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Fish as feed inputs for aquaculture

Practices, sustainability and implications

Cover photographs:
Left: Preparation of trash fish/low-value fish to be fed in a soft-shelled crab farm, Myanmar (courtesy of U Hla Win).
Right top to bottom: Anchoveta (*Engraulis ringens*) for fishmeal production, Chimbote City, Peru (courtesy of N. Sánchez Durand). Feeding of mouse grouper with trash fish/low-value fish in a cage farm, Lampung bay, Lampung, Indonesia (courtesy of Mohammad R. Hasan). Heading and gutting operation of anchoveta, Chimbote City, Peru (courtesy of N. Sánchez Durand).

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Preparation of this document

This document was prepared by a group of experts under the leadership of Dr Mohammad R. Hasan as part of the FAO Aquaculture Management and Conservation Service (FIMA) project "Towards Sustainable Aquaculture: Selected Issues and Guidelines" (GCP/INT/936/JPN), implemented with funding from the Government of Japan. Component 4 of the project addressed the issue of "Use of wild fish and/or other aquatic species to feed cultured fish and its implications to food security and poverty alleviation". It reviewed the status of and trends in the use of wild fish as aquafeed, the types of uses (fresh or processed) for aquaculture, the relative amount used for aquaculture and the potential alternative uses, e.g. for human consumption. To reflect the diversity of the use of wild fish to feed aquaculture species in the various regions, four regional reviews (Africa and the Near East, Asia and Pacific, Europe, and Latin America and North America) and three case studies from Latin America were conducted. On the basis of the regional reviews and case studies, an attempt was made to develop a global perspective on the status and trends in the use of fish as feed and the issues and challenges confronting reduction fisheries. The global perspective was further supported by case studies in China and Viet Nam. In addition, a targeted workshop entitled Use of Wild Fish and/or Other Aquatic Species as Feed in Aquaculture and its implications to Food Security and Poverty Alleviation was convened in Kochi, India, from 16 to 18 November 2007. The workshop was organized by FIMA of FAO and was hosted by the Marine Products Export Development Authority (MPEDA), India. The report of the workshop was published as a FAO Fisheries Report (www.fao.org/docrep/fao/011/i0263e/i0263e.pdf).

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[1] FAO. 2008. Report of the FAO Expert Workshop on the Use of Wild Fish and/or Other Aquatic Species as Feed in Aquaculture and its Implications to Food Security and Poverty Alleviation, Kochi, India, 16–18 November 2007. FAO Fisheries Report No. 867. Rome, FAO. 29 pp.

Abstract

This technical paper provides a comprehensive review of the use of wild fish as feed inputs for aquaculture covering existing practices and their sustainability as well as implications of various feed-fish fisheries scenarios. It comprises four regional reviews (Africa and the Near East, Asia and the Pacific, Europe, and Latin America and North America) and three case studies from Latin America (Chile, Peru and the study on the use of the Argentine anchoita in Argentina, Uruguay and Brazil). The four regional reviews specifically address the sustainable use of finite wild fish resources and the role that feed-fish fisheries may play for food security and poverty alleviation in these four regions and elsewhere. With additional information from case studies in China and Viet Nam, a global synthesis provides a perspective on the status and trends in the use of fish as feed and the issues and challenges confronting feed-fish fisheries. Based on the information presented in the global synthesis, regional reviews and three case studies, and through the fresh analysis of information presented elsewhere, an exploratory paper examines the use of wild fish as aquaculture feed from the perspective of poverty alleviation and food security.

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Preface

BACKGROUND

In 2006, global aquaculture production (including aquatic plants) was estimated at 85.9 million tonnes and valued at US$85.9 billion (FAO, 2008a)[2]. The average annual percentage growth rate (APR) of the aquaculture sector between 1990 and 2004 was 9.4 percent (FAO, 2008b)[3]. In 2005, about 28.2 million tonnes or 44.8 percent of total global aquaculture production (excluding filter-feeding species such as silver carp and bighead carp) was dependent upon the direct use of feed, either a single dietary ingredient, farm-made aquafeed or industrially manufactured compound aquafeeds (FAO, 2007)[4].

Fishmeal and fish oil are two major dietary ingredients used in compound aquafeeds. Total estimated compound aquafeed production in 2006 was about 25.4 million tonnes (Gill, 2007)[5] and about 42 percent of this amount was consumed by non-filter feeding carps (Tacon and Hasan, 2007)[6]. In 2006, the total global industrial feed output exceeded 635 million tonnes to which the aquafeed industry contributed only 4 percent (Gill, 2007). World reduction fisheries have remained at between 20 and 30 million tonnes for the last 30 years (FAO, 2008b). Global fishmeal and fish oil production has remained relatively static over the last quarter century, fishmeal production fluctuating from a low of 4.57 million tonnes in 1977 to a high of 7.48 million tonnes in 1994 (mean of 6.07 million tonnes), and fish oil production fluctuating from a low of 0.85 million tonnes in 2002 to a high of 1.67 million tonnes in 1986 (mean of 1.25 million tonnes) (Tacon, Hasan and Subasinghe, 2006).

Aquaculture is the largest overall user of fishmeal. Pigs and poultry account for around a quarter of total usage, with other livestock types account for the remainder. Ruminants now account for only 1 percent and this is likely to drop. Total estimated amount of fishmeal and fish oil used in the production of aquafeeds has grown over three-fold from 0.96 million tonnes to 3.06 million tonnes and from 0.23 million tonnes to 0.78 million tones, respectively, from 1992 to 2006, (Tacon, Hasan and Subasinghe, 2006[7]; Tacon, 2007). This increase has come from the land-animal sector, particularly

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[2] FAO. 2008a. FAO. *Fishstat Plus: Universal software for fishery statistical time series.* Aquaculture production: quantities 1950–2006; Aquaculture production: values 1984–2006; Capture production: 1950–2006; Commodities production and trade: 1950–2006; Total production: 1970–2006, Vers. 2.30. FAO Fisheries Department, Fishery Information, Data and Statistics Unit. (available at www.fao.org/fi/statist/FISOFT/FISHPLUS.asp).

[3] 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 Implications to Food Security and Poverty Alleviation*, Kochi, India, 16–18 November 2007. FAO Fisheries Report No. 867. Rome, FAO, 29 pp.

[4] FAO. 2007. *Fishstat Plus: Universal software for fishery statistical time series.* Aquaculture production: quantities 1950–2005; Aquaculture production: values 1984–2006; Capture production: 1950–2005; Commodities production and trade: 1950–2005; Total production: 1970–2005, Vers. 2.30. FAO Fisheries Department, Fishery Information, Data and Statistics Unit. (available at www.fao.org/fi/statist/FISOFT/FISHPLUS.asp).

[5] Gill, C. 2007. World feed panorama: bigger cities, more feed. *Feed International*, 28(1): 5–9.

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

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

from the poultry sector, which is continuously reducing its use of fishmeal because the price has risen (FAO, 2008b). The aquafeed sector uses fishmeal, thus reducing availability to the poultry sector and fish oil, thus reducing availability to the all other sectors.

The estimate of fishmeal use for aquaculture varies from 46 to 56 percent and of fish oil use is over 80 percent of total production. It is estimated that aquaculture sector used about 3.06 million tonnes or 56.0 percent of the world's fishmeal production and 0.78 million tonnes or 87.0 percent of total fish oil production in 2006 (Tacon, 2007)[8], with major consumers of fishmeal being marine shrimp (22.4 percent), marine fish (18.3 percent), salmon (18.0 percent), carp (13.1 percent), trout (6.6 percent), freshwater crustaceans (5.3 percent) and eels (5.1 percent), and over 64 percent of fish oil production going into the diets of salmonids (salmon 49.7 percent and trout 14.8 percent) diets (Huntington and Hasan, 2009)[9]. The trend in fishmeal use indicates a decrease in use for salmon and trout although use may increase after 2010, while consumption of fishmeal by marine finfish and penaeid shrimp is increasing and is likely to continue to increase over the next few years.

Demand and use of fishmeal in some of the emerging aquaculture countries in Asia are increasing rapidly. Viet Nam uses approximately 62 500 tonnes of fishmeal per year, solely for aquaculture (Hasan *et al*., 2007[10]). China is the single largest user of fishmeal and used 1.6 million tonnes in 2004, of which 1.2 million tonnes were imported and 0.4 million tonnes were produced domestically (Weimin and Mengqing, 2007[11]). Of this 1.6 million tonnes of fishmeal, approximately 75 percent was used for aquafeed production. It was estimated that the Asia-Pacific aquaculture sector uses about 2.4 million tonnes of fishmeal (equivalent to approximately 10.3 tonnes of raw material) as a feed source. The low and high predictions for the year 2010, are in the order of 2.0 and 2.2 million tonnes of fishmeal, respectively (equivalent to 8.4 and 12.8 million and/or 7.3 and 11.2 million tonnes of raw material, based on efficiency of raw material to fishmeal conversion rates of 4.0 and 3.5, respectively) (FAO, 2008b).

In addition to fishmeal and fish oil used in compound and farm-made aquafeeds, low-value fish or "trash" fish are used in different parts of the world as a complete or supplementary feed for farmed fish, crustaceans and a few molluscan species. It is generally estimated that an approximate 5 to 6 million tonnes of low-value/trash fish are used as direct feed in aquaculture worldwide (Tacon, Hasan and Subasinghe, 2006), particularly for marine carnivorous fish species in China and in several Southeast Asian countries (e.g. Viet Nam, Indonesia, Thailand), marine crustaceans (lobsters and crabs) and certain freshwater fish species. A recent estimate placed the Asian use of trash fish as fish feed at about 1.6 to 2.8 million tonnes per year and the low and high predictions for the year 2010 are in the order of 2.2 to 3.9 million tonnes of trash fish/low-value fish, respectively as direct feed inputs (FAO, 2008b). The total use of trash

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8 Tacon, A.G.J. 2007. *Meeting the feed supply challenges.* Paper presented FAO Globefish Global Trade Conference on Aquaculture, Qingdao, China, 29–31 May 2007.

9 Huntington, T.C. & Hasan, M.R. 2009. Fish as feed inputs for aquaculture – practices, sustainability and implications: a global synthesis. *In* M.R. Hasan and M. Halwart (eds.). *Fish as feed inputs for aquaculture: practices, sustainability and implications,* pp. 209–268. FAO Fisheries and Aquaculture Technical Paper. No. 518. Rome, FAO. 407 pp.

10 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.

11 Miao, W.M. & Liang, M.Q. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in China. *In* M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds.). S*tudy and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 141–190. FAO Fisheries Technical Paper. No. 497. Rome, FAO. 510 pp.

12 Edwards P., Tuan, L.A. & Allan, G.L. 2004. *A survey of marine trash fish and fish meal as aquaculture feed ingredients in Viet Nam*. ACIAR Working Paper 57. 56 pp.

fish by the aquaculture industry in Viet Nam was estimated to be between 176 420 and 323 440 tonnes in 2001 (Edwards *et al.*, 2004)[12]. It is further projected that Viet Nam will use nearly 1 million tonnes of trash fish and China will require approximately 4 million tonnes by the year 2013 to sustain their marine cage-culture activities (De Silva and Hasan, 2007)[13]. Available information indicates that a significant quantity of trash fish/low-value fish (conservatively estimated at 2.3 million tonnes per year) is being used by the pet food industry (FAO, 2008b).

Other fishery products used in the production of aquafeeds are krill meal, squid meal, squid liver powder and squid oil, shrimp meal and crab meal, and the market size for these products as inputs to aquafeeds is currently estimated to be about 0.29 million tonnes (range: 0.19 to 0.52 million tonnes) (Tacon, Hasan and Subasinghe, 2006). Finfish and crustacean aquaculture is, therefore, highly dependent upon capture fisheries for sourcing feed inputs in the form of fishmeal and fish oil, low-value/trash fish or other marine resources.

The issue

Although capture fisheries provide a significant input for the growth of aquaculture production, questions surrounding the ethics and long-term sustainability of this practice are often raised. The global fishmeal industry observes that there might not be enough demand (i.e. for direct human consumption) for 90 percent of the wild-caught fish that is reduced to fishmeal. However, on a regional or on an individual country basis, it is possible that a good portion of the reduction fishery products is simply not available for human consumption, though if available, a certain portion of it would certainly have been consumed. In Asia and Africa, small pelagic fish are an important component of the diet of lakeside and coastal communities. In several countries, the increasing demand for pelagic fish by the animal feed industry is reducing the availability of fresh fish for poor communities, and this has a negative impact on food security. Nevertheless, it has also been shown that reduction fisheries and downstream animal production activities contribute to employment generation and eventually contribute to improved living standards and, hence, food security (Hecht and Jones, 2009)[14]. This may be the case when the fishmeal is used in the country of origin, i.e. employment generated through the production of fishmeal as well as created through the aquaculture or the animal feed industries where fishmeal is used in aquafeeds.

The situation in Europe and the Americas, however, is very different from that in Africa and Asia. The catch of the large feed fisheries targeted for fishmeal and fish oil in Europe is considered to have few alternative uses (Huntington, 2009)[15]. However, some fish such as blue whiting, capelin, anchovy, herring and sprat can be used for direct human consumption. The portion that goes for human consumption is not determined by technical limitations but depends largely on economic and cultural factors, which are more difficult for the fishery industry to address directly. Despite their relatively low cost, products originating from small pelagic fisheries do not contribute significantly

[13] De Silva, S.S. & Hasan, M.R. 2007. Feeds and fertilizers: the key to long term sustainability of Asian aquaculture. *In* M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 19–47. FAO Fisheries Technical Paper. No. 497, Rome, FAO. 510 pp.

[14] Hecht, T. & Jones, C.L.W. 2009. Use of wild fish and other aquatic organisms as feed in aquaculture – a review of practices and implications in Africa and the Near East. *In* M.R. Hasan and M. Halwart (eds.). Fish as feed inputs for aquaculture: practices, sustainability and implications, pp. 129–157. FAO Fisheries and Aquaculture Technical Paper. No. 518. Rome, FAO. 407 pp.

[15] Huntington, T. 2009. Use of wild fish and other aquatic organisms as feed in aquaculture – a review of practices and implications in Europe. *In* M.R. Hasan and M.H. Halwart (eds). *Fish as feed inputs for aquaculture: practices, sustainability and implications,* pp. 209–268. FAO Fisheries and Aquaculture Technical Paper. No. 518. Rome, FAO. 407 pp.

towards ensuring the food security in any part of Europe, due to the ready availability of other nutritional options. Although Japanese and Eastern European markets have shown interest in utilizing feed-fish species such as capelin for human consumption, the volumes consumed are low and are not likely to grow significantly. In case of Latin America, some fish species (e.g. mackerel, anchovy), even though acceptable for direct human consumption, are available in too large quantities relative to the size of nearby markets.

Further, there are issues related to the long-term ecological sustainability of reduction/feed fisheries. Feedfish are mainly short lived, small pelagic fish that show a high level of inter-annual variability that may depend upon extrinsic, often climate-related factors. For example, the Peruvian anchovy fishery (which represented over a quarter or 28.5 percent of the total estimated marine fisheries landings destined for reduction in 2003) is extremely vulnerable to the El Niño southern oscillation events (Tacon, Hasan and Subasinghe, 2006). Although the high levels of fecundity of small pelagic fish species and the relatively short life cycles permit stocks to recover relatively quickly and thus provide a certain degree of protection from high levels of exploitation, the consequences of stock variability on natural predators, as well as the contribution of fishing mortality to these variations in stock sizes, are not fully understood.

