau, D.P., Lemos, D. & Swisher, K. 2009. Rendered ingredients and their use in shrimp diets: status and prospects. *In* C.L. Browdy & D.E. Jory, eds. *The Rising Tide, Proceedings of the Special Session on Sustainable Shrimp Farming*, pp. 137–146. World Aquaculture 2009. Baton Rouge, USA, World Aquaculture Society.

Naylor, R.L., Hardy, R.W., Bureau, D.P., Chiu, A., Elliot, M., Farrell, A.P., Forster, I., Gatlin, D.M., Goldburg, R.J., Hua, K. & Nichols, P.D. 2009. Feeding aquaculture in an era of finite resources. *Proceedings of National Academy of Sciences USA*, 106 (36): 15103–15110.

New, M.B., Tacon, A.G.J. & Csavas, I., eds. 1995. *Farm-made aquafeeds.* FAO Fisheries Technical Paper No. 343, FAO, Rome, FAO. 434 pp.

Ng, W-K., Soe, M. & Phone, H. 2007. Aquafeeds in Myanmar: a change from farm-made to factory-made feeds. *Aquaculture Asia Magazine*, XII(3): 7–12.

Nielsen, N.C.L. 2009. Updates Europe. *Seventy-sixth Annual Convention of the National Renderers Association*. San Francisco, USA, 23 October, 2009.

Nur, A. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Indonesia, pp. 245–267. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Palmer, C. 2009. Australian rendering industry update. *Seventy-sixth Annual Convention of the National Renderers Association*. San Francisco, USA, October 23, 2009.

Phan, L.T., Bui, T.M., Nguyen, T.T.T., Gooley, G.J., Ingram, B.A., Nguyen, H.V., Nguyen, P.T. & De Silva, S.S. 2009. Current status of farming practices of striped catfish, *Pangasianodon hypophthalmus* in the Mekong Delta, Vietnam. *Aquaculture,* 296: 227–236.

Quintero, H.E., Cremer, M.C., Manomaitis, L. & Davis, V. 2010. Using feed with reduced levels of fishmeal for commercial production of the Pacific white shrimp in Asia. *AQUA Culture Asia Pacific*, 6(2): 18–20.

Renewable Fuels Association. 2008. Feeding the future: The role of the U.S. ethanol industry in food and feed production. September 2008. Washington, DC, Renewable Fuels Association.

Rimmer, M.A. & Ponia, B. 2007. A review of cage aquaculture: Oceania. *In* M. Halwart, D. Soto & J.R. Arthur, eds. *Cage aquaculture – Regional reviews and global overview*, pp. 208–231. FAO Fisheries Technical Paper No, 498. Rome, FAO. 241 pp.

Robinson, E.H. & Li, M.H. 2007. Catfish feeds and feeding. Mississippi Agricultural and Forestry Experiment Station, *Mississippi State University, Bulletin* 1163, 14 pp.

Rojas, A. & Wadsworth, S. 2007. A review of cage aquaculture: Latin America and the Caribbean. *In* M. Halwart, D. Soto & J.R. Arthur, eds. *Cage aquaculture – Regional reviews and global overview*, pp. 70–100.FAO Fisheries Technical Paper No. 498. Rome, FAO. 241 pp.

Sakashita, H. 2009. DDGS use and potential in Japan. *Midwest Speciality Grains Conference and Trade Show*. 2 September 2009. Sioux Falls Convention Center, Sioux Falls, South Dakota, USA (also available at www.midwestshippers.com/conferencePresentatio ns/HirokoSakashita.pdf).

SEAFISH. 2009a. *Fishmeal and fish oil – facts and figures*. Sea Fish Industry Authority, June 2009 (also available at www.seafish.org).

SEAFISH. 2009b. *Annual review of the feed grade fish stocks used to produce fishmeal and fish oil for the UK market*. Sea Fish Industry Authority, August 2009 (also available at www.seafish.org).

Sevilla, F.M. 2007. *The Philippine feeds industry*. Agri-Food Trade Service, Agriculture and Agri-Food Canada, 6 pp. (also available at www.ats.agr.gc.ca/ase/4317-eng.htm).

Shepherd, J. 2009. *Past and present priorities*. Annual Conference of the International Fishmeal and Fish Organization, 5–8 October 2009, Vienna, Austria.

SES (Stanton, Emms & Sia). 2009a. *Characteristics of Thailand's market for animal feed*, *March 2009.* Agri-Food Trade Service, Agriculture and Agri-Food Canada. Report prepared for the Regional Agri-Food Trade Commissioner, Southeast Asian and Embassy of Canada, Thailand, 12 pp. (also available at www.ats.agr.gc.ca/ase/4774-eng.htm).