Although quality and price are the main determinants for fishmeal purchasers in the aquafeeds industry, the sustainability of feed-fish sources is beginning to become more important. At present, most buyers depend upon the FIN S*ustainability Dossier*[16] for information on what stocks are "sustainable", but there is a recognized need for a comprehensive analytical framework that integrates target stock assessment with the wider ecosystem linkages (Huntington, 2009). To a degree this exists with the development of ecosystem models and approaches such as the MSC (Marine Stewardship Council) criteria for "responsible fishing". Once such a framework has been created and is accepted as a suitable benchmark by the aquafeed industry and its detractors, then it will be easier for purchasers to purchase only from sustainable feed-fish stocks. This process will inevitably have consequences, such as greater pressure on those stocks deemed sustainable as well as possible effects on market economics. This implies that greater use of vegetable-based substitutes will be essential, which in turn may require a reduction in consumer attitudes towards their inclusion in farmed-fish diets.

The above scenarios, therefore, call for a comprehensive study and analysis to determine the sustainability of feed fisheries in relation to food security, poverty alleviation, long-term ecological sustainability and the environment, and indeed the growth and sustainability of important subsectors of the aquaculture industry.

Activities

With funding from the Government of Japan, the Aquaculture Management and Conservation Service (FIMA) of FAO implemented the project "Towards Sustainable Aquaculture: Selected Issues and Guidelines" (GCP/INT/936/JPN). Five key thematic areas was identified for targeted action under the project. Component 4 of the project addressed the issue of the "Use of Wild Fish and/or Other Aquatic Species to Feed Cultured Fish and its Implications to Food Security and Poverty Alleviation". Component 4 assessed and reviewed the status of and trends in the use of wild fish as aquafeeds, the types of uses (fresh or processed) for aquaculture, the relative amount

[16] Fishmeal Information Network (FIN) *Sustainability Dossier*, an annually updated assessment initiated by the Grain and Feed Trade Association (GAFTA) and funded by the United Kingdom Sea fish Industry Authority (SFIA). FIN aims to provide the latest information available about fishmeal and its role in livestock production. A key element of this is the assurance that fishmeal is produced from fish stocks that are properly monitored according to independent scientific advice and managed to ensure that supplies are not over-fished, or from the recycled trimmings from the food-fish processing sector. (www.nautilus-consultants.co.uk/seafeeds/Files/IFFO-sustainability%20dossier.pdf)

used for aquaculture and the potential alternative uses, e.g. for human consumption. The project is expected to develop policy and technical guidelines on sustainability issues of feed-fish fisheries, including improved management and the criteria for the sustainable use of fish as aquafeeds. These guidelines are expected to assist policy-makers in deciding ways and means of utilizing low-value fish, *inter alia* through development and application of methodologies to estimate optimal allocations of fish for animal and human purposes.

Under this component, four regional reviews (Africa and the Near East, Asia and the Pacific, Europe, and Latin America and North America) and three case studies from Latin America were conducted. The regional reviews specifically addressed the ways of feed-fish fisheries may impinge on food security and poverty alleviation in the four regions and elsewhere, including the sustainable use of these finite resources and the environmental implications of the direct use of fish as feed. On the basis of the four regional reviews and the three case studies, an attempt was made to develop a global perspective on the status of and trends in the use of fish as feeds and issues and challenges confronting feed-fish fisheries.

As a part of the consultative process and to review and analyse critical issues related to the use of wild fish to feed aquaculture species, a targeted workshop entitled "Use of Wild Fish and/or Other Aquatic Species as Feed in Aquaculture and its Implications to Food Security and Poverty Alleviation" was convened in Kochi, India, from 16 to 18 November 2007. The workshop addressed the following thematic areas and other issues of significance emerging from the regional reviews and case studies: a) fisheries management; b) policy development; c) food security; d) poverty alleviation; e) social and ethical issues; and f) aquaculture technology and development. Following several working group deliberations, the workshop agreed on ten principles on the use of wild fish as feed in aquaculture, concluded that such use should be governed by the above ten guiding principles and recommended a number of actions for the FAO to undertake to address the issues raised. The ten guiding principles adopted in the workshop (for details see FAO Fisheries Report No. 867 available at www.fao.org/docrep/fao/011/i0263e/i0263e.pdf) will be elaborated to develop FAO Technical Guidelines for Responsible Fisheries on the "Use of wild fish as feed in aquaculture".

This technical paper has been published in response to the recommendation of the workshop and contains a global synthesis, four regional reviews, selected case studies and a review on the use of wild fish as aquaculture feed from the perspective of poverty alleviation and food security.

ABBREVIATIONS AND ACRONYMS

AA	Arachidonic acid
ACFM	Advisory Committee on Fishery Management (ICES)
AFMA	Animal Feed Manufacturers Association of South Africa
AIC	Agricultural Industries Confederation
APB	Anchoita protein base
APR	Annual percentage growth rate
ASIPES	Asociación de Industriales Pesqueros
AUD	Australian dollar
B.C.	Before Christ
BCC	Banco Central de Chile
BCLME	Benguela Current Large Marine Ecosystem programme
BMP	Better management practices
BSE	Bovine spongiform encephalopathy
BV	Biological value
CBR	Cost/benefit ratio
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CCRF	Code of Conduct for Responsible Fisheries
CE	Conversion efficiencies
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CEP–Paita	Centro de Entrenamiento Pesquero (Perú)
CFP	Common Fisheries Policy (EC)
CJD	Creutzfeld-Jacob Disease
CNPq	Conselho Nacional de Ciência e Tecnologia do Brazil
CNY	Chinese yuan
CONA	Comité Oceanográfico Nacional (Chile)
CORFO	Corporación de Fomento de la Producción (Chile)
CPUE	Catch per unit effort
DFID	Department for International Development, (United Kingdom)
DG	Directorate-General
DHA	Docosahexaenoic acid
DHC	Direct human consumption
DIEESE	Dipartamento Intersindical de Estatísticas e Estudios Socioeconômicos (Brazil)
DP	Digestible protein
EAF	Ecosystem Approach to Fisheries
EC	European Commission
EEZ	Exclusive economic zone
EIA	Environmental impact assessment
ELIFONTS	Effects of Large-scale Feed fisheries On Non-Target Species
ENSO	El Niño Southern Oscillation
EPA	Eicosapentaenoic acid
EQS	Environmental Quality Standards
EQV	Environmental quality variables
ETFU	Estimated trash fish/low-value fish used

EU	European Union
F	Fishing mortality
FAO	Food and Agriculture Organization of the United Nations
FCR	Food conversion ratio
FEMAS	Feed Materials Assurance Scheme
FIN	Fishmeal Information Network
FOB	Freight on board
FOI	Danish Research Institute of Food Economics
FONDEPES	Fondo de Desarrollo Pesquero (Perú)
FOPROBI	Fund for the Protection of the Biomass (Perú)
FPC	Fish protein concentrates
FTE	Full time equivalent
g	gram
GAFTA	Grain and Feed Trade Association
GDP	Gross Domestic Product
GFCM	General Fisheries Council for the Mediterranean
GRT	Gross registred tonnes
GTZ	Gesellschaft für Technische Zusammenarbeit
HACCP	Hazard Analysis and Critical Control Points
H&G	Head and gutted
HIV	Human immunodeficiency virus
IAFMM	International Association of Fish Meal Manufacturers
ICCAT	International Commission for the Conservation of Atlantic Tuna
ICES	International Council for the Exploration of the Sea
ICLARM	International Center for Living Aquatic Resources Management, now renamed WorldFish Center
IFFO	International Fishmeal and Fish Oil Organisation
IFPRI	International Food Policy Research Institute
IHC	Indirect human consumption
IIAP	Peruvian Amazon Research Institute
ILO	International Labour Organization
IMARPE	Instituto del Mar del Perú
INAPE	National Fisheries Institute (Uruguay)
INE	Instituto Nacional de Estadísticas
INEI	Instituto Nacional de Estadística e Informática (Perú)
INR	Indian rupee
INRH	Institut National de Recherche Halieutique
ITP	Instituto Tecnológico Pesquero (Perú)
ITQ	Individual Tradable Quota
K	Condition Factor
LT	Low temperature
M	Natural mortality
MAFF	Ministry of Agriculture, Fisheries and Food (United Kingdom)
mm	millimetre
MMBM	meat meal and bone meal
MSC	Marine Stewardship Council
MSFOR	Multi-species Forward Projection (ICIES)
MSVPA	Multispecies Virtual Population Analysis
N	Nitrogen
NAO	North Atlantic Oscillation
NEPAD	New Partnership for Africa’s Development

ng	nanogram
NGO	Non-governmental organization
NMFS	National Marine Fisheries Service (United States of America)
NOAA	National Oceanic and Atmospheric Administration
OMP	Operational Management Procedure
PAMA	Adaptation Program for Environmental Impact
PBDE	Polybrominated diphenyl ethers
PCB	Polychlorinated biphenyls
PEPPA	Perspectives of Plant Protein Use in Aquaculture
POP	Persistent organic pollutants
ppt	parts per thousand
PRODUCE	Ministry of Production (Perú)
PROMPEX	Oficina Nacional para la Promoción de Exportaciones (Perú)
RAFOA	Researching Alternatives to Fish Oils in Aquaculture
RFO	Regional Fisheries Organizations
RPP	Radio Programas del Perú
RSPB	Royal Society for the Protection of Birds
RUP	rumen undegradable protein
SANIPES	Servicio Nacional de Sanidad Pesquera (Perú)
SAPW	Subantarctic Platform Waters
SCAHAW	Scientific Committee on Animal Health and Animal Welfare (EC)
SCAN	Scientific Committee on Animal Nutrition
SDRS	Sustainable Development Reference System
SEAFEEDS	Sustainable Environmental Aquaculture Feeds
SENATI	Servicio Nacional de Adiestramiento en Trabajo Industrial (Perú)
SERNAC	Servicio Nacional del Consumidor (Chile)
SERNAPESCA	Servicio Nacional de Pesca (Chile)
SFIA	United Kingdom Sea Fish Industry Authority
SISESAT	Sistema de Seguimiento Satelital
SNP	National Society of Fisheries (Perú)
SOFIA	The State of World Fisheries and Aquaculture
SONAPESCA	Sociedad Nacional de Pesca (Chile)
SQS	Scottish Quality Salmon
SSB	Spawning Stock Biomass
STECF	Scientific, Technical and Economic Committee for Fisheries (of the EC)
STSF	Subtropical Shelf Front
STSW	Subtropical Shelf Waters
SUBPESCA	Subsecretaria de Pesca (Chile)
SWAO	South Western Atlantic Ocean
TAC	Total allowable catch
Taiwan POC	Taiwan Province of China
THB	Thai baht
TSE	Transmissible spongiform encephalopathy
TWI	Tolerable weekly intake
UFAS	Universal Feed Assurance Scheme
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
US$	United States dollar
USA	United States of America

VMP	Vice-ministry of Fisheries (Perú)
VMS	Vessel monitoring systems
VND	Vietnamese dong
W	weight
WHO	World Health Organization
WWF	World Wildlife Fund
Y/B	yield/biomass
ZCPAU	Argentine-Uruguayan Common Fishing Zone

Fish as feed inputs for aquaculture – practices, sustainability and implications: a global synthesis

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SUMMARY

With around three quarters of the world's capture fisheries fully or overexploited, aquaculture is seen as the main source for future growth of fish production. Given this finite state of affairs, this paper examines the role of "feed" fisheries in fish and animal farming and considers whether the direct human consumption of these resources might be preferable on environmental, food security and livelihood grounds. This synthesis draws on four regional analyses and a number of country case studies.

There are marked differences among regions regarding the sourcing and use of fish-based protein for feeds. In South America and Europe high-performance compounded feeds derived from target feed stocks are utilized, although Asian demand for these resources is increasingly causing South American and European aquaculture producers to substitute fishmeal with plant-based alternatives. Asian aquaculture – apart from the intensive culture of marine shrimp – still largely depends upon "trash fish" and farm-made diets due to their availability and low cost, characteristics which are considered by farmers to outweigh their poor growth and environmental performance. With the exception of Egyptian mariculture, most of Africa's culture of herbivorous/omnivorous species uses locally made fishmeal.

In some key feed fisheries and particularly in South America, there is considerable scope to increase the proportion of feedfish used for human consumption to address food security concerns. However, this switch depends upon the development of low-cost, easily conserved products that are accessible by the poor in inland rural areas. In Asia, there is some scope for greater use of low-value fish for human consumption, but again affordability and required product preservation are limitations.

In terms of food security and livelihood maintenance, such a switch would be particularly beneficial to South American populations. However, the situation in Asia is less clear cut, as cheap and abundant trash fish allow small-scale aquaculture development and the accompanying livelihood opportunities. In summary, there is no single "answer" as to whether more "feedfish" should be used for human consumption. Solutions to this issue require a regional approach that examines all the consequences – economic, social and environmental – to ensure that inappropriate policy changes are not rushed through on the basis of simplistic assertions.

1. INTRODUCTION

1.1 Background

World capture fisheries have reached a plateau at approximately 94 million tonnes (FAO, 2007). The most recent estimates suggest that 52 percent of marine stocks are fully exploited, 17 percent are overexploited and 7 percent are totally depleted (FAO, 2005a), while human population and the demand for marine and other aquatic resources continue to increase. Global aquaculture has made a considerable contribution towards bridging the gap between supply and demand. Global aquaculture production (excluding aquatic plants, corals and amphibians) in 2005 amounted to just over 47 million tonnes, contributing over half of total global fish production (FAO, 2007). Globally, aquaculture production has more than tripled in the past 15 years (FAO, 2006a). Most notable have been the increases in production in China and Chile.

Fishmeal and fish oil are important feed ingredients in aquaculture, and by 2003 their consumption by the sector had increased to 2.94 million and 0.80 million tonnes, representing 53.2 and 86.8 percent of global production, respectively (Tacon, Hasan and Subasinghe, 2006). Naylor *et al.* (2000) argue that the farming of carnivorous fish has placed undue pressure on world fishmeal supplies by using up to five times more fish protein than that which is produced. Although there are discrepancies in the ratio of wild fish consumed to farmed fish produced, there is general agreement that species such as salmon, trout and other carnivorous marine finfish consume considerably more fish protein than they produce. However, this is not the case for herbivorous, omnivorous, detritivorous and planktivorous species, which produce considerably more fish protein than they consume (Naylor *et al.*, 2000). The growth of the aquaculture industry is fortunately skewed in favour of non-carnivorous species that are produced by more extensive and traditional methods of aquaculture (i.e. with little to no fishmeal in the diet). It is mainly for this reason that the balance is tipped in favour of aquaculture (Roth *et al.*, 2002). Nonetheless, aquaculture is reported to be the single largest user of fishmeal, using in excess of 53 percent of global supply (Tacon, 2004; Tacon, Hasan and Subasinghe, 2006).

The demand for aquafeeds continues to increase, yet the overall global supply of fishmeal and fish oil is relatively fixed (SEAFEEDS, 2003). This implies that there will be increased pressure on the fisheries that supply these commodities unless substitutes become both available and widely accepted. While there is no real reason why feed fisheries should not continue to supply the aquaculture industry in the future, adequate assurances of sustainability need to be in place. Furthermore, as the demand for fishmeal and fish oil expands from both aquaculture and the production of chickens, pigs and livestock, it is important that the use of small pelagics and other fish for feeds does not have an impact on the food security and livelihoods of coastal and lakeside populations that traditionally use these species for direct consumption.

1.2 Objectives

This global synthesis brings together four region-specific reviews that examine the often contrasting situations in the Americas (Tacon, 2009), Europe (Huntington, 2009), Africa and the Near East (Hecht and Jones, 2009) and the Asia-Pacific (De Silva and Turchini, 2009).

It is further supported by the following country/species-specific case studies:

- China (Xianjie, 2008);
- Viet Nam (Phuc, 2007 and Sinh, 2007);
- Chile (Bórquez and Hernández, 2009);
- Peru (Sánchez Durand and Gallo Seminario, 2009); and
- South American anchovy – Brazil, Uruguay and Argentina (Pastous Madureira *et al.*, 2009).

This compilation provides a comparative analysis of the different regional patterns in terms of the status of and trends in the use of fish as aquafeeds (the species and volumes involved, as well as the seasonal and spatial distribution of use), the actual types of uses in aquaculture (either directly as trash fish or in compounded diets), the relative amount being used by aquaculture and the potential alternative uses (e.g. for direct human consumption).

1.3 Scope

In this study, the wild fish destined for inclusion in aquafeeds will include the so-called "feed-fish" stocks (also known as reduction fisheries) that are directly targeted for fishmeal production, together with bycatch species and those species (including offal and trimmings) reduced to fishmeal in certain market situations. It also includes the so-called trash or low-value bycatch that is currently the mainstay of Asian small-scale aquaculture. The review is not restricted to finfish feed sources – other marine species used in aquafeeds such as squid, krill and shrimp are also included.

2. OVERVIEW OF AQUACULTURE SYSTEMS AND PRACTICES

This section looks at the contrasting nature of aquaculture undertaken in different regions of the world, examines the past trends in production and then attempts to forecast where the industry will be in the next decade.

2.1 Current status and trends

Aquaculture is the farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated (FAO, 2009)[1]. For the purpose of this report, four broad categories of aquaculture are considered, based upon the relative position of the animals cultured in the trophic hierarchy and thus the fishmeal and fish oil in their diets (Tacon, Hasan and Subasinghe, 2006).

- *Carnivorous finfish:* those species dependent upon high protein levels in their diet, normally derived from animal sources. This group includes the salmonids, as well as many marine and freshwater species such as seabass, seabream, eels, amberjack, groupers and snakeheads. These species require from 20 to 40 percent fishmeal in their diets.
- *Herbivorous/omnivorous finfish:* those species that have lower protein requirements (i.e. <20 percent) that can be derived from both plant and animal sources. This group includes grass carp, common carp, other cyprinids, tilapias, milkfish and catfish, all of which require around 5 percent fishmeal content in their feeds.
- *Omnivorous/scavenging crustaceans:* those species include the marine shrimps, freshwater prawns, crabs and crayfish that currently require between 15 and 25 percent fishmeal in their diets.
- *Filter-feeding finfish*: those species that are able to derive their dietary requirements from phyto- and zooplankton and thus do not necessarily need supplementary feed. They include silver carp, bighead carp, catla and rohu.

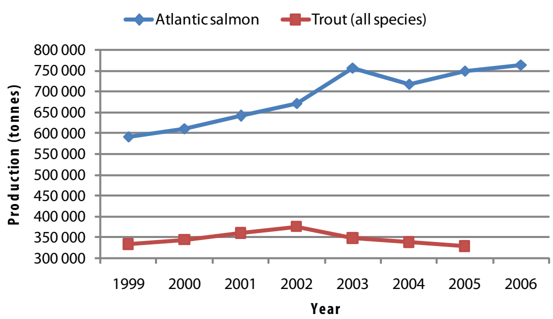
2.1.1 Carnivorous finfish

Although relatively new to aquaculture when compared with the cyprinids, which have been cultivated for thousands of years, a combination of the development of high performance compounded feeds and technological advances in marine fish hatchery production has resulted in a huge expansion in the largely intensive culture of carnivorous species over the last 50 years. This includes the production of channel catfish

[1] FAO Glossary of aquaculture (accessed on 31 July 2009) (http://www.fao.org/fi/glossary/aquaculture/default.asp)

(*Ictalurus punctatus*) in the United States of America, and salmon and trout farming in Europe and more recently Chile and Canada. The culture of marine fish – seabass and seabream in the Mediterranean and grouper in Asian waters – has also grown rapidly over the last ten years, as has the culture of freshwater species such as pangasiid catfish and snakeheads. The culture of these species is usually intensive, often using large cage systems, computerized feeding systems and other technology to improve performance and reduce costs. In Europe, the expansion of Atlantic salmon (*Salmo salar*|) farming still dominates mariculture in terms of volume (Figure 1), although growth is slowing as a result of softening prices and competition from Chile. In China, the culture of Mandarin fish (*Siniperca* spp.) and largemouth bass (*Micropterus salmoides*) has expanded rapidly in recent years, utilizing large volumes of live feed and trash fish, respectively.

FIGURE 1
Atlantic salmon and trout production in Europe, 1998–2006



Source: http://www.feap.info/feap/aquaculturedata/default_en.asp

In the Americas, aquaculture production has been growing at an average compound rate of 8.9 percent per year since 1995, increasing over two-fold from 968 128 tonnes in 1995 to 2 093 003 tonnes in 2004 (Tacon, 2009). In marked contrast, capture fisheries production within the region over the same period has decreased by over 6 percent, from 27 944 203 tonnes in 1995 to 26 256 508 tonnes in 2004 (FAO, 2006a). The majority of this growth has been in Atlantic salmon in Chile, as well as Canada. Other important species that show steady growth include channel catfish from the United States of America, rainbow trout (*Oncorhynchus mykiss*) and tilapia (*Oreochromis* spp.). While the diadramous salmonids are mostly farmed in cages, most other species are raised in earthen ponds.

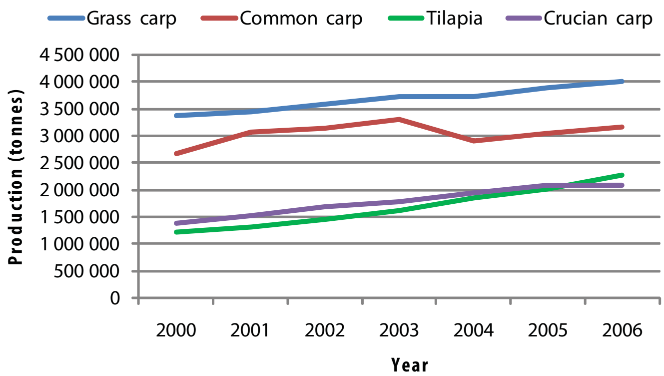
Asian production of carnivorous fish currently amounts to around 3 368 956 tonnes (FAO, 2006a) or about 8 percent of the region's production, which itself accounts for over 90 percent of global output. These carnivorus fish mostly (60 percent) tend to be the warmer water freshwater species such as white Amur bream (*Parabramis pekinensis*), snakeheads, mandarin fish and pirapatinga (*Piaractus brachypomus*), while the remainder are marine and brackishwater species such as milkfish (*Chanos chanos*), eels, Japanese seabass (*Lateolabrax japonicus*) and amberjack (*Seriola* spp.).

The production of carnivorous species in Africa and the Near East only accounts for 12 percent of the region's aquaculture production, which is dominated by the herbivorous/omnivorous finfish and crustaceans. Aquaculture of carnivorous species in the region includes trout in the Islamic Republic of Iran and seabass and seabream in Egypt. In Sub-Saharan Africa, only low volumes of carnivorous fish are cultured.

2.1.2 Herbivorous/omnivorous finfish

This group of species represents the bulk of fish farmed in Asia and Africa, although they are also well represented elsewhere, accounting for around 60 percent of global finfish production. They are able to derive protein from plant sources but are often able to utilize fishmeal as an important protein source for rapid growth. Given their global importance, even at low levels of fishmeal inclusion, they exert a significant demand for this commodity – for instance, non-filter-feeding carps utilized around 8.75 million tonnes of aquafeeds in 2003, around 45 percent of total use (Tacon, Hasan and Subasinghe, 2006).

FIGURE 2
Production of the primary non-filter-feeding carps and all tilapias, 2000–2005



Source: FAO (2006a)

Growth in the production of this species group is steady if unspectacular. For instance, the production of the primary non-filter-feeding carps has increased 25 percent since 2000 (Figure 2), which is higher than 5–10 percent global average for finfish over the same period.

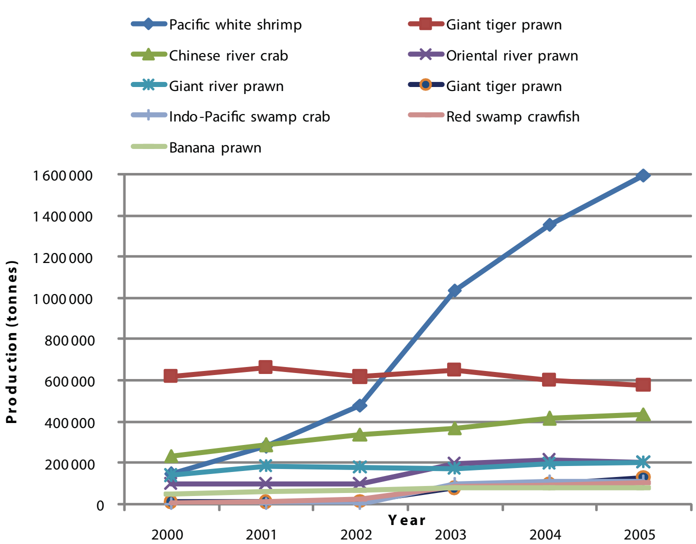
The factors driving growth of this species group reflect local demand in the areas of production rather than a global commodity status, as is the case for salmonids and other intensively farmed marine species. This demand reflects their important role both in local economies and in supporting livelihoods through income generation, especially for small-scale farming operations.

2.1.3 Omnivorous/scavenging crustaceans

This group includes marine shrimps, freshwater prawns and other crustaceans. Similar to the carnivorous group, they produce high-value crops that are sold on the international markets with valuable economic returns to farmers, processors and other downstream interests. Although they have an important function in providing coastal and rural employment, the relatively high intensity of the culture systems used and the producers´ position as an initial point in a long distribution chain results in narrow margins and an increasing need for cost efficiency. This has resulted in both vertical integration through the sector and the increasing development of cluster farming to reduce the cost of inputs and to share marketing and other costs. However, given that most shrimp and prawns are either sold in the larger cities or exported, their direct contribution to rural food security is limited.

The global farmed crustacean production is currently just under 4 million tonnes (FAO, 2006a). Over a third of this amount consists of Pacific white shrimp (*Litopenaeus vannamei*, also known as the whiteleg shrimp), whose culture has expanded extremely rapidly, mainly due to production in China, which has increased from 100 000 tonnes in 2000 to over 800 000 tonnes in 2005. Thailand and Indonesia have also recorded impressive increases in the production of this species, which is usually reared in brackishwater systems. The Pacific white shrimp has also seen a gradual increase in production in Brazil and in its native eastern Pacific region of central and southern America, where production is growing, particularly in Mexico.

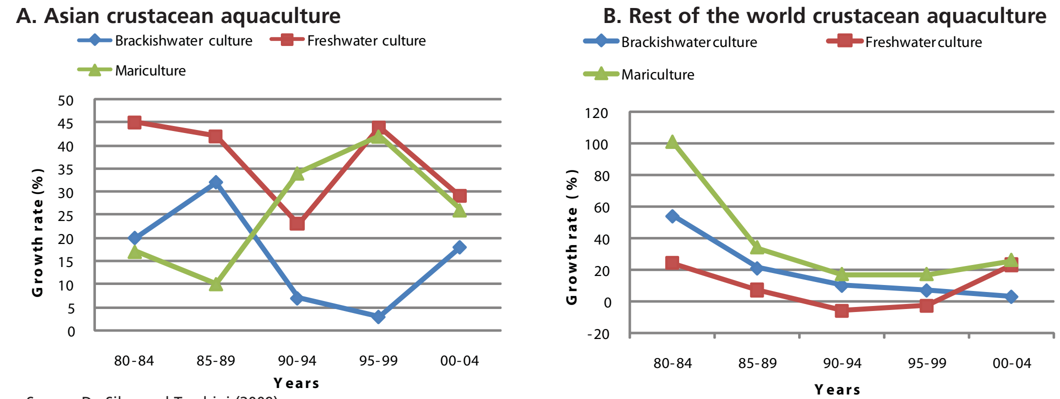
FIGURE 3
Global production of key crustacean species, 2000–2005



Source: FAO (2006a)

The production of other shrimp species such as the giant tiger prawn (*Penaeus monodon*) has shown a gradual growth over the last five years (Figure 3). This steady growth demonstrates a consolidation of the shrimp farming sector since the "boom and bust" days of the previous two decades and indicates a growing maturity of the sector marked by improved management, including better risk analysis.

FIGURE 4
Rate of growth of Asian crustacean aquaculture compared with the rest of the world



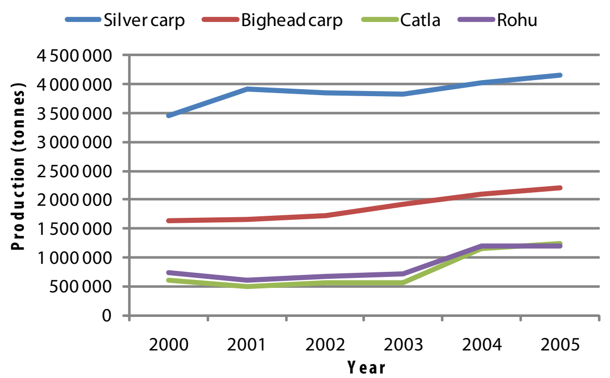
Source: De Silva and Turchini (2009)

2.1.4 Filter-feeding finfish species

This group of finfish species depends on natural productivity, which in turn may be enhanced through pond fertilization. Typical species include the Chinese carps and Indian major carps such as silver carp (*Hypothalmichthys molithrix*), bighead carp (*H. nobilis*), catla (*Catla catla*) and rohu (*Labeo rohita).* These species have particular dietary selectivity and so are often produced in polyculture systems that maximize the productivity of a given waterbody.

Production of these filter-feeding species is dominated by China, which produces 65 percent of the 8.8 million tonnes of global output and is limited to only the silver and bighead carps. India and Bangladesh also produce significant amounts (25 and 5 percent, respectively) of filler-feeding fishes, although these are mainly the Indian major carps (rohu, catla and mrigal (*Cirrhinus cirrhosus*), although there is a growing use of the Chinese carps.

FIGURE 5
Production of the key filter-feeding carp species, 2000–2005



Source: FAO (2006a)

Although irrelevant in terms of their usage of fishmeal and fish oil (the use of supplementary diets with these species is rarely practiced), these species are highly important in terms of their contribution to local economies and their role in ensuring food security in rural areas. They are often grown in small-scale operations, with the produce being locally sold and consumed; thus they represent a significant contribution to the protein consumed by rural communities. It is important to recognize this contribution and assess the food security and poverty implications of a transition to more intensive systems and species with a wider market.

2.2 Future outlook

2.2.1 Global population growth

In 2000, the United Nations (UN) estimated that the world's population was then growing at the rate of 1.14 percent (or about 75 million people) per year. Globally, the population growth rate has been steadily declining from its peak of 2.19 percent in 1963, but growth remains high in the Middle East and sub-Saharan Africa. In some countries, there is negative population growth (i.e. net decrease in population over time), especially in Central and Eastern Europe (mainly due to low fertility rates) and southern Africa (due to the high number of human immunodeficiency virus (HIV) related deaths). Currently at 6.6 billion people, the total global population is expected to rise to nearly 9 billion people by 2050; Asia's population of around 60 percent of the world's population is unlikely to change, while Africa's population is likely to increase by 5 percent to over 20 percent of the world's population, mainly at the expense of Europe (Table 1).