SES (Stanton, Emms & Sia). 2009b. *Characteristics of Vietnam's market for animal feed*, *March 2009.* Agri-Food Trade Service, Agriculture and Agri-Food Canada. Report prepared for the Regional Agri-Food Trade Commissioner, Southeast Asian and Embassy of Canada, Viet Nam, 10 pp. (also available at www.ats.agr.gc.ca/ase/4776-eng.htm).

SES (Stanton, Emms & Sia). 2009c. *Characteristics of Indonesia's market for animal feed*, *March 2009.* Agri-Food Trade Service, Agriculture and Agri-Food Canada. Report prepared for the Regional Agri-Food Trade Commissioner, Southeast Asian and Embassy of Canada, Indonesia, 10 pp. (also available at www.ats.agr.gc.ca/ase/4771-eng.htm).

SES (Stanton, Emms & Sia). 2009d. *Characteristics of Malaysia's market for animal feed, March 2009.* Agri-Food Trade Service, Agriculture and Agri-Food Canada. Report prepared for the Regional Agri-Food Trade Commissioner, Southeast Asian and Embassy of Canada, Malaysia, 11 pp. (also available at www.ats.agr.gc.ca/ase/5231-eng.htm).

Soto, D., ed. 2009. *Integrated mariculture: a global review*. FAO Fisheries and Aquaculture Technical Paper No. 529. Rome, FAO. 183 pp.

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 & 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.

Suresh, V.A. 2007. Development of the aquafeed industry in India, *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 221–243. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Swisher, K. 2009a. *U.S. industry review*. Seventy-sixth Annual Convention of the National Renderers Association, October 23, 2009. San Francisco, USA.

Swisher, K. 2009b. Market report 2008. *Render Magazine*, 38(2): 10–17.

Tacon, A.G.J. 2008. *Global study on the existing and projected competition between humans and aquaculture for pelagic forage fish species*. A report prepared for the Lenfest Ocean Program, Washington, DC. Aquatic Farms Ltd., Kaneohe, Hawaii, USA, January 31, 2008. 98 pp.

Tacon, A.G.J. & Hasan, M.R. 2007. Global synthesis of feeds and nutrients for sustainable aquaculture development. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 3–17. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Tacon, A.G.J. & Metian, M. 2008a. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: trends and future prospects. *Aquaculture*, 285: 146–158.

Tacon, A.G.J. & Metian, M. 2008b. *Aquaculture feed and food safety: the role of FAO and Codex Alimentarius*. New York Academy of Sciences, 1140: 50–59.

Tacon, A.G.J. & Metian, M. 2009a. Fishing for aquaculture: non-food use of small pelagic forage fish – a global perspective. *Reviews in Fisheries Science*, 17(3): 305–317.

Tacon, A.G.J. & Metian, M. 2009b. Fishing for feed or fishing for food: increasing global competition for small pelagic forage fish. *Ambio*, 38(6): 294–302.

Tacon, A.G.J., Cody, J.J., Conquest, L.D., Divakaran, S., Forster, I.P. & Decamp, O.E. 2002. Effect of culture system on the nutrition and growth performance of Pacific white shrimp *Litopenaeus vannamei* (Boone) fed different diets. *Aquaculture Nutrition*, 8(2): 121–139.

Tacon, A.G.J., Metian, M. & Hasan, M.R. 2009. *Feed ingredients and fertilizers for farmed aquatic animals: sources and composition*. FAO Fisheries and Aquaculture Technical Paper No. 540. Rome, FAO. 210 pp.

Tacon, A.G.J., Nates, S.F. & McNeil, R.J. 2006. Overview of farming systems for marine shrimp with particular reference to feeds and feeding (Chapter 20). *In* P.S. Leung & C. Engle, eds. *Shrimp Culture: Economics, Market and Trade*, pp. 301–314. Ames, Iowa, Blackwell Publishers.

Talbot, C. & Rosenlund, G. 2002. Learning from the salmonid industry growing fish on nutrient-dense diets. *Aquafeed International*, 5(2): 7–10.

Thomsen, M. 2009. *Fishmeal Europe 2009*. Annual Conference of the International Fishmeal and Fish Organization. 5–8 October 2009, Vienna, Austria.

Thongrod, S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Thailand. *In* M.R. Hasan, T. Hecht, S.S. De Silva & 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.

Turchini, G.M., Torstensen, B.E. & Ng, W-K. 2009. Fish oil replacement in finfish nutrition. Reviews in *Aquaculture*, 1: 10–57.

USDA (United States Department of Agriculture). 2010a. *Oilseeds: world markets and trade*. USDA Foreign Agricultural Service, United States Department of Agriculture, Circular Series FOP-01 10, January 2010, 33 pp.