TABLE 1
Global population forecasts

Year	World	Africa	Asia	Europe	Latin America	North America	Oceania
2010	6 830 283 000 (100%)	984 225 000 (14.4%)	4 148 948 000 (60.7%)	719 714 000 (10.5%)	594 436 000 (8.7%)	348 139 000 (5.1%)	34 821 000 (0.5%)
2015	7 197 247 000 (100%)	1 084 540 000 (15.1%)	4 370 522 000 (60.7%)	713 402 000 (9.9%)	628 260 000 (8.7%)	363 953 000 (5.1%)	36 569 000 (0.5%)
2020	7 540 237 000 (100%)	1 187 584 000 (15.7%)	4 570 131 000 (60.6%)	705 410 000 (9.4%)	659 248 000 (8.7%)	379 589 000 (5.0%)	38 275 000 (0.5%)
2025	7 851 455 000 (100%)	1 292 085 000 (16.5%)	4 742 232 000 (60.4%)	696 036 000 (8.9%)	686 857 000 (8.7%)	394 312 000 (5.0%)	39 933 000 (0.5%)
2030	8 130 149 000 (100%)	1 398 004 000 (17.2%)	4 886 647 000 (60.1%)	685 440 000 (8.4%)	711 058 000 (8.7%)	407 532 000 (5.0%)	41 468 000 (0.5%)
2035	8 378 184 000 (100%)	1 504 179 000 (18.0%)	5 006 700 000 (59.8%)	673 638 000 (8.0%)	731 591 000 (8.7%)	419 273 000 (5.0%)	42 803 000 (0.5%)
2040	8 593 591 000 (100%)	1 608 329 000 (18.7%)	5 103 021 000 (59.4%)	660 645 000 (8.0%)	747 953 000 (8.7%)	429 706 000 (5.0%)	43 938 000 (0.5%)
2045	8 774 394 000 (100%)	1 708 407 000 (19.5%)	5 175 311 000 (59.0%)	646 630 000 (7.4%)	759 955 000 (8.7%)	439 163 000 (5.0%)	44 929 000 (0.5%)
2050	8 918 724 000 (100%)	1 803 298 000 (20.2%)	5 217 202 000 (58.5%)	653 323 000 (7.3%)	767 685 000 (8.6%)	447 931 000 (5.0%)	45 815 000 (0.5%)

Source: The 2004 Revision Population Database (http://esa.un.org/unpp/)

Within the next decade, Japan and some countries in western Europe are also expected to encounter negative population growth due to sub-replacement fertility rates. Over the last ten years, the UN had consistently revised these projections downward, until the 2006 revision issued March 14, 2007, revised the 2050 mid-range estimate upwards by 273 million people.

2.2.2 Per capita food consumption

Global consumption of fish as food has doubled since 1973, and the developing world has been responsible for over 90 percent of this growth. The Food and Agriculture Organization of the United Nations (FAO) reports that while growth of fish consumption as food in the relatively richer countries has tapered off, food-fish consumption in the poorer countries has grown rapidly (Ye, 1999). In particular, the consumption of freshwater fish has grown massively in recent decades, primarily in East Asia. Large increases have also occurred in the consumption of crustaceans and non-cephalopod molluscs such as oysters and clams. In both cases, this growth in consumption has been matched by an equally rapid growth in production from aquaculture, primarily but not exclusively within Asia (Delgado *et al.*, 2003).

It has been shown that animal product consumption grows fastest in countries with rapid population growth, rapid income growth and urbanization, which is reflected

TABLE 2
Global per capita seafood consumption (historical and predicted)

Regions	Historical per capita fish consumption (kg/person/year)							Forecasted		Increase 1995–2030	
	1965	1970	1975	1980	1985	1990	1995	2015	2030	%	kg
Africa	4.8	5.6	6.3	7.2	6.9	7.6	7.4	10.5	14.8	98.4	7.3
Asia	8.5	9.2	10.2	9.7	11.2	13.0	17.9	20.1	24.1	34.7	6.2
Europe	17.4	19.6	21.1	20.1	22.7	21.7	16.8	26.3	30.8	83.0	14.0
Latin America	5.7	6.7	7.3	9.1	8.4	9.4	9.5	10.7	14.2	49.0	4.7
North America	12.8	14.4	14.0	15.5	19.4	21.4	21.6	30.0	35.5	64.0	13.9
Oceana	14.3	15.0	15.2	17.0	19.9	20.9	19.5	27.5	33.2	70.6	13.7
Global Average	**9.9**	**10.8**	**11.6**	**11.4**	**12.6**	**13.6**	**15.6**	**18.7**	**22.5**	**44.3**	**6.9**

Source: Ye (1999)

in the rapidly increasing consumption of fish in some developing countries, especially China. Delgado *et al.* (2003) consider that aggregate consumption trends largely mirror production trends in terms of composition and region of production, except that annual rates of growth of consumption in developing countries outstrip rates of growth of production by 0.2 percent per annum and are expected to continue to do so through 2020 (0.3 percent, excluding China), suggesting decreasing net exports of foodfish from developing to developed countries.

2.2.3 Supply from capture fisheries and aquaculture

According to FAO's "The state of world fisheries and aquaculture" (FAO, 2005c), total global fish production (capture fisheries plus aquaculture) might increase to 146 million tonnes by the year 2010 from 131 million tonnes in 2000 and then to 179 million tonnes by the year 2015 (Table 3). This means that growth in global fish production is projected to decline from the annual rate of 2.7 percent during the last decade (1990-2000) to 2.1 percent per year between 2000 and 2010 and to 1.6 percent per year between 2010 and 2015. Global capture production is projected to stagnate, while global aquaculture production is projected to increase substantially, albeit at a slower rate than in the past. Out of the expected increase of 48 million tonnes in total global fish production from 1999/2001 to 2015, 73 percent would come from aquaculture, which is projected to account for 39 percent of global fish production in 2015 (up from 27.5 percent in 1999/2001).

2.2.4 Regional outlook for aquaculture development

- **Asia:** Marine and brackishwater aquaculture in Asia is likely to grow at a faster rate than freshwater aquaculture, possibly due to a growing shortage of suitable freshwater sites and declining quality and availability of freshwater (De Silva and Turchini, 2009). This shift from freshwater to brackishwater aquaculture implies an intensification of brackishwater aquaculture production as well as a greater proportion of seafood output being directed towards regional urban centres and international markets, a trend that is being reinforced by rapid globalization and a reduction in import tariff structures. This in turn indicates a movement towards production of high-value finfish and crustaceans, thus increasing the region's demand for fishmeal and fish oil. This has potential consequences for the existing small-scale farmers in the region and how they adapt to the new technologies and processes involved.
- **Europe:** Aquaculture is now a maturing industry in Europe, especially for the established species such as salmon and trout. Past sectoral growth has been driven

TABLE 3

Predicted production from capture fisheries and aquaculture (million tonnes)

Year	2000	2004	2010	2015	2020	2030
Information source	FAO statistics[a]	FAO statistics[b]	SOFIA 2004[c]	FAO study[d]	SOFIA 2004[c]	SOFIA 2004[c]
Capture fisheries	95	96	93	105	*93*	*93*
Marine capture	86	87	87		87	87
Inland capture	9	9	6		6	6
Aquaculture	36	45	53	74	70	83
Total production	**131**	**141**	**146**	**179**	**163**	**176**
Foodfish production	96 (73%)		120 (82%)		138 (85%)	150 (85%)
Non-food use	35 (27%)		26 (18%)		26 (15%)	26 (15%)

Source: [a]FAO (2002); [b]FAO (2006a); [c]FAO (2005c); [d]FAO (2004a)

TABLE 4

Regional share of total food-fish production, 1973–1997 (actual) and 2020 (projected)

Region	Actual annual production (%)			Projected (%)
	1973	1985	1997	2020
EU-15	13	9	6	5
Eastern Europe and former USSR	17	14	5	4
China	10	13	36	41
Other Asia	17	19	21	21
Latin America	5	6	7	7
West Asia and northern Africa	1	2	2	2
Sub-Saharan Africa	4	4	4	5
United States of America	4	6	5	4
Japan	17	1	6	4
Others	12	13	8	7
Total	**100**	**100**	**100**	**100**

Source: Delgado *et al.* (2002)

by the development of breeding and grow-out technologies for new species and their adoption by the commercial sector. Salmonid production showed a steady increase until 2003 and more or less steady growth to date. Production of other species, especially seabass and seabream, continues to expand as more eastern Mediterranean countries adopt the technology and as prices recover from a slump in 2002–2003. Future growth is unlikely to reflect historical trends, with a 10–15 percent increase from 2005 to 2015 considered realistic (Brugère and Ridler, 2004; Huntington, 2009). Much of this growth will be from marine species such as cod and halibut, as well as from expansion of Mediterranean seabass and seabream farming. The main constraint to European aquaculture will be the lack of suitable sites for sustainable development. Other factors are competition from lower cost centres and access to fishmeal supplies in the face of increased competition from Asia.

- **Americas**: Various studies indicate that the future outlook and potential for growth for the aquaculture industry within the region is bright (Masser and Bridger, 2006; Rojas, Simonsen and Wadsworth, 2006; Flores-Nava, 2007), especially for the continued growth of cage culture for salmonids and warmwater species such as red drum (*Sciaenops ocellatus*), mahi mahi (*Coryphaena equiselis*, also known as pompano dolphinfish) and cobia (*Rachycentron canadum*). As elsewhere, there are concerns over the expansion of high-value species, and conclusions were drawn that increased aquaculture production and availability of low-grade foodfish may have potential roles in improving food security in the region (Tacon, 2009).

- **Africa:** Food insecurity remains a serious problem in the developing world, particularly in Africa (Hecht and Jones, 2009). There have been many attempts to promote aquaculture as a means to address poverty and food security in Africa, although with limited success. The potential of aquaculture in Africa was once described as a sleeping giant (New, 1991b), and it has been predicted that the developing world is where the bulk of aquaculture production will come from in the future (New, 1991a; Hecht, 2000). The growth of the industry in Africa and the Near East over the last ten years is testimony to this potential (see also Aguilar-Manjarrez and Nath, 1998). On the basis of several assumptions, Hecht (2006) made some projections for the growth of the sector in sub-Saharan Africa and suggested that by 2013 total fish production would be somewhere between 200 000 and 380 000 tonnes per annum. The outlook in North Africa differs from that of sub-Saharan Africa and the Near East largely due to the impact that Egypt has in the region. Aquaculture in Egypt has already doubled approximately seven times in the last decade, and Egypt is currently ranked the twelfth largest aquaculture-producing country in the world (El-Sayed, 2007). Although there are no projections for North Africa or the Near East, both El-Sayed (2007) in his review of Egypt and Poynton (2006) in her regional review of North Africa and the Near East predicted continued and sustained growth of aquaculture in those regions.

3. USE OF FISH AND OTHER AQUATIC SPECIES AS FEED FOR FISH AND LIVESTOCK

A captured fish, either in its basic form or once it has been reduced to fishmeal, provides an important protein and oil source for most fish and animal culture. Its unique amino acid profile, high digestibility and oil content have led to its use in most carnivorous fish diets, as well as in poultry, ruminant and pig farming. The following section provides an overview of the main species utilized, the forms in which they are used and the main end users.

There are three principle ways in which fish are utilized in feeds:

- **As fishmeal and fish oil** – mainly derived from the reduction of whole small pelagic fish to a concentrated high protein form/oil that is used in formulating compounded feeds. These are known as "directed feed fisheries".
- **As processing or other waste** – fishmeal can be produced from fish processing waste (trimmings, offcuts and offal). In some countries, landed bycatch may be channeled into fishmeal production.
- **As whole fish** – usually in the form of trash fish[2], either used directly or mixed as a slurry or mash. Frozen whole pelagic fish are also used for fattening tuna and other large fish in cages.

3.1 Landings of fish and other aquatic species destined for reduction

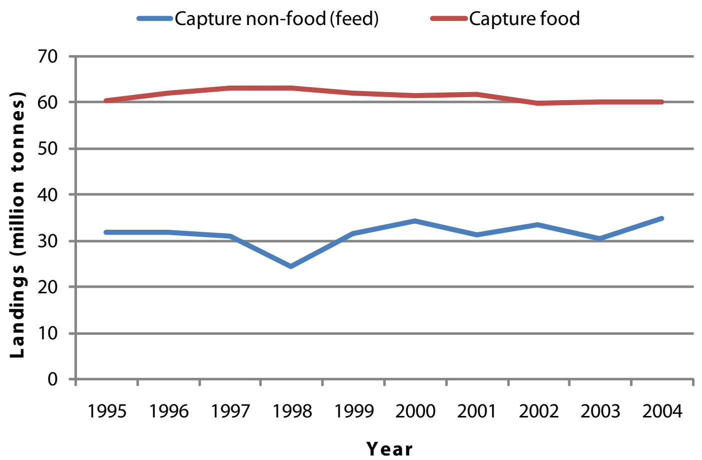
Although total global fish and shellfish landings from capture fisheries were 95 million tonnes in 2004, over 34.8 million tonnes or 36.6 percent was destined for non-food uses and reduction into fishmeal and fish oil and/or for direct animal feeding. The bulk of these landings were in the form of lower-value (in marketing terms) small pelagic oily fish species, including anchovies, herring, capelin, sardines, pilchards, mackerel, sand eels, menhaden and under-sized commercial food-fish species (Figure 6).

[2] Fish with little or no commercial value and not sorted by species before landing, often part of the trawlers' bycatch.

3.1.1 Fish species reduced for fishmeal and fish oil

Some fish and other aquatic species are specifically targeted for their reduction into fishmeal and fish oil. These species tend to be those pelagic species with a high oil content, small in size (that makes them easy to reduce) and available in large biomass shoals for easy capture on a large scale. The main species used are characterized by early maturation and high fecundity. Their populations respond quickly and strongly to changes in environmental conditions, which increases the uncertainty of stock forecasts, especially in eastern Pacific waters that are vulnerable to the "El Niño" effect.

FIGURE 6
Global capture food and non-food (feed) fish production, 1995–2004



Source: FAO (2006a)

- **European aquaculture:** The main species used for fishmeal reduction from European stocks are capelin (*Mallotus villosus*), blue whiting (*Micromesistius poutassou*), small sand eel (*Ammodytes tobianus*), and to a lesser extent, Norway pout (*Trisopterus esmarki*). Landings of these species by the various European countries are shown in Table 5. European aquaculture mostly (around 35 percent) sources fishmeal from European feed fisheries. Peruvian anchovy (*Engraulis ringens*) and Chilean jack mackerel (*Trachurus murphyi*) (around 20 percent of European feed-fish use) are both imported from South America for use in European fish feed, and Poland and Ukraine both use Antarctic krill as a fishmeal source. The balance of fishmeal is derived from processing wastes. The volume of European feedfish being used in aquaculture is likely to remain static despite the anticipated increase in aquaculture production (see Section 2.2.4), with increasing proportions of South American meal and greater substitution with plant-based protein alternatives.
- **American aquaculture:** Aquaculture in the Americas depends mainly upon the small pelagic fisheries in the eastern Pacific Ocean (Tacon, 2009), where the main fish species used are Peruvian anchovy and Chilean jack mackerel (Table 6). With this abundance in feed fisheries, over 9.9 million tonnes or 47.2 percent of total finfish and shellfish landings from capture fisheries (21.0 million tonnes in 2003) was destined for reduction and other non-food uses. In addition, some other fish species (either from by-products or whole) are destined for reduction, including Alaska pollock (*Theragra chalcogramma*) (with total reported landings of 1 522 860 tonnes in 2004), Argentine hake (*Merluccius hubbsi*) (467 748 tonnes), and southern blue whiting (*Micromesistius australis*) (92 83 tonnes).
- **African and Near East aquaculture:** Information on fish species used for African fishmeal and fish oil production is less certain (Hecht and Jones, 2009). In contrast to Europe and in the Americas, most small pelagic fish production is destined for human consumption, with only South Africa having a dedicated feed fishery. The main fisheries are those in Morocco (landings in 2004 of 653 474 tonnes, mainly consisting of the European pilchard (*Sardina pilchardus*), sardines (*Sardinella* spp.) and European anchovy (*Engraulis encrasicolus*) while South Africa's small pelagic fish catch of 611 159 tonnes mainly consisted of southern African pilchard