USDA (United States Department of Agriculture). 2010b. *Feed outlook*. Report of the Economic Research Service, United States Department of Agriculture, FDS-10a, 14, January 2010. 22 pp.

Wang, C. 2009. *Update on Chinese market*. Seventy-sixth Annual Conference of the International Fishmeal and Fish Organization, 5–8 October 2009, Vienna, Austria.

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 & 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.

Woodgate, S.L. 2010. *European Union: Update*. Third Global Feed and Food Congress, Cancun, Mexico, April 20–23, 2010. 10 pp.

Wu, M.H. 2009. Insight into the aqua feed business in China. *Aquaculture Asia Pacific Magazine*, 5(1): 16.

ANNEX 1 – Global production of finfish and crustaceans

TABLE A1.1
Total global production of the major cultivated finfish and crustacean species commonly fed on fresh food items, farm-made and/or commercially compounded aquafeeds

Major fed species	Production (tonnes)	Percent	Total value (US$)	Value (US$/kg)
FRESHWATER FISHES				
Fed carps (Family *Cyprinidae*)	**14 426 803**		**15 299 746**	**1.06**
Chinese carps[1]	**9 679 992**	**67.1**	**9 542 684**	**0.99**
Grass carp (*Ctenopharyngodon idellus*)	3 775 267	26.2	4 797 279	1.27
Common carp (*Cyprinus carpio*)	2 987 433	20.7	3 696 415	1.24
Crucian carp (*Carassius carassius*)	1 957 337	13.6	2 135 857	1.09
Wuchang bream (*Megalobrama amblycephala*)	599 623	4.2	989 378	1.65
Black carp (*Mylopharyngodon piceus*)	360 332	2.5	835 610	2.32
Indian major carps	**3 904 812**	**27.1**	**5 177 898**	**1.33**
Catla (*Catla catla*)	2 281 838	15.8	3 303 124	1.45
Rohu (*Labeo rohita*)	1 159 454	8.0	1 334 193	1.15
Mrigal (*Cirrhinus mrigala*)	463 520	3.2	540 581	1.17
Other cyprinids	**841 999**	**5.8**	**579 164**	**0.69**
Cyprinids nei[2]	540 133	3.7	928 371	1.72
Silver barb (*Barbonymus gonionotus*)	106 457	0.7	99 033	0.93
Others[3]	195 409	1.4	273 458	1.40
Tilapias (Family *Cichlidae*)	**2 797 819**		**4 021 164**	**1.44**
Nile tilapia (*Oreochromis niloticus*)	2 334 432	83.4	3 208 561	1.37
Tilapias nei (*Oreochromis* spp.)	419 982	15.0	766 946	1.83
Java tilapia (*Oreochromis mossambicus*)	38 140	1.4	32 476	0.85
Blue tilapia (*Oreochromis aureus*)	2 687	0.1	5 798	2.16
Three spotted tilapia (*Oreochromis andersonii*)	1 996	0.1	5 749	2.88
Longfin tilapia (*Oreochromis macrochir*)	187	< 0.1	538.6	2.88
Redbreast tilapia (*Tilapia rendalli*)	160	< 0.1	352	2.20
Redbelly tilapia (*Tilapia zillii*)	130	< 0.1	325	2.50
Sabaki tilapia (*Oreochromis spilurus*)	105	< 0.1	420	4.00

TABLE A1.1, continued

Total global production of the major cultivated finfish and crustacean species commonly fed on fresh food items, farm-made and/or commercially compounded aquafeeds