TABLE 5

Landings of European feed-fish species, 2004 tonnes

Country	Primarily (>70%) feed fisheries						Mixed feed and food fisheries						
	Blue whiting	Capelin	Sand eel	Norway pout	Antarctic krill	*Subtotal*	Atlantic herring	Sprat	European pilchard	Horse mackerel	European anchovy	*Subtotal*	Total
	Approximate proportion used for fishmeal						Approximate proportion used for fishmeal						
	>95%	c. 95%	100%	100%	c. 70%		<30%	<50%	c. 50%	<20%	n/a*		
Bulgaria						–		2 889			88	***2 977***	**2 977**
Croatia						–			16 357		5 044	***21 401***	**21 401**
Denmark	89 500		299 606	13 646		***402 752***	136 809	274 129		23 955	6 936	***441 829***	**844 581**
Estonia						–	27 358	37 306				***64 664***	**64 664**
Faeroes	322 322	33 078	3 476	1 159		***360 035***	50 106			3 867		***53 973***	**414 008**
Finland						–	71 214	16 588				***87 802***	**87 802**
France	19 476		162			***19 638***	36 558	195	31 450	12 828	16 215	***97 246***	**116 884**
Germany	15 293		2 658	107		***18 058***	70 586	26 353	1 398	22 938		***121 275***	**139 333**
Greece						–		138	9 217	609	13 404	***23 368***	**23 368**
Iceland	422 079	524 516				***946 595***	224 580					***224 580***	**1 171 175**
Ireland	75 393					***75 393***	26 234	4 096	13 000	26 432		***69 762***	**145 155**
Italy						–					58 261	***58 261***	**58 261**
Latvia						–	23 559	52 399				***75 958***	**75 958**
Lithuania						–	1 845	6 185			13 774	***21 804***	**21 804**
Netherlands	95 311					***95 311***	129 643	118	46 770	66 678	3	***243 212***	**338 523**
Norway	957 684	49 009	48 667	7 498		***1 062 858***	616 221	1 526		10 747		***628 494***	**1 691 352**
Poland	345		1		8 967	***9 313***	27 914	95 798				***123 712***	**133 025**
Portugal	3 973					***3 973***			75 928	20 761	664	***97 353***	**101 326**
Romania						–		1 350			135	***1 485***	**1 485**
Russian Federation	346 762	1 757			775	***349 294***	123 242	39 433	7 851		14 873	***185 399***	**534 693**
Spain	29 021	10	24			***29 055***		1	64 353		20 615	***84 969***	**114 024**
Sweden	19 083		34 607	88		***53 778***	89 032	90 724	56	800		***180 612***	**234 390**
United Kingdom	57 028		595	13		***57 636***	96 298	3 883	2 682	12 244		***115 107***	**172 743**
Ukraine					12 261	***12 261***		30 894	28 053		9 383	***68 330***	**80 591**
Total	**2 453 270**	**608 370**	**389 796**	**22 511**	**22 003**	***3 495 950***	**1 751 199**	**684 005**	**297 115**	**201 859**	**159 395**	***3 093 573***	**6 589 523**

*not available

Source: FAO (2006a); Huntington (2009)

TABLE 6

Landings of capture fisheries in the Americas destined mainly for reduction

Species	2004 landings		Fishery
	Tonnes	Percent (%)	
Peruvian anchovy/anchoveta (*Engraulis ringens*)	10 679 338	65.8	Peru 82.5%, Chile 17.4%, Ecuador 0.1%
Chilean jack mackerel/inca scad (*Trachurus murphyi*)	1 638 530	10.1	Chile 88.6%, Peru 11.4%
Chub mackerel (*Scomber japonicus*)	730 427	4.5	Chile 79.0%, Peru 8.5%, Ecuador 7.1%, Mexico 3.6%
California pilchard/South American pilchard (*Sardinops sagax*)	683 560	4.2	Mexico 86.9%, United States of America 13.1%,
Jumbo flying squid (*Dosidicus gigas*)	555 764	3.4	Peru 48.6%, Chile 31.5%, Mexico 19.8%
Gulf menhaden (*Brevootia patronus*)	464 148	2.9	United States of America c. 100%
Araucanian herring (*Strangomera bentincki*)	356 090	2.2	Chile 100%
Atlantic herring (*Clupea harengus harengus*)	268 690	1.7	Canada 68.1%, United States of America 30.3%
Atlantic menhaden (*Brevoortia tyrannus*)	215 163	1.3	United States of America c. 100%
Round sardinella (*Sardinella aurita*)	142 982	0.9	Venezuela (Bov. Rep. of) 99.2%
Atlantic mackerel (*Scomber scombrus*)	107 682	0.7	United States of America 50%, Canada 50%
Pacific anchoveta (*Cetengraulis mysticetus*)	73 203	0.5	Panama 64.2%, Colombia 28.9%
Pacific herring (*Clupea pallasi pallasi*)	57 981	0.4	United States of America 58.9%, Canada 41.1%
Pacific thread herring (*Opisthonema libertate*)	54 105	0.3	Panama 84.1%, Ecuador 15.9%
Brazilian sardinella (*Sardinella janeiro*)	53 421	0.3	Brazil 100%
Capelin (*Mallotus villosus*)	52 351	0.3	Canada 69.1%, Greenland 30.9%
Atka mackerel (*Pleurogrammus monopterygius*)	49 508	0.3	United States of America 100%
Argentine anchovy (*Engraulis anchoita*)	39 367	0.2	Argentine 94.7%
Total	**16 222 310**	**100**	

Source: Tacon (2009)

(*Sardinops sagax*), southern African anchovy (*Engraulis capensis*) and Whitehead's round herring (*Etrumeus whiteheadi*) (Table 7). The proportion destined for reduction rather than human consumption in African and Near East fisheries is difficult to state exactly, but by way of example around 10 percent of Namibia`s 2004 horse mackerel (*Trachurus trachurus*) catch was reduced to fishmeal (Van Zyl, 2001). In 2004, the total recorded sliver cyprinid (*Rastrineobola argentea*, locally known as "dagaa"*)* catch was 31 659 tonnes (FAO, 2006b), suggesting that between 15 800 to 20 500 tonnes of fish were reduced to fishmeal. In Ghana up to half the anchovy catch, which equates to approximately 26 000 tonnes of anchovy is reduced to fishmeal annually (Directorate of Fisheries, Ghana, 2003),

- **Asian aquaculture:** In contrast to elsewhere, Asian aquaculture depends mainly upon trash fish/low-value fish. There are some targeted feed fisheries in Asia, notably in China and Japan, but these are declining in the face of dwindling stocks. For instance, there is an installed capacity of 1.5 million tonnes of fishmeal production in China, yet two-thirds of this capacity lies idle as a result of the declining jack mackerel catches and the increasing use of sardine for fresh

TABLE 7

Small pelagic landings for Africa and the Near East, 2000–2004

Country	2000	2001	2002	2003	2004	5-year average
Morocco	562 684	812 551	707 874	677 635	653 474	682 844
South Africa	441 650	534 680	528 950	591 399	611 159	541 568
Senegal	250 715	244 754	210 692	281 723	276 340	252 845
Ghana	223 624	166 173	139 668	183 069	166 674	175 842
Nigeria	108 620	92 907	93 519	100 676	97 070	98 558
Algeria	76 405	99 873	100 750	100 372	99 600	95 400
Other (Africa) *	450 075	397 836	408 229	404 570	453 815	422 905
Other (Near East)*	81 595	97 624	76 739	71 127	81 396	81 696
Total	**2 195 368**	**2 446 398**	**2 266 421**	**2 410 571**	**2 439 528**	**2 351 658**

*Other Africa (23 countries); other Near East (9 countries)
Source: FAO (2006a); Hecht and Jones (2009)

aquaculture feeds (GAIN Report, 2004). Trash and other low-value fish are also converted into fishmeal – in Viet Nam it is purported that there is a specialized fleet for trash fish, and a total of 300 000 to 600 000 tonnes of trash fish/low-value fish are landed, of which about 280 000 tonnes are utilized by the fishmeal plants with a yield of 0.29 (fish: fishmeal conversion efficiency = 3.45:1.00) (Dao, Dang and Huynh Nguyen, 2005). On the other hand, Edwards, Le and Allan (2004) estimated the trash fish landings in Viet Nam to be 933 182 tonnes in 2001, valued at VND1 390 416 million (US$99 315 428). The commercial landings of trash fish/low-value fish in Viet Nam vary depending on the locality, season, species composition and demand. Trash fish/low-value fish are used for fishmeal production, fish powder production and direct feeding to cultured fish stocks (De Silva and Turchini, 2009).

3.1.2 Processing wastes

The processing of fish frequently gives rise to waste in the form of fish frames (e.g. skeletons), offal, trimmings and offcuts. These wastes can be utilized for the preparation of fishmeal and fish oil. Some of these byproducts such as livers, gonads (roes) and heads are to a certain degree recovered and processed for human consumption. There are no global estimates of fish waste generation and use in fishmeal production. In Europe, trimmings from other fisheries represent around 33 percent of the total supply of raw material to the fishmeal and fish oil industry (IFFO, 2002). It is estimated that 80 percent of the trimmings from fish processing enter the fishmeal and fish oil industry in Denmark, while only 10 percent of trimmings enter the industry in Spain. In the United Kingdom, Germany and France, between 33 and 50 percent of fish trimmings enter the fishmeal and fish oil industry (Table 8).

The dependence of the United Kingdom and Germany on whitefish trimmings has fallen. This is in response to a decline in whitefish supplies. In contrast, a greater proportion of supplies are now derived from pelagic trimmings, because this raw material supply is healthy. Salmon also increasingly provides an added source of supply to fishmeal plants in the United Kingdom, but this fishmeal made from salmon can no longer be allowed to re-enter the food chain though use in aquaculture. The introduction of a number of animal by-products regulations[3] by the European Commission (EC), together with the feed industry's own initiatives, have constrained the use of fishmeal and fish-derived waste in both aquaculture and agriculture feeds as a result of concerns over the cross-species transmission of pathogens.

TABLE 8

Raw material sources for fishmeal and fish oil in the European Union (EU-15), 2002

Country	Feedfish (tonnes)	Trimmings (tonnes)	Proportion of trimmings (%)
Denmark	332 000	33 200	10
United Kingdom	7 800	42 500	84
Spain		42 000	100
Sweden	18 750	6 250	25
France		25 000	100
Ireland	8 800	13 200	60
Germany		17 000	100
Italy		3 000	100
Total	**367 350**	**182 150**	**33**

Source: IFFO (2002)

3.1.3 Trash fish and other fishery by-products

In Asia in particular, trash fish or low-value fish are the main source of fish for use in aquaculture. They are fed directly to fish in the form of a slurry or mash and are distinct from the trash fish that are first converted into fishmeal.

Direct estimates of trash fish/low-value fish usage in aquaculture, either directly and/or indirectly, are available only for Australia and Viet Nam. In the case of Viet Nam, it was estimated that use of trash fish/low-value fish in inland aquaculture ranged from 64 800 to 180 000 tonnes and in coastal aquaculture from 71 820 to 143 640 tonnes, and the total amount used in aquaculture in Viet Nam to be between 176 420 and 323 640 tonnes (Edwards, Le and Allan, 2004). The latter figures amount to approximately 22 percent of all trash fish/low-value fish production in Viet Nam. The main bulk of trash fish/low-value fish is used for production of fish sauce (Dao, Dang and Huynh Nguyen, 2005). While anchovy is preferred for fish sauce production, it is less popular for cage aquaculture, as it is difficult to store on ice because the flesh is very soft and breaks down readily. Thus there is limited competition between fish sauce production and cage culture in the Mekong Delta. In a recent survey conducted in central Viet Nam (Phuc, 2007), the main reasons fish farmers choose to use trash fish for aquaculture were low cost (77 percent of total households interviewed), ease of purchase (31 percent), fast animal growth (62 percent) and lack of alternative feeds (31 percent).

The Australian southern blue fin tuna (*Thunnus maccoyii*) fattening farming, based on the on-growing of wild-caught young, is totally dependent on low-value/trash fish as the sole feed source. In 2003, 5 409 tonnes of wild-caught tuna (average weight 15 to 30 kg) were fattened to 9 102 tonnes over a period of three to five months, fed solely on pilchard and mackerel (EconSearch Pty Ltd, 2004). The approximate increase of 4 000 tonnes to fattened weight required 50 000 to 60 000 tonnes of imported feed – in this instance trash fish/low-value fish (Allan, 2004), which is at best a food conversion ratio of 12.5:1.

Estimations on projected needs of trash fish/low-value fish by the Asia-Pacific region in the year 2010 suggest that the main growth phase of the mariculture sector has already occurred and that most suitable areas for small-scale farming are already utilized. In addition, the advances in seed production technologies have not progressed

[3] EC Disposal, Processing and Placing on the Market of Animal By-products Regulations (SI 257, 1994); EC Regulation No. 1774/2002 of the European Parliament and of the Council of 3 October 2002 lay down health rules concerning animal by-products not intended for human consumption (recently amended by Commission Regulation (EC) No. 808/2003 of 12 May 2003); and the Commission Regulation (EC) No. 811/2003 on the intra-species recycling ban for fish.

as expected, with, for example, a survival rate for grouper species that is at best, only 3 to 5 percent (Rimmer, McBride and Williams, 2004). De Silva and Turchini (2009) suggest that trash/lower-value fish usage in aquaculture may almost halve by 2010 as there is a shift over to more intensive aquaculture and a greater dependence upon formulated feeds. This has implications for both the fate of trash/low-value fish and an increased demand for fishmeal, largely from South American sources, unless there is a significant substitution with plant-based protein alternatives.

3.2 Fishmeal and fish oil production and trade

3.2.1 Production

Fishmeal is produced by cooking the fish, pressing them to remove water and body oil, and finally drying them at temperatures of between 70 and 100 °C, depending upon the meal type being manufactured. After extraction from the fish, fish oils are purified through centrifugation and represent around 5–6 percent of the total raw material body weight.

Worldwide, annual production of about 400 dedicated fishmeal plants is about 6.3 million tonnes (it has fluctuated between 5.9 and 6.2 million tonnes over the last five years) of fishmeal and 1 million tonnes of oil from about 33 million tonnes of whole fish and trimmings (FIN, 2007). The main producing countries in 2005 were Peru, Chile, China, Thailand, United States of America, Japan and Denmark (see Table 9). South America provides the bulk (37 percent) of the global landings (21.5 million tonnes) destined for fishmeal and fish oil; the Far East and Southeast Asia, which provide 27 and 12 percent, respectively, are also major sources of raw material. In Europe, Denmark, Iceland and Norway are all significant suppliers, each providing around 5 percent of the global supply. The South American supply mostly consists of anchovy (35 percent of the global supply), while capelin (6 percent of global supply) is the main constituent of European supplies. Sand eel is used for around 4 percent of the global supply and is the main EU feed fishery, largely from the Danish fleet.

Fish oils are largely a by-product of fishmeal production, with global supply at around 1 million tonnes per annum, mainly supplied by Peru and Chile (47 percent) and the EU (16 percent).

TABLE 9

Fishmeal production by country, 1996–2005 (thousands tonnes)

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Peru	1 972	1 741	815	1 904	2 309	1 844	1 941	1 251	1 983	2 019
Chile	1 376	1 195	642	957	842	699	839	664	933	794
Thailand	382	386	410	398	387	381	387	397	403	410
China	359	534	693	707	806	723	460	420	400	305
United States of America	329	394	294	355	335	342	337	318	353	268
Japan	406	363	379	409	387	227	225	230	295	230
Denmark	297	341	324	311	318	299	311	246	259	213
Iceland	265	279	220	234	272	286	304	279	204	188
Norway	214	253	301	241	264	216	241	212	215	154
South Africa	65	55	94	84	109	111	93	113	114	108
Ecuador	110	44	72	51	78	89	59	79	85	87
Morocco	75	70	55	59	53	55	61	64	63	66
Russian Federation	207	177	163	155	126	98	95	68	70	60
Mexico	68	63	45	48	65	61	65	65	55	55
United Kingdom	55	51	52	53	50	47	48	52	51	53

Source: FIN (2007)

3.2.2 Imports

With global fishmeal production being dominated by South American feed fisheries, most aquaculture producers are net importers. China is the largest consumer of fish oil, while Chile and Norway use the majority of fishmeal, largely for salmon feed. As can be seen in Table 10, Asia's imports are almost double its current production of fishmeal. While improvements in regional fishmeal processing capacity and efficiency may result in some increase in production, the anticipated expansion of more intensive aquaculture will inevitably result in a greater regional dependency on imports.