Major fed species	Production (tonnes)	Percent	Total value (US$)	Value (US$/kg)
Catfishes (Order *Siluriformes*)	**2 780 897**		**3 920 365**	**1.41**
Family Pangasiidae	**1 411 732**	**50.8**	**2 024 527**	**1.43**
Pangasiid catfishes nei (*Pangasius* spp.)	1 380 702	49.6	1 994 685	1.44
Striped catfish (*Pangasianodon hypophthalmus*)	23 186	0.8	15 446	0.67
Pangas catfish (*Pangasius pangasius*)	7 844	0.3	14 396	1.84
Family Ictaluridae	**463 638**	**16.7**	**692 552**	**1.49**
Channel catfish (*Ictalurus punctatus*)	462 416	16.6	688 800	1.49
Catfishes nei (*Ictalurus* spp.)	1 022	< 0.1	2 280	2.23
Black bullhead (*Ameiurus melas*)	200	< 0.1	1 472	7.36
Family Claridae	**407 075**	**14.6**	**539 017**	**1.32**
Torpedo-shaped catfishes nei (*Clarias* spp.)	237 634	8.5	304 564	1.28
Catfish, hybrid (*C. gariepinus x C. macrocephalus*)	135 507	4.9	133 794	0.99
North African catfish (*Clarias gariepinus*)	33 924	1.2	100 593	2.97
Asian catfish (*Clarias batrachus*)	10	< 0.1	66	6.60
Family Siluridae	**322 551**	**11.6**	**430 378**	**1.33**
Amur catfish (*Silurus asotus*)	321 071	11.5	422 931	1.32
Wels catfish (*Silurus glanis*)	1 480	0.1	7 448	5.03
Family Bagridae	**152 728**	**5.5**	**199 564**	**1.31**
Yellow catfish (*Pelteobagrus fulvidraco*)	134 448	4.8	174 782	1.30
Chinese longsnout catfish (*Leiocassis longirostris*)	15 347	0.6	19 951	1.30
Asian redtail catfish (*Mystus nemurus*)	2 513	0.1	4 132	1.64
Bayad (*Bagrus bajad*)	400	< 0.1	608	1.52
Bagrid catfish (*Chrysichthys nigrodigitatus*)	20	< 0.1	89.7	4.49
Others				
Freshwater siluroids nei (*Siluroidei*)	19 700	0.7	26 410	1.34
Family Mochokidae				
Upsidedown catfishes (*Synodontis* spp.)	2 772	0.1	6 376	2.30
Family Pimelodidae				
South American catfish (*Rhamdia sapo*)	701	< 0.1	1 542	2.20

TABLE A1.1, continued

Total global production of the major cultivated finfish and crustacean species commonly fed on fresh food items, farm-made and/or commercially compounded aquafeeds

Major fed species	Production (tonnes)	Percent	Total value (US$)	Value (US$/kg)
Miscellaneous freshwater fishes	**1 334 135**		**4 120 134**	**3.09**
Family Channidae	**376 480**	**28.2**	**475 844**	**1.26**
Snakehead (*Channa argus*)	324 318	24.3	396 585	1.22
Snakeheads nei (*Channa* spp.)	22 300	1.7	31 860	1.43
Indonesian snakehead (*Channa micropeltes*)	15 831	1.2	18 153	1.15
Striped snakehead (*Channa striata*)	14 031	1.1	29 247	2.08
Family Percichthyidae	**229 339**	**17.2**	**2 135 370**	**9.31**
Mandarin fish (*Siniperca chuatsi*)	229 269	17.2	2 134 494	9.31
Murray cod (*Maccullochella peelii*)	70	< 0.1	875.3	12.50
Family Synbranchidae				
Asian swamp eel (*Monopterus albus*)	212 209	15.9	553 795	2.61
Family Characidae	**170 381**	**12.8**	**316 319**	**1.86**
Pirapatinga (*Piaractus brachypomus*)	91 951	6.9	134 166	1.46
Cachama (*Colossoma macropomum*)	44 219	3.3	101 728	2.30
Characins nei (*Characidae*)	18 186	1.4	39 645	2.18
Pacu (*Piaractus mesopotamicus*)	13 125	1.0	34 110	2.60
Brycon cephalus	2 900	0.2	6 670	2.30
Gouramis	**82 844**	**6.2**	**127 818**	**1.54**
Snakeskin gourami (*Trichogaster pectoralis*)	40 756	3.1	56 443	1.38
Giant gourami (*Osphronemus goramy*)	37 983	2.8	67 932	1.79
Kissing gourami (*Helostoma temminckii*)	3 955	0.3	3 362	0.85
Gouramis nei (*Trichogaster* spp.)	150	< 0.1	81.2	0.54
Family Moronidae				
Striped bass, hybrid (*Morone chrysops x M. saxatilis*)	5 725	0.4	32 154	5.62
Striped bass (*Morone saxatilis*)	5	< 0.1	18.5	3.70
Family Centropomidae				
Nile perch (*Lates niloticus*)	8 584	0.6	20 660	2.41
Others[4]	**248 573**	**18.6**	**458 175**	**1.84**

TABLE A1.1, continued

Total global production of the major cultivated finfish and crustacean species commonly fed on fresh food items, farm-made and/or commercially compounded aquafeeds

Major fed species	Production (tonnes)	Percent	Total value (US$)	Value (US$/kg)
DIADROMOUS FISHES				
Salmons (Family *Salmonidae*)	**1 570 990**		**7 698 989**	**4.90**
Atlantic salmon (*Salmo salar*)	1 456 721	91.9	7 204 152	4.95
Coho salmon (*Oncorhynchus kisutch*)	105 117	7.4	437 023	4.16
Chinook salmon (*Oncorhynchus tshawytscha*)	9 152	0.7	57 814	6.32
Trouts (Family *Salmonidae*)	**676 730**		**2 806 270**	**4.15**
Rainbow trout (*Oncorhynchus mykiss*)	576 289	85.2	2 389 669	4.15
Trouts nei (*Salmo* spp.)	80 265	11.9	275 984	3.44
Sea trout (*Salmo trutta*)	19 432	2.9	135 601	6.98
Brook trout (*Salvelinus fontinalis*)	719	0.1	4 867	6.77
Golden trout (*Oncorhynchus aguabonita*)	25	< 0.1	150	6.00
Eels (Family *Anguillidae*)	**265 338**		**1 230 852**	**4.64**
Japanese eel (*Anguilla japonica*)	253 795	95.6	1 137 766	4.48
European eel (*Anguilla anguilla*)	7 264	2.7	100 055	13.77
River eels nei (*Anguilla* spp.)	4 279	1.6	4217.4	0.99
Milkfish *(*Family *Chanidae)*				
Milkfish *(Chanos chanos)*	676 228	100	951 472	1.41
Miscellaneous diadromous fishes	**70 642**		**262 245**	**3.71**
Family Centropomidae				
Barramundi (*Giant seaperch*; *Lates calcarifer*)	**44 959**	**63.6**	**156 906**	**3.49**
Family Acipenseriformes	**25 683**	**36.4**	**105 339**	**4.10**
Sturgeons nei (*Acipenseridae*	25 123	35.6	97 279	3.87
Adriatic sturgeon (*Acipenser naccarii*)	220	0.3	3 885	17.66
Siberian sturgeon (*Acipenser baerii*)	169	0.2	2 379	14.08
Danube sturgeon (*Acipenser gueldenstaedtii*)	110	0.2	967	8.79
Sterlet sturgeon (*Acipenser ruthenus*)	31	< 0.1	465.4	15.01
Sturgeon (*Acipenser sturio*)	30	< 0.1	363.6	12.12

TABLE A1.1, continued

Total global production of the major cultivated finfish and crustacean species commonly fed on fresh food items, farm-made and/or commercially compounded aquafeeds

Major fed species	Production (tonnes)	Percent	Total value (US$)	Value (US$/kg)
MARINE FISHES				
Seabass	**213 762**		**909 744**	**4.26**
Japanese seabass (*Lateolabrax japonicus*)	97 754	45.7	132 007	1.35
European seabass (*Dicentrarchus labrax*)	66 738	31.2	496 898	7.45
Seabasses nei (*Dicentrarchus* spp.)	49 270	23.0	280 839	5.70
Mullets (Family *Mugilidae*)	**234 686**		**667 651**	**2.84**
Flathead grey mullet (*Mugil cephalus*)	220 932	94.1	647 709	2.93
Mullets nei (*Mugilidae*)	13 420	5.7	19 081	1.42
So-iuy mullet (*Mugil soiuy*)	329	0.1	855.4	2.60
Squaretail mullet (*Liza vaigiensis*)	5	< 0.1	5.3	1.06
Porgies, seabreams (Family *Sparidae*)	**253 273**		**1 285 642**	**5.08**
Gilthead seabream (*Sparus aurata*)	133 026	47.7	718 866	5.40
Silver seabream (*Pagrus auratus*)	78 515	28.3	479 058	6.10
Porgies, seabreams nei (*Sparidae*)	39 143	22.4	65 705	1.68
Blackhead seabream (*Acanthopagrus schlegeli*)	2 003	1.3	17 022	8.50
Others[5]	586	0.3	4 991	8.52
Jacks, crevalles (Family *Carangidae*)	**184 051**		**1 398 890**	**7.60**
Japanese amberjack (*Seriola quinqueradiata*)	158 508	86.1	1 346 684	8.50
Amberjacks nei (*Seriola* spp.)	20 792	11.3	30 916	1.49
White trevally (*Pseudocaranx dentex*)	2 700	1.5	6 750	2.50
Japanese jack mackerel (*Trachurus japonicus*)	1 762	1.0	13 702	7.78
Jacks, crevalles nei (*Caranx* spp.)	273	0.1	725	2.65
Snubnose pompano (*Trachinotus blochii*)	13	< 0.1	87.6	6.74
Greater amberjack (*Seriola dumerili*)	2	< 0.1	19	9.50
Golden trevally (*Gnathanodon speciosus*)	1	< 0.1	5.7	5.70
Flounders, halibuts, soles	**148 526**		**647 736**	**4.36**
Lefteye flounders nei (*Bothidae*)	78 141	52.6	92 988	1.19
Bastard halibut (*Paralichthys olivaceus*)	50 632	34.1	444 803	8.79
Turbot (*Psetta maxima*)	9 573	6.4	76 749	8.02
Righteye flounders nei (*Pleuronectidae*)	8 274	5.6	9 846	1.19
Atlantic halibut (*Hippoglossus hippoglossus*)	1 832	1.2	22 332	12.19
Senegalese sole (*Solea senegalensis*)	60	< 0.1	792.9	13.22
Common sole (*Solea solea*)	13	< 0.1	220.6	16.97
European flounder (*Platichthys flesus*)	1	< 0.1	4	4.00