TABLE 10

Fishmeal production in the Asia-Pacific region

Country	Year	Production (tonnes)	No. of plants	Imports (tonnes)
China	2005	300 000	n/a	1 580 000
Taiwan Province of China	2005	16 100	n/a	220 976
India	2004	182 000	18	20 000–25 000
Myanmar	2005	12 610	14	n/a
Japan	2004	195 000	n/a	402 000
Republic of Korea	2005	45 000	n/a	n/a
Thailand	2004	403 000	95	4 800
Viet Nam	2004	80 000	15–20	82 000
Total		**1 233 710**		**2 312 276**

n/a: not available

Source: De Silva and Turchini (2009) except for fishmeal production and import data of India which has been obtained from Ayyappan and Ahamad Ali (2007)

Europe too is a net importer of fish meal (~1.6 million tonnes) and fish oil (~240 000 tonnes), although this is a rather simplistic interpretation, as there are significant international product flows based on product specification and price. Norway imports almost half of total European exports and 52 percent of its requeriments. The United Kingdom is the largest importer of fishmeal, for which Iceland (22 percent), Norway (16 percent) and Denmark (12 percent) are the main European sources, and imports represent around three-quarters of all fishmeal requeriments. South American fishmeal currently accounts for around 19 percent of the United Kingdom's imports, but the amount can vary from year to year and may occasionally increase to around 30 percent. Norway and Denmark are major European fishmeal producers but also import 64 percent and 41 percent, respectively, of their fishmeal needs. Total fishmeal imports and consumption are known to have fallen markedly in 2003 and 2004 and are down 18 percent from the preceding years. This is a result of the ban on the use of fishmeal in ruminant feed.

3.2.3 Exports

Not surprisingly, the Americas (with the exception of Canada) are net exporters of fishmeal (Tacon, 2009). Peru essentially exports all its production, as it is only a minor consumer. In contrast Chile, while still a net exporter of fishmeal, has now emerged as a major importer of fish oil, second only to Norway in terms of total imports. In addition to consumption of domestically produced fish oil, Chile also imports fish oil mainly from Peru to meet the demands of its rapidly growing salmonid aquaculture industry (FAO, 2006a; Mittaine, 2006; Tacon, Hasan and Subasinghe, 2006).

3.3 Utilization of fishmeal and fish oil by aquaculture and other food-producing industries

3.3.1 Overview

Fishmeal is an important nutritional input into feeds for both fish and terrestrial livestock. Fishmeal is fed to farm animals not only to improve productivity but also to protect health and welfare and reduce dependence on antibiotics and other drugs, as it has both low antigenicity (making it easy for young animals to digest) and anti-inflammatory properties that improve disease resistance.

Aquaculture is the largest overall user of fishmeal, currently accounting for around 46 percent of global use. Pigs and poultry farming account for around a quarter of total usage, with the remainder consumed by other types of livestock (figure 7). Ruminants now account for only 1 percent, and this is likely to drop further because of persistent fears that fishmeal could be accidentally or deliberately adulterated with (banned in the EC) meat meal and bone meal (MMBM).

Although fishmeal and fish oil are shipped all over the world, three major regions are large users: Asia (particularly China, Japan and Taiwan POC); Europe (particularly Norway, the United Kingdom and Denmark); and the Americas (particularly the United States of America, Canada and Chile).

In Asia, which is a major fishmeal consumer but a minor consumer of fish oil, fishmeal usage is largely led by finfish and crustacean aquaculture. In China, large quantities of fishmeal are incorporated into "concentrate" pre-mixes for poultry and pigs.

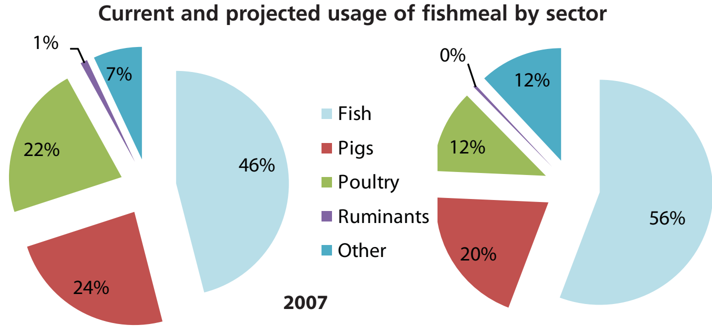
In Europe, over half of fishmeal usage is now for aquaculture. Both fishmeal and fish oil are used in large quantities by the salmon industry, particularly in Norway and Scotland. The development of marine aquaculture (seabass, seabream, etc.) in southern Europe, particularly in Greece, Spain and Turkey, has led to important flows of fishmeal to these countries.

In the Americas, fishmeal and fish oil are widely used by the salmon aquaculture industry in Chile, Canada and the United States of America. Fishmeal production in the United States of America traditionally uses the menhaden resource (Tacon, 2009).

It is estimated that in 2004 the global finfish and crustacean aquaculture sector consumed 3 452 000 tonnes of fishmeal (Figure 8a) or 52.3 percent of the total global fishmeal production of 6 604 229 tonnes in 2004, and 893 400 tonnes of fish oil (Figure 8b) or 82.2 percent of the total global fish oil production of 1 085 674 tonnes in 2004 (FAO, 2006a).

The total estimated global amount of fishmeal and fish oil used in compound aquafeeds has risen almost two-fold from 1995 to 2004, increasing from 1 728 000 to 3 452 000 tonnes in the case of fishmeal and from 494 000 to 893 000 tonnes in the case of fish oil.

FIGURE 7
Current and projected usage of fishmeal by sector



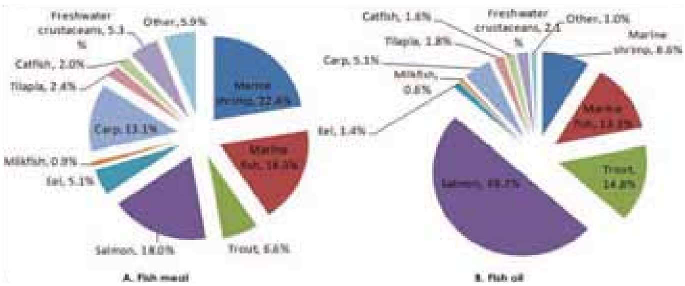
Source: FIN (2007)

3.3.2 Fishmeal

The preference for the use of fishmeal and fish oil in all forms of diet for cultured fish is based on a favourable amino acid profile providing all the essential amino acids, the availability of unknown growth factors and some micronutrients, easy digestibility, and availability of highly unsaturated fatty acids such as eicosapentaenoic acid (EPA) (20:5n-3), docosahexaenoic acid (DHA) (22:6n-3) and arachidonic acid (AA) (22:4n-6), all of which cannot be synthesized in adequate quantities by most cultured stocks, in particular marine finfish.

Salmon, marine shrimp and marine fish each currently consume around a fifth of the fishmeal used in aquaculture. Grower diets for salmon currently contain around 35 percent of fishmeal, while diets for marine shrimp and marine fish contain 22 and

FIGURE 8
Estimated use of fishmeal and fish oil in compounded aquafeeds by major cultured species, 2004



Source: Tacon (2006)

40 percent, respectively (Tacon, 2007), although these feeds vary highly in their protein and oil levels depending upon the species and life-cycle stage being fed. Starter diets are typically rich in protein and lower in oil than grower feeds. Smaller fish also have different nutritional requirements that may favour the use of a particular fishmeal such as the histidine-rich South American feeds. Carp diets have lower fishmeal inclusion rates of around 5 percent, but still account over 13 percent of the fishmeal used by aquaculture due to the high volumes of fish cultured.

Given a combination of the rising cost of fishmeal, the growing demand for a finite resource and growing concern over the "food miles" involved in transporting fishmeal around the world (Huntington, 2004), feed suppliers have focused on the potential to substitute fishmeal and fish oil with plant-based alternatives. However, the level of substitution possible is restricted by their lack of essential amino acids (such as lysine, methionine and histidine), which may limit growth at high substitution levels. Another issue is consumer opinion and the effect that this may have on the continued acceptance of farmed fish as a "high quality" product similar to its wild counterpart.

3.3.3 Fish oil

Fish oil is a proven energy source and, as well as providing essential fatty acids to farmed fish and crustaceans, it imparts to the final product with high levels of omega-3 fatty acids, increasingly sought by the consumer. Fish oil is an important component of salmon and trout feeds (25 percent and 17.5 percent, respectively), and nearly 65 percent of all fish oil used by aquaculture goes to these two species alone. Marine fish also require fish oils (around 7.5 percent), but cyprinids, tilapia, catfish and shrimp require lower amounts, typically 1–2 percent. To produce a product as "near to the wild product as possible", research is also focusing on the "dilution" of vegetable oils in the flesh when the fish are fed diets containing 100 percent marine fish oils for six months prior to harvest. In addition, vegetable oil substitutes do not necessarily improve the environmental sustainability of the product (e.g. increased soybean production may lead to further rainforest clearance).

3.3.4 Future trends

Projections concerning the future availability, price and use of fishmeal and fish oil vary widely depending upon the viewpoint and assumptions used (Shepherd, 2005; Tacon, 2005; Jackson, 2006; Tacon, Hasan and Subasinghe, 2006). For example, according to Tacon, Hasan and Subasinghe (2006), fishmeal and fish oil use in aquaculture is expected to decrease in the long run; assumptions used included rising prices due to limited supplies and increased demand, increasing competition for pelagics for direct human consumption and the desire on the part of consumers for sustainability and a concern for the state of the oceans. However, according to industry estimates, and in particular that of the International Fishmeal and Fish Oil Organisation (IFFO), fishmeal and fish oil use is expected to steadily increase, such that by 2012 aquaculture would use 60 percent of the global supply of fishmeal and 88 percent of the global supply of fish oil (Jackson, 2006).

3.3.5 Fishmeal and fish oil use in agriculture

The agriculture sector uses predominantly Peruvian and Icelandic fishmeal, with Moroccan and other minor sources making up the balance. With fishmeal and fish oil production predicted to remain stable over the next decade and the proportion being utilized by aquaculture increasing considerably, there is likely to be a fall in the proportion utilized by agriculture.

For most domestic animal species, fishmeal is included in animal diets as a feed supplement in order to increase the protein content of the diet and to provide essential minerals and vitamins. In general, fishmeal is considered an excellent protein source for all animal species, and fish is rich in amino acids, particularly lysine, cysteine, methionine and tryptophan, which are key limiting amino acids for growth and productivity in the major farmed species. Manipulation of protein quality during fishmeal production is important in the manufacture of specialist feed supplements. For example, low temperature (high digestibility and biological value, BV) products are used in diets for fish, young piglets and poultry, whereas products for ruminant diets are heated differently to reduce the breakdown of the protein by the rumen microflora and thus increase the content of rumen undegradable protein (RUP) and to reduce the soluble nitrogen content.

Typical inclusion rates for fishmeal in animal diets are around 2–10 percent for terrestrial animal species. Efficiencies of conversion of feed to live weight gain are usually quoted in terms of feed conversion ratio (FCR, units of weight gain per unit of feed consumed). In general, efficiencies of feed conversion are higher for fish at 30 percent compared with poultry, pigs and sheep at 18 percent, 13 percent and 2 percent, respectively (Asgard and Austreng, 1995). It is important to note, however, that with the lower inclusion rates of fishmeal in poultry and pig diets, production per kilogram of edible product from these species requires less fishmeal than for fish products.

- **The use of fishmeal in ruminant diets[4]:** Although sheep and cattle diets are predominantly forage-based, there is increased use of concentrate diets and supplements at times of increased productivity, such as during pregnancy, lactation and rapid growth. The use of fishmeal in these situations has considerable advantages over other protein sources such as soybean meal and bone meal in supplying RUP at times when metabolizable protein requirements may be greater than can be supplied by microbial protein synthesis and forage RUP.
- **The use of fishmeal in diets of non-ruminants:** Fishmeal use in pig diets accounts for approximately 20 percent of total fishmeal use, and fishmeal is recognized as a key protein source with a good balance of essential amino acids. Pigs fed diets containing fishmeal show improved feed conversion efficiencies and generally produce leaner carcasses (Wood *et al.*, 1999). The protein is well tolerated in pigs of all ages and has a high digestibility. As with fishmeal used in ruminant diets, however, processing has a significant impact on protein quality in pig diets. Excessive heat treatment results in a significant reduction in digestibility and biological value, due mainly to loss of lysine, a key limiting amino acid in growing pigs. One major environmental benefit in the use of fishmeal in pig diets is that the high digestibility of the added protein results in an improved efficiency of dietary protein use with a concomitant reduction in the production of high N-containing effluent.

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[4] Currently, the inclusion of fishmeal and fishmeal products in feed for ruminants is banned under EU legislation as a consequence of the bovine spongiform encephalopathy (BSE) crisis. While there is no inherent risk of the transfer of transmissible spongiform encephalopathies (TSE) via fishmeal, the ban was introduced in response to fears about possible contamination of fishmeal products with processed animal proteins.

- **The use of fishmeal in poultry diets:** As with diets for mammalian species, fishmeal is considered a natural, balanced ingredient for poultry diets with high protein, mineral and micronutrient contents. The protein in fishmeal is readily digested by poultry, and it contains all the essential amino acids necessary for adequate growth and production, especially the growth-limiting amino acid lysine. However, as with pig diets, the quality of the fishmeal can seriously affect protein digestion and biological value. Inclusion of fishmeal in poultry diets at about 4 percent results in improved feed conversion efficiency and growth rates. Laying performance is also improved by feeding fishmeal.

4. SUSTAINABILITY ISSUES OF REDUCTION FISHERIES AND FEEDFISH AS INPUTS FOR AQUACULTURE AND ANIMAL FEED

4.1 Impacts of feed fisheries on ecosystems

4.1.1 Direct and indirect effects of feed fisheries

The removal of large numbers of fish from an ecosystem may directly impact their prey, predators and the viability of target and bycatch populations. The physical effect of fishing activity will also affect the ecosystem directly through the disturbance of habitats (Auster *et al*., 1996; Langton and Auster, 1999) and the death and injury of non-target species (Kaiser and Spencer, 1995).

Feed-fish stocks

Feed-fish species caught for the production of fishmeal and fish oil are largely small pelagic fish that forage low in the food chain and are preyed upon by fish, marine mammals and seabirds at higher trophic levels. The population dynamics of many small feed-fish species are characterized by their high fecundity and early maturity. The recruitment patterns are highly variable and coupled with extrinsic environmental drivers (such as sea temperature and associated climatic/hydrological patterns, e.g. the North Atlantic Oscillation (NAO) and the El Nino in the southeastern Pacific Ocean) may rapidly influence stock size due to the short lifespan of the species. This will inevitably lead to uncertainty in the stock forecasts.

Most commercially exploited fish populations are capable of withstanding relatively large reductions in the biomass of fish of reproductive capacity (Daan *et al.*, 1990; Jennings, Kaiser and Reynolds, 2001). However, the removal of extremely high numbers of spawning stock may impair recruitment due to inadequate egg production. This has been termed "recruitment overfishing" (Jennings, Kaiser and Reynolds, 2001). Pelagic species are particularly vulnerable to this type of overfishing, as they are short-lived (Lluch-Belda *et al*., 1989; Santos, Borges and Groom, 2001).

Beverton (1990) reviewed the collapse of stocks of small, short-lived pelagics by examining the effect of fishing and natural extrinsic drivers. In four of the stocks studied (Icelandic spring-spawning herring, Georges Bank herring, California sardine and Pacific mackerel), the evidence indicated that each stock's reproductive capability had fallen, probably due to environmental conditions, but suggested that fishing accelerated the collapse. Beverton (1990) concluded that although the likelihood of harvesting small pelagic species to extinction was remote, a major population collapse may result in subtle changes to the ecosystem that may change the biological structure of the community.

Others also consider that harvesting an entire industrial fish species to extinction seems unlikely (Hutchings, 2000; Sadovy, 2001), but the treatment of stocks as single, panmictic populations means that if there are relatively local and sedentary stocks, overall catches could conceal community extirpation. This has implications, for instance, for the management of localized substocks such as in the case of the North Sea sand eel.

Habitats

The pelagic gear and purse seines used to target many industrial fish species such as sprats, blue whiting and Peruvian anchovy are deployed in the water column and have minimal contact with the sea floor. Demersal otter trawls are used to catch some species, such as sand eel and Norway pout, and these may have more of an impact on the sea bed and benthos. The degree of impact depends on the targeted species and the location, as specific gears will be used to target specific species, and the impact on the sea floor will relate to both the substrate type and the physiology of the flora and fauna.

Typically in the North Sea sand-eel fishery, the trawl is kept close to the sea bed, which is usually sandy (Wright, Jensen and Tuck, 2000), but actual contact is kept to a minimum. The gear is also lighter than the gear used in other demersal trawls. The effect of this disturbance on the more dynamic sand habitats is less significant than disturbance in areas of lower energy such as muddy substrates and in deep water, as the level of natural disturbance in the more dynamic areas is likely to be greater than that caused by fishing (Kaiser *et al*., 1998).

Based on the results of 11 studies, six of which involved experimental trawling, Johnson (2002) concluded that the physical effects of trawling on sand habitat include trawl-door tracks left on the sea floor, smoothed sediments and removal of biogenic mounds. At greater depths (>120 m), tracks were evident up to one year after trawling. At shallow sites (< 7 m), tracks were no longer visible after a few days. Four studies that examined the effects of chronic trawling and documented decreased abundance and biomass of sedentary macrofauna and decreased diversity. Studies examining the effects of short-term or pulse trawling documented changes in the abundance of some infaunal and epifaunal taxa, such as polychaetes, nematodes and benthic diatoms. These changes mimicked natural disturbance. Recovery ranged from weeks in intertidal areas to possibly years at depths of 80–200 m.

Bycatch and discards

The incidental catch of non-target species, and in particular, the capture of juveniles of commercial species, is one of the most controversial aspects of feed fisheries, as most undersized fish are landed and processed. In North Atlantic waters, juvenile herring are known to shoal with sprat (Hopkins, 1986), while juveniles of commercial species such as whiting and haddock are known to shoal with industrial teleost feedfish such as Norway pout (Huse *et al.*, 2003; Eliasen, 2003). Bycatch levels are not necessarily high – the bycatch in the Danish and Norwegian North Sea sand-eel fishery (mainly herring, saithe and whiting) averaged 3.5 percent of the total catch over the period 1997–2001 (ICES, 2003a). While levels are low given the scale of the feed fisheries being prosecuted, actual quantities of bycatch can be significant. In 2002, the Danish sand-eel landings accounted for 622 100 tonnes, of which 3.7 percent was considered bycatch, which is a total of 23 018 tonnes of bycatch herring, cod, haddock, whiting, saithe and mackerel. In the same period, the sprat fishery took 27 972 tonnes of bycatch.

Globally, purse seines and other seines catch the vast majority of small pelagics. These seine fisheries contribute over 350 000 tonnes to the global discard estimate and have a weighted discard rate[5] of 1.6 percent (proportion of the catch discarded) (Kelleher, 2005). Chilean fisheries harvests an average (1992–2001) of 5 million tonnes of small pelagics – these fisheries have a low discard rate and account for less than 40 000 tonnes of discards. Peruvian fisheries show a similar pattern of discards, although a higher discard rate in the small pelagic fisheries (average nominal catch of 8 million tonnes, 1992–2001) generates discards of 260 000 tonnes.

With the exception of the industrial shrimp trawl fishery, most Asian fisheries have low discard rates, as most are small-scale, short-trip ventures with any bycatch being landed for trash/low-cost fish use in aquaculture and livestock feeds. An arbitrary discard rate of 1 percent has been assigned to the fisheries of Thailand, Malaysia and Cambodia, which are considered to generate combined discards of less than 50 000 tonnes (Kelleher, 2005). Similarly the fisheries of Viet Nam and China are considered to have insignificant discards.

Seabirds

The methods used for catching fish species depend on the behaviour of the fish. Many fish species shoal, and small-mesh trawls and gillnets are used to capture them. Many of the feed-fish fisheries use trawls, and birds are less likely to be caught by this type of gear (Tasker *et al.*, 2000). A study in the Baltic Sea assessing the bycatch of common guillemot (*Uria alga*) indicated that a small unquantified degree of bird mortality could be attributed to trawls, but the researchers did not identify the trawls as specifically targeting an industrial fish species (Österblom, Fransson and Olsson, 2002). Bycatch of birds is potentially an issue in the purse-seining for anchovy, but the level of interaction is little researched (Majluf *et al.,* 2002).

Seabirds are long-lived, producing few fledglings that breed only if they survive for several years, and normally have various mechanisms to overcome periods of low food supply. Specialist seabirds, such as small, surface-feeding species with energetically expensive foraging methods are the most vulnerable to local depletion and (natural) variability in prey availability. The relationship between the reproductive success of black-legged kittiwakes on Shetland and sand-eel abundance has been proposed as an indicator of local sand-eel availability in the North Sea (ICES, 2003a). Potential conflicts between fisheries and seabirds are likely to arise only on a local or regional scale (Tasker *et al.*, 2000). Industrial fisheries can affect seabirds by reducing prey stock biomass, leading to declining recruitment or alterations in the food-web structure. Although seabirds consume only an insignificant proportion of North Sea sand-eel stocks compared with fish predators (Bax, 1991; Gislason, 1994; ICES, 1997), this relationship is sensitive to the population levels of key predators such as mackerel and gadoids, therir levels are currently low in the North Sea.

A classic example of how the removal of large quantities of feedfish by industrial fisheries might reduce food supply to seabirds has been reported in Peru. Extrinsically driven dramatic decreases in numbers of guano seabirds occur regularly during El Niño events, but historically, species were shown to recover between events, showing cyclic fluctuations in populations. However, as the Peruvian anchovy fishery activity increased, seabird numbers began to fail to recover after El Niño-driven crashes, and the seabird population fell to only a small fraction of its earlier numbers (Duffy, 1983). Jahncke, Checkley and Hunt (2003) modeled the guano-producing seabirds (cormorant, *Phalacrocorax bougainvillii;* booby, *Sula variegata;* and pelican, *Pelecanus thagus*) that feed almost exclusively on *Engraulis ringens* to determine if there is a response in the annual population size of the birds to changes in primary and secondary production of the Peruvian upwelling system. The seabirds were shown to respond positivily to the increased productivity of the Peruvian upwelling system, and declines in seabird abundance after El Niño events were likely due to competition with the fishery for food.

[5] Weighted discard rate (%) = [Summed discards (tonnes) x 100) / (Summed discards + summed landings (tonnes)]

Marine mammals

The "Ecological Quality Objective" for bycatch of small cetaceans adopted under the Bergen Declaration[6] requires anthropogenic mortality of marine mammals to be below 1.7 percent per annum. No bycatch of marine mammals has been reported in the industrial fisheries, but Huse *et al*. (2003) provide anecdotal evidence that there are occasional bycatches of cetaceans in the North Sea sand-eel fishery. The opportunistic feeding behaviour of cetaceans and pinnepeds in and around trawls means they are vulnerable to becoming trapped (Fertl and Leatherwood, 1997). There is a need for further investigation of the level and spatial and temporal extent of marine mammal bycatch in the North Sea. Should bycatch prove significant in certain areas or seasons, pingers[7] could prove an effective management measure (Larsen, 1999).

Bycatch of cetaceans is a potential issue in the purse-seining for anchovy (Majluf *et al.*, 2002). The dusky dolphin (*Lagenorhynchus obscurus*) is known to take *E. ringens* as a major component of its diet (McKinnon, 1994), and the species was reported as caught by purse seines before cetaceans were protected in the region (Read *et al.*, 1988). Van Waerebeek *et al.* (1997) conducted a survey of Peruvian fisherfolk to estimate mortality of 722 by-caught cetaceans (and direct takes). The animals reported captured in multifilament gillnets were 82.7 percent dusky dolphin (*Lagenorhynchus obscurus*), 12.6 percent Burmeister's porpoise (*Phocoena spinipinnis*), 2.4 percent long-beaked common dolphin (*Delphinus capensis*) and 2.4 percent bottlenose dolphin (*Tursiops truncatus*). Van Waerebeek *et al.* (1997) found that there was no indication of a reduction in dolphin mortality in the industrial purse-seine fisheries, and that large numbers of long-beaked common dolphins are known to be by-caught. Currently dolphin catches are thought to occur, but evidence is anecdotal.

Diet composition analyses of cetaceans show the presence of industrial feed-fish species in the diet of harbour porpoise (*P. phocoena*), bottlenose dolphin (*Tursiops truncates*), white-beaked dolphin (*Lagenorhynchus albirostris*), common dolphin, Risso's dolphin (*Grampus griseus*), Atlantic white-sided dolphin (*L. acutus*) and minke whale (*Balaenoptera acutorostrata*) (Fontaine *et al*., 1994; Santos *et al*., 1994, 1995; Couperus, 1997; Olsen and Holst, 2001; Kastelein *et al.*, 2002; Borjesson, Berggren and Ganning, 2003). In some cetaceans, the proportion of feedfish reported in the diet is minimal, but in Scottish waters, sand eels constitute 58 percent by weight of the stomach contents of harbour porpoises and 49 percent by weight of the stomach contents of common dolphin. Other feedfishes, sprat and Norway pout, were less than 1 percent by weight of dolphin and porpoises (Santos *et al.*, 1995). Industrial fisheries may thus impact marine mammal populations by altering their food supply in certain areas. When assessing the effects of feed-fish fisheries on marine mammals, it is, therefore, important to consider the local availability of feedfish to cetaceans and the ability of cetaceans to switch to other prey if feed-fish stocks are depressed. This, however, has yet to be demonstrated in cetacean population.

Ecosystem changes

The complexity of marine systems makes it difficult to identify the effects of predator/prey removal on other communities. Marine communities often exhibit size-structured

[6] Fifth International Conference on the Protection of the North Sea (the "Bergen Declaration") of 20–21 March 2002

[7] Pingers are underwater sound-emitting devices (maximum level of intensity equivalent to approximately 175 dB re 1 µPa @ 1 m) attached to fishing gear, principally gillnets. Pingers are now mandated for use in some fisheries in the United States Northwest Atlantic, in the California driftnet fishery and in Europe. The sound of these devices is believed to alert an animal to the presence of the net and thus decrease the probability of entanglement (http://209.85.135.132/search?q=cache:_pEliK3n8AgJ:bycatch.org/glossary/view_term.php%3Fvocab%3Dtechnique%26id%3D1+definition+of+pingers&cd=4&hl=en&ct=clnk&gl=uk)

food webs, and changes in the abundance and size composition of populations are likely to lead to changes in the quantity and type of prey consumed (Frid *et al*., 1999). However, these changes may not be predicted by simplistic models of predator-prey interactions, as models do not account for prey switching, ontogenetic shifts in diet, cannibalism or the diversity of species in marine ecosystems (Jennings and Kaiser, 1998; Jennings, Kaiser and Reynolds, 2001).

Ecological dependence takes account of the ecological linkages in the marine systems. However, assessing ecological dependence is problematic, as evidence for the effects of strong ecological interactions on some stocks should not be taken as evidence that the effects are necessarily a concern to managers of all stocks. ICES (2003b) suggested that the current approaches for assessing ecological dependence could not be widely applied and that fundamental research is needed to develop an appropriate method for assessing and ranking the strength of ecological dependence of species.

Commercial species as predators of feed-fish species

Feedfish tend to feed at or near the bottom of the food chain, so fisheries interactions with the marine food web are more likely to affect their predators. Gislason (1994) reported that the sand-eel and Norway pout fisheries of the North Sea took in about 20 percent of the annual production of these fish species. The consumption of sand eels in the North Sea by fish that are targeted for human consumption, seabirds and "other species" (including some fish species and marine mammals) has been estimated as 1.9, 0.2 and 0.3 million tonnes, respectively (ICES, 1997). Bax (1991) reviewed the fish biomass flow to fish, fisheries and marine mammals using a variety of data sets in the Benguela system, on Georges Bank, in Balsfjorden, the East Bering Sea, the North Sea and the Barents Sea and calculated that consumption of fish by predatory fish was 5–56 tonnes/km^2 compared with fisheries (of all types), which caught 1.4–6.1 tonnes/km^2; marine mammals, which consumed 0–5.4 tonnes/km^2 and seabirds, which consumed 0–2 tonnes/km^2. Fish predation on feedfish is, therefore, considered to be higher than industrial fisheries' removals, and this is especially true for the sand-eel fisheries.

If small pelagic industrial feed-fish species have become more dominant in marine systems as a result of a decline in demersal fish predators (commercial species) due to fishing, then there is an argument for management to allow larger harvests of industrial feed-fish species due to the reduced natural predation pressure on these stocks. However, Naylor *et al.* (2000) argued that in the North Sea, exploitation of the industrial species such as sand eel and Norway pout is implicated in the decline of the higher trophic predator cod. It has been suggested that a reduction in fishing effort on industrial feed-fish stocks will benefit higher trophic predators (including gadoids) (Dunn, 1998; Cury et al., 2000; Furness, 2002). ICES assessments of the Norway pout stocks in ICES Sub-area IV and Division IIIa indicate that fishing mortality is lower than natural mortality, and multispecies analyses have indicated that when F (fishing mortality) is below M (natural mortality), the fisheries are not causing problems for their predators on the population size of the stock. It further noted that locally concentrated harvesting may cause local and temporary depletions of predators and, therefore, harvesting should spread widely across large geographical areas.

Feedfish as predators of commercial species

The survival of the early planktonic phases of the fish life cycle is essential for stock recruitment (Blaxter, 1974; Chambers and Trippel, 1997; Horwood, Cushing and Wyatt, 2000). Even small variations in the mortality rate between egg fertilization and recruitment can have a profound effect on the subsequent adult abundance (Jennings, Kaiser and Reynolds, 2001). Many industrial fish species prey on the eggs and larvae of commercial fish. In the North Sea in Europe, sand eel, Norway pout and capelin consume fish eggs and larvae (http//: www.fishbase.org), and sprat and herring prey on cod eggs (Stokes, 1992; Köster and Möllmann, 2000). As the abundance of the larger predatory gadoids has been reduced to low levels, the industrial feedfish that prey on their juveniles and eggs may now be exerting a higher level of mortality than previously, and may potentially affect gadoid stock recruitment and slow recovery. However, it should be noted that such profound trophic impacts are difficult to verify, given the lack of information and the confounding effects of other impacts.

Genetic impacts

Overfished populations may exhibit the "Allee effect", which is an inverse density dependence at low densities (e.g. the per capita birth rate declines at low densities). The primary factors involved in generating inverse density dependence include genetic inbreeding and loss of heterozygosity and demographic stochasticity, including sex ratio fluctuations (Courchamp, Clutton-Brock and Grenfell., 1999). Common factors behind the Allee effect are not of a genetic nature and can include gregariousness, sperm competition and cultivation effects.

If a stock collapses and recovers, its genetic viability is harmed due to the reduced number of genes in the population. However, Stephenson and Kornfeld (reported in Beverton, 1990) concluded that the Georges Bank herring, which reappeared after a collapse in 1977 to 1/1000th of the 1967 peak of over 1 million tonnes, has an unchanged genetic constitution. This result may be an artifact of the limited DNA technology at the time.

Feed-fish species are characterized by a tendency to shoal. Fishing pressure causes shoaling fish to reduce their range number and maintain the same average school size (Ulltang, 1980; Winters and Wheeler, 1985). Consequently, there can be a high number of individuals in a shoal, which may lead to a high level of genetic diversity within the shoal (Ryman, Utter and Laikre, 1995). The next question is: what size can a genetically distinct shoal/or population be reduced to and still recover? Beverton (1990) calculated that the smallest size that a collapsed population could drop to and subsequently recover is in the order of a million fish, but local density has to play a role.

4.2 Criteria and indicators used to measure the sustainability of reduction fisheries

The FAO *Code of Conduct for Responsible Fisheries* (CCRF), adopted in 1995, aims to ensure that the right to fish "carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources". Together with its Technical Guidelines for implementation and the other international fisheries instruments developed and adopted within its framework (e.g. International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries, IPOA-Seabirds; International Plan of Action for the Conservation and Management of Sharks, IPOA-Sharks; International Plan of Action for the Management of Fishing Capacity, IPOA-Capacity; International Plan of Action to Prevent, Deter and Eliminate Illegal and Unreported and Unregulated Fishing; IPOA-IUU fishing), the CCRF is now widely recognized by governments and non-governmental organizations (NGOs) as the global standard for setting out the aims of sustainable fisheries and aquaculture and as a basis for reviewing and revising national fisheries legislation.

FAO has also produced technical guidelines on indicators for sustainable development of marine capture fisheries (FAO, 1999) that outline the process to be followed at the national or regional levels to establish a Sustainable Development Reference System (SDRS). The guidelines were produced in support of the CCRF and cover all dimensions of sustainability (ecological, economic, social and institutional), as well as the key aspects of the socio-economic environment in which fisheries operate.

4.2.1 FIN "Sustainability Dossier"

When most feed manufacturers state that they only procure from "sustainable" sources, this claim is usually based upon the Fishmeal Information Network (FIN) Sustainability Dossier, an annually updated assessment initiated by the Grain and Feed Trade Association (GAFTA) and funded by the United Kingdom Seafish Industry Authority (SFIA). This dossier has recently been expanded to reflect wider ecosystem impacts, based on the latest ICES and FAO advice (see www.gafta.com/fin/index.php).

4.2.2 MSC "Principles and Criteria" for responsible fisheries

The concept of sustainability is complex and therefore has implications for the selection of criteria for "sustainable fishing". The most widely accepted generic model is the principles and criteria for "responsible fishing" developed by the Marine Stewardship Council (MSC). The MSC principles and criteria consider whether a fishery is sustainable depending upon a demonstration of:

- the maintenance and re-establishment of healthy populations of targeted species;
- the maintenance of the integrity of ecosystems;
- the development and maintenance of effective fisheries management systems, taking into account all relevant biological, technological, economic, social, environmental and commercial aspects; and
- compliance with relevant local and national laws and standards and international understandings and agreements.

While the MSC criteria respond well to fisheries and ecosystem issues, they do not provide a specific assessment of the economic or social elements. Huntington (2004) took the basic MSC criteria and adapted them to specifically suit feed fisheries, applying them to the five main fisheries that provide the bulk of fishmeal destined for the Scottish fish farming industry. These criteria are reproduced in Table 11.

Indicators are used to assist the scoring of fisheries "sustainability". For each indicator, there are three "scoring guideposts" that assist assessors in determining the score out of 100. For instance, there are guideposts for what passes at 60, 80 and the ideal score of 100.

The advantage of the MSC approach is that it provides a vigorous quantitative approach to assessing the main elements that ensure that a fishery is sustainable. The main question is whether this approach can be successfully applied to feed fisheries, whose main species constitute an important forage prey, unlike many of the top predators that have been the focus of many fisheries certification schemes to date. While MSC does look at implications of target species removal on ecosystem structure and function, it has been a challenge to both determine and quantify the implications in practice. With growing interest in ensuring the sustainability of aquaculture products throughout the production chain, the certification of feed-fish stocks has become an urgent priority – indeed this has become a priority with MSC, which has launched a partnership with the Soil Association to develop certified sustainable sources of fishmeal and oil for organic farmed-fish diets (www.fishupdate.com, April 2006).

4.3 Sustainable use of fishery resources for aquafeeds

While a future goal may be the complete or majority use of feedfish from a certified "responsibly managed" fishery, in the meantime, it is important that intensive aquaculture makes a committed move towards sourcing from the better managed and more sustainable fisheries. As mentioned earlier, the main buying criteria for fishmeal for inclusion in aquafeeds are price and quality. Beyond ensuring that fish are purchased from stocks that are managed within national and international laws and agreements, there is little real attempt to limit fishmeal procurement to "sustainable sources". There are a number of obstacles that must be overcome if the feed-supply chain is to become more sustainable. However, it is increasingly recognized that the long-term future of the aquaculture industry is entirely dependent on sustainably managed fisheries and that change is needed to take this into full account.

TABLE 11

Summary of principles, criteria and corresponding indicators of feed fisheries sustainability

Principle	Criterion (C)		Indicator
1. Fishing pressure and sustainability	1.1 High productivity of stock maintained		a) Level of understanding of species and stock biology
			b) Knowledge of fishing methods, effort and mortality
			c) Existence of acceptable reference points
			d) Existence of defined harvest strategy
			e) Robust and regular assessment of stocks
			f) Stocks are at an appropriate precautionary reference level
	1.2 Fishery is able to rebuild stock to a predefined level within a specific time frame		
	1.3 Reproductive capacity of stock maintained		a) Information on fecundity and recruitment dynamics
			b) Information on stock age/sex structure
			c) Evidence of changes in reproductive capacity
2. Structure, productivity, function and diversity of dependent ecosystem	2.1 Natural functional relationships among species maintained without ecosystem state changes		a) Understanding of ecosystem factors relevant to target species
			b) General risk factors known and understood
			c) Impacts of gear use and loss known
			d) Ecosystem management strategy developed
			e) Ecosystem assessment shows no unacceptable impacts
	2.2 Fishery does not threaten biodiversity		a) Level of knowledge and implications of interactions
			b) Management objectives set for impact identification/avoidance
	2.3 Recovery of non-target species populations permitted		a) Information on necessary changes to allow appropriate recovery
			b) Management measures permit adaptive change to fishing
			c) Management measures allow recovery of affected populations
3. Information, organizational and legislative capacity for sustainable management	3.1 Management system criteria	C2	a) Clearly defined institutional and operational framework
		C1, 2, 3	b) Clear legal basis for management system
		C2, 5, 7	c) A consultative and dispute resolution strategy and pathways in place
		C6	d) Subsidies or incentives exist that affect fishing practices
		C8	e) Adequate, operational research plan to address information needs
		C7, 9, 10	f) Monitoring and evaluation system for fisheries management objectives
		C11	g) Control mechanisms for enabling and enforcing management objectives
	3.2 Operational criteria	C12, 13	a) Operational mechanisms to reduce impacts on habitats and non-target species
		C14, 15	b) Measures to discourage operational wastes and destructive practices
		C16	c) Fishers aware of/compliant with managerial, administrative and legal requirements
		C17	d) Fishers involved in catch, discard and other relevant data collection
4. Economic and social considerations	4.1 The needs of fisheries-dependent communities, historic rights and cultures respected		a) Does not impact resource availability or access, directly or indirectly
			b) Fisheries and fishers demonstrate understanding and sensitivity to traditional practices and ways of life
	4.2 Fishery and market operate under natural conditions		a) Fishery operates in an economically efficient manner
			b) Product trade is not artificially favoured by trade barriers or protectionism
	4.3 Labour conditions conform to International Labour Organization (ILO) standards		a) Freedom from enforced labour
			b) Freedom of association and collective bargaining
			c) No discrimination of individuals and organizations
			d) Non-use of child labour
	4.4 Fishery does not prejudice food security		a) Pricing structure operates within market norm
			b) Supply operates within market norm

Source: Huntington (2004)

4.3.1 Barriers to buying aquafeeds sourced from sustainable feed fisheries

There are a number of practical reasons why it has been difficult for the feed manufacturing industry to source fish feeds entirely from sustainable sources:

- *Lack of recognized criteria for suitability:* At present the feed manufacturing industry has no standardized definitions or criteria for the sustainability of feed fisheries. It currently uses the FIN Sustainability Dossier for guidance, but this dossier is essentially limited to examining stock assessment reports and regulatory frameworks. It does not include some of the elements included in the assessment criteria used in this study, such as non-target species impacts, regulatory compliance levels, availability of key information and knowledge relevant to sustainability, as well as economic and social factors. It is recommended that principles and criteria for sustainable fisheries be based on those developed by the FAO (FAO, 1995, 1999, 2003) and that ecosystem impacts (including socio-economic and food security impacts) also address the issue of the intended use and destination of the fish or shellfish in question (FAO, 1998). For example, Article 2.f of the FAO CCRF states one of the major objectives of the Code as being to "promote the contribution of fisheries to food security and food quality, giving priority to the nutritional needs of local communities". In particular, "States should encourage the use of fish for human consumption and promote consumption of fish whenever appropriate", and discourage the use of foodfish fit for human consumption for animal feeding (FAO, 1995, 1998; Tacon, Hasan and Subasinghe, 2006). In addition, the MSC-derived framework described above is also a useful starting point. The setting of sustainability criteria will ultimately enable both producer and consumer to purchase selectively, creating a market for a sustainable product.
- *Traceability:* Although the traceability of feed ingredient sources is improving rapidly, it may be difficult to ensure the origin of all fishmeal. For instance, fishmeal is often blended to give constant characteristics of density, flow, digestibility and protein content; thus species identity tends to be uncertain. Much of the South American fishmeal is blended at the time of loading of tankers (both ship and road) and hence cannot be traced beyond that point. Traceability is high on the feed industry's agenda, and some manufacturers are looking to traceability schemes such as the Universal Feed Assurance Scheme (UFAS) and Feed Materials Assurance Scheme (FEMAS) to reduce the purchase of feed products where there is not a full traceability chain.
- *Fishmeal nutritional performance:* Restrictions on certain fish-feed stocks may have implications for fishmeal nutritional performance. For instance, smaller fish (i.e. salmon <1 kg) need high levels of amino acid histidine, which is found in much higher levels in South American fishmeal. Exclusion from these sources would necessitate much higher inclusion levels of European fishmeals and thus higher levels of consumption. There is the potential for substitution with porcine blood meal, but this is likely to meet retail and consumer resistance. Conversely, the use of meals from the Northern Hemisphere producced at low temperature (LT) for larger fish is favoured because they are higher in protein and of the highest digestibility. For instance, blue whiting meal is a highly digestible meal and while some users dislike its higher ash level, most processors find it worthwhile and may be reluctant to reduce its use.
- *Supply assurance:* Should the aquaculture industry become selective for more sustainable fishmeal stocks, the demand for those fish product from these stocks will increase. This has a number of implications:
  - o Fishmeal Supply may be restricted for reasons outside the control of fishmeal manufacturers and their clients (e.g. the wide inter-annual variability of South American production due to El Niño events).

- o Connected with the above, prices may become more variable, with a general shift upwards as the supply base is effectively reduced.
- o Increased pressure will be put upon sustainable fishmeal stocks. This should not be an issue if stocks are well managed (as they should be if deemed as sustainable).
- o To reduce the risk of unforeseen quality or contamination problems, formulators will continue to prefer a mix of fishmeals from different sources.

These concerns are only really valid over the short-term. Longer-term supply assurance depends on the sustainable management of feed fisheries, and thus the industry may have to review its approach to fishery exploitation if it is to continue to be viable in the future.

- *Seasonal availability:* Most fishmeal manufacturers use several species throughout the year to reflect seasonal availability and condition (i.e. oil content). Although it is possible to choose (or avoid) a particular fish species, to do so necessitates increasing purchases of other meals, possibly at higher cost and, given shipping and storage constraints, holding higher stocks to get past the seasons involved. Producers are reluctant to hold stock for more than a few months. When forced to do so, they usually reduce prices to clear stock out. If aquaculture buyers have no storage available, then they spot buy and this occurs almost always above the market price, and because they generally beat the market by buying long and at lows in the cycle whenever possible, this severely impacts their buying strategy. Some aquaculture companies have very long-term frame contracts with fishmeal producers. Agriculture feed buyers source fishmeal in smaller quantities, use traders and have shorter-term buying positions. They are more numerous than the oligopoly of aquaculture feed buyers, and so their behaviour is more of an approximation to a perfect market.
- *Buying power:* Asian pig and poultry farming requires more fishmeal than aquaculture in the West and is important in determining world price and supply. Aquaculture buyers no longer influence fishmeal producers and traders in Peru and elsewhere to the extent they did formerly. Norway has become a net importer rather than, as once, an exporter, while Chile is now a net importer of fish oil; so freedom to avoid or choose certain meals could be constricted by this factor.

4.3.2 Recommendations for improving responsible sources of aquafeeds

Huntington (2004) made a number of recommendations to the Scottish fish-farming industry to improve their sourcing of sustainable fishmeal and oils for aquafeeds. These have been reviewed and expanded to apply to aquaculture as a whole:

- *Critera for feed-fish fishery sustainability:* The majority of European aquafeed manufacturers use the FIN Sustainability Dossier, which is published every year once the EC's annual fisheries management regime has been accepted. As previously discussed, this dossier now includes a review of the wider ecosystem ramifications of feed-fish utilization. To assist this process, it would be useful to have a formal series of "sustainability criteria" specifically for feed fisheries that could be applied to the main species being sourced and independently verified to provide consumer confidence. This could act as a first stage to pre-assessment and full certification of the more sustainable feed fisheries over the longer term.
- *Improved traceability:* Fishmeal purchasers should request improved information on fishmeal species ingredients and their origin, together with improved traceability and chain of custody. Such information should be made fully available to the public to provide assurance of the industry's transparency.

- *Sustainable purchasing strategies:* Fishmeal purchasers should develop a purchasing strategy that minimizes and, where possible, eliminates the use of those species of those fisheries considered unsustainable. This strategy could be prepared with a number of different timescales:
  - o *short term*: reduce the purchase of less sustainable species such as blue whiting or jack mackerel, where possible;
  - o *medium term:* develop approaches to halting purchases of less sustainable species through a detailed analysis of alternatives; and
  - o *long term:* develop alternative protein and oil substitutes for fishmeal and fish oil; set a date for and establish an approach to purchasing all fishmeal and fish oils from sources that have been independently verified as "responsibly managed" and that originate from sustainable fisheries.

  The purchasing strategy could be updated regularly to reflect changes in different fishing practices and the latest "sustainability assessments", together with emerging trends in fish nutrition and alternative feed materials. The use by procurement departments of environmental management systems such as the International Organization Stadarization (ISO), ISO 14001 to ensure that procurement strategies minimize the environmental implications of purchasing should also be considered.
- *Substitution with non-fish protein and oil sources:* Greater knowledge should be developed about the options for substituting different species at different times of year to obtain a required fishmeal quality and specification.
- *Premium branding:* Aquaculture, in partnership with its customers, should seek to develop its premium brand image by encouraging feed suppliers to move towards targets for achieving sustainable supplies.

5. ENVIRONMENTAL IMPACTS OF