TABLE A1.1, continued
Total global production of the major cultivated finfish and crustacean species commonly fed on fresh food items, farm-made and/or commercially compounded aquafeeds

Major fed species	Production (tonnes)	Percent	Total value (US$)	Value (US$/kg)
Croakers, drums (Family *Sciaenidae*)	**123 257**		**168 314**	**1.37**
Large yellow croaker (*Larimichthys croceus*)	65 977	53.5	78 513	1.19
Red drum (*Sciaenops ocellatus*)	53 511	43.4	74 588	1.39
Meagre (*Argyrosomus regius*)	3 769	3.1	15 214	4.04
Groupers (Family *Serranidae*)	**78 425**		**373 018**	**4.76**
Groupers nei (*Epinephelus* spp.)	70 232	89.6	240 793	3.43
Greasy grouper (*Epinephelus tauvina*)	5 222	6.7	48 049	9.20
Groupers, seabasses nei (*Serranidae*)	2 612	3.3	79 285	30.35
Orange-spotted grouper (*Epinephelus coioides*)	195	0.2	2 188	11.22
Areolate grouper (*Epinephelus areolatus*)	96	0.1	1 664.4	17.34
Brown-marbled grouper (*Epinephelus fuscoguttatus*)	64	0.1	931.2	14.55
Spotted coral grouper (*Plectropomus maculates*)	3	< 0.1	72	24.00
Humpback grouper (*Cromileptes altivelis*)	1	< 0.1	36.7	36.70
Cods, hakes, haddocks	**21 387**		**83 831**	**3.92**
Atlantic cod (*Gadus morhua*)	21 381	100.0	83 798	3.92
Pollack (*Pollachius pollachius*)	6	< 0.1	33	5.50
Tunas, bonitos, billfishes	**8 926**		**123 094**	**13.79**
Southern bluefin tuna (*Thunnus maccoyii*)	4 532	50.8	74 188	16.37
Pacific bluefin tuna (*Thunnus orientalis*)	2 193	24.6	14 117	6.44
Atlantic bluefin tuna (*Thunnus thynnus*)	1 471	16.5	30 091	20.46
Yellowfin tuna (*Thunnus albacares*)	730	8.2	4 699	6.44
Miscellaneous marine fishes	**499 214**		**957 805**	**1.92**
Marine fishes nei (*Osteichthyes*)	394 236	79.0	525 331	1.33
Korean rockfish (*Sebastes schlegeli*)	32 992	6.6	191 715	5.81
Cobia (*Rachycentron canadum*)	24 860	5.0	38 637	1.55
Puffers nei (*Tetraodontidae*)	21 733	4.4	112 121	5.16
Eastern pomfred (*Schuettea scalaripinnis*)	11 749	2.4	11 867	1.01
Mangrove red snapper (*Lutjanus argentimaculatus*)	3 502	0.7	17 563	5.02
Finfishes nei (*Osteichthyes*)	3 286	0.7	14 467	4.40
Others[6]	6 856	1.4	46 104	6.72

TABLE A1.1, continued

Total global production of the major cultivated finfish and crustacean species commonly fed on fresh food items, farm-made and/or commercially compounded aquafeeds

Major fed species	Production (tonnes)	Percent	Total value (US$)	Value (US$/kg)
MARINE CRUSTACEANS				
Marine shrimps (Family *Penaeidae*)	**3 398 844**		**14 290 444**	**4.20**
Whiteleg shrimp (*Litopenaeus vannamei*)	2 259 183	66.5	8 985 289	3.98
Giant tiger prawn (*Penaeus monodon*)	721 867	21.2	3 349 552	4.64
Penaeus shrimps nei (*Penaeus* spp.)	167 908	4.9	754 035	4.49
Banana prawn (*Penaeus merguiensis*)	80 165	2.4	335 029	4.18
Kuruma prawn (*Penaeus japonicus*)	49 512	1.5	206 026	4.16
Fleshy prawn (*Penaeus chinensis*)	42 682	1.3	172 163	4.03
Indian white prawn (*Penaeus indicus*)	40 714	1.2	315 654	7.75
Metapenaeus shrimps nei (*Metapenaeus* spp.)	33 234	1.0	140 006	4.21
Blue shrimp (*Penaeus stylirostris*)	2 727	0.1	27 173	9.96
Greasyback shrimp (*Metapenaeus ensis*)	671	< 0.1	5 057	7.54
Akiami paste shrimp (*Acetes japonicus*)	100	< 0.1	130	1.30
Palaemonid shrimps nei (*Palaemonidae*)	69	< 0.1	270	3.91
Redtail prawn (*Penaeus penicillatus*)	10	< 0.1	52	5.24
Atlantic ditch shrimp (*Palaemonetes varians*)	1	< 0.1	2	1.50
Baltic prawn (*Palaemon adspersus*)	1	< 0.1	4	4.00
Marine crabs (Family *Portunidae*)	**241 042**		**749 047**	**3.11**
Indo-Pacific swamp crab (*Scylla serrata*)	138 032	57.3	376 767	2.73
Swimming crabs nei (*Portunidae*)	83 803	34.8	294 149	3.51
Marine crabs nei (*Brachyura*)	18 759	7.8	75 899	4.05
Swimcrabs nei (*Callinectes* spp.)	261	0.1	1024.8	3.93
Portunus swimcrabs nei (*Portunus* spp.)	187	0.1	1207	6.45
Lobsters	**372**		**5 491**	**14.76**
Tropical spiny lobsters nei (*Panulirus* spp.)	364	97.8	5 324	14.63
Flathead lobster (*Thenus orientalis*)	4	1.1	52	13.08
Mud spiny lobster (*Panulirus polyphagus*)	4	1.1	115	28.68
Others				
Marine crustaceans nei (*Crustacea*)	109		714	6.55

TABLE A1.1, continued

Total global production of the major cultivated finfish and crustacean species commonly fed on fresh food items, farm-made and/or commercially compounded aquafeeds

Major fed species	Production (tonnes)	Percent	Total value (US$)	Value (US$/kg)
FRESHWATER CRUSTACEANS				
Freshwater crabs (Family *Grapsidae*)				
Chinese mitten crab (*Eriocheir sinensis*)	518 365	100	3 608 126	6.96
Crawfishes, crayfishes	**418 256**		**1 867 527**	**4.47**
Red swamp crawfish (*Procambarus clarkia*)	417 904	99.9	1 862 938	4.46
Red claw crayfish (*Cherax quadricarinatus*)	119	< 0.1	1 552	13.04
Yabby crayfish (*Cherax destructor*)	84	< 0.1	1 158	13.79
Euro-American crayfishes nei (*Astacidae, Cambaridae*)	76	< 0.1	282.5	3.72
Marron crayfish (*Cherax tenuimanus*)	61	< 0.1	1 419	23.26
Noble crayfish (*Astacus astacus*)	12	< 0.1	177.3	14.78
River prawns	**425 885**		**2 140 938**	**5.03**
Giant river prawn (*Macrobrachium rosenbergii*)	207 749	48.8	1 102 642	5.31
Oriental river prawn (*Macrobrachium nipponense*)	205 010	48.1	975 848	4.76
Freshwater prawns, shrimps nei (*Palaemonidae*)	13 096	3.1	62 337	4.76
River prawns nei (*Macrobrachium* spp.)	30	< 0.1	110.8	3.69
Others	**7 120**		**49 943**	
Freshwater crustaceans nei (Crustacea)	7 116	99,9	49 740	6.99
Sawtooth caridina (*Caridina denticulate*)	4	< 0.1	203	50.75

[1] Excludes the filter-feeding species silver carp (3 558 923 tonnes in 2008) and bighead carp (2 299 391 tonnes in 2008; FAO, 2010a).
[2] Species not reported.
[3] Others include pond loach, nilem carp, small-scale mud carp, hoven's carp, lsok barb, mud carp, goldfish, roach, tench, Algerian barb, freshwater bream, roaches nei, bleak, white bream, asp, barbel, rudd, chub.
[4] Others include largemouth black bass, Kafue pike, Reticulate knifefish, netted prochilod, grass-eaters nei, Citharinus nei, aba, prochilods nei, climbing perch, bonytongues nei, Pacific fat sleeper, marble goby, northern pike, pike-perch, silver perch, European perch, African bonytongue, bluegill, American yellow perch, freshwater drum, white crappie, arapaima, knifefishes, Argentinian silverside, gudgeons, sleepers nei.
[5] Others include blackspot (= red) seabream, Sobaity seabream, common pandora, sharpsnout seabream, white seabream, common dentex, goldlined seabream, sargo breams nei.
[6] Others include John's snapper, fourfinger threadfin, filefishes, leatherjackets nei, flatfishes nei, scorpionfishes nei, spinefeet (= rabbitfishes) nei, mackerels nei, trumpet emperor, snappers nei, snappers, jobfishes nei, gobies nei, Russell's snapper, rice-paddy eel, snooks (= robalos) nei, silversides (= sand smelts) nei, streaked spinefoot, marbled spinefoot, spotted rose snapper, Waigieu seaperch, papuan black snapper, sixfinger threadfin (FAO, 2010a).
Source: FAO (2010a).

ANNEX 2 – Fed cultured species production by country

TABLE A2.1
Total fed cultured species production by major producing country in 2008 (tonnes)[1]

China	15 670 948	Guatemala	18 727
India	3 080 161	Bolivarian Republic of Venezuela	18 627
Viet Nam	2 124 400	Iraq	16 746
Indonesia	1 642 957	Nepal	16 086
Thailand	1 032 387	Nicaragua	16 078
Norway	841 786	Finland	13 367
Philippines	697 903	Hungary	13 232
Egypt	693 815	Ukraine	12 584
Myanmar	653 696	Ireland	11 350
Chile	630 929	Madagascar	9 580
Bangladesh	621 605	Belize	9 549
United States	344 819	New Zealand	9 080
Japan	303 986	Netherlands	8 650
Brazil	267 156	Syrian Arab Republic	8 595
Taiwan Province of China	216 971	Croatia	8 356
Ecuador	172 120	Panama	8 224
Malaysia	166 590	Sri Lanka	7 468
Turkey	152 064	Romania	7 260
United Kingdom	144 314	Bosnia and Herzegovina	7 220
Mexico	143 321	Cuba	6 786
Nigeria	142 477	Serbia	6 351
Pakistan	135 098	Jamaica	5 948
Republic of Korea	115 591	Sweden	5 684
Canada	109 913	Zambia	5 640
Iran, Islamic Republic of	102 372	Ghana	5 594
Russian Federation	96 345	Iceland	5 088
Greece	93 486	Kenya	4 452
Colombia	66 400	Portugal	4 050
Spain	63 875	Belarus	3 960
Lao People's Democratic Republic	63 530	Bulgaria	3 810
Italy	58 459	El Salvador	3 766
Uganda	52 250	Cyprus	3 403
France	48 263	Tunisia	3 199
Honduras	47 080	China, Hong Kong Special Administrative Region	3 119
Faroe Islands	45 929	Lithuania	2 997
Australia	38 603	Democratic Republic of the Congo	2 970
Cambodia	38 505	Argentina	2 452
Poland	36 413	Zimbabwe	2 450
Germany	33 875	Algeria	2 384
Denmark	33 600	Democratic People's Republic of Korea	2 200
Peru	28 176	Paraguay	2 100
Costa Rica	27 034	Austria	2 086
Saudi Arabia	22 253	New Caledonia	2 041
Israel	19 762	Sudan	2 000
Czech Republic	19 260	Other countries (<2 000)	30 458
		Total fed species	**31 486 244**

[1]Total fed species country production excludes data for silver carp (3 558 923 tonnes in 2008), bighead carp (2 299 391 tonnes in 2008), and freshwater fishes nei; total global production of freshwater fishes nei (species not given) was reported as 1 244 258 tonnes in 2008 (FAO, 2010a).
Source: FAO (2010a).

The rise into global prominence and rapid growth of finfish and crustacean aquaculture has been due, in part, to the availability and on-farm provision of feed inputs within the major producing countries. More than 46 percent of the total global aquaculture production in 2008 was dependent upon the supply of external feed inputs. For the aquaculture sector to maintain its current average growth rate of 8 to 10 percent per year to 2025, the supply of nutrient and feed inputs will have to grow at a similar rate. This had been readily attainable when the industry was young, but it may not be the case anymore as the sector has grown into a major consumer of and competitor for feed resources.

This paper reviews the dietary feeding practices employed for the production of the major cultured fed species, the total global production and market availability of the major feed ingredient sources used and the major constraints to feed ingredient usage, and recommends approaches to feed ingredient selection and usage for the major species of cultivated fish and crustaceans. Emphasis is placed on the need for major producing countries to maximize the use of locally available feed-grade ingredient sources, and, in particular, to select and use those nutritionally sound and safe feed ingredient sources whose production and growth can keep pace with the 8 to 10 percent annual average annual growth of the fed finfish and crustacean aquaculture sector.

ISBN 978-92-5-106933-2 ISSN 2070-7010

9 789251 069332

BA0002E/1/08.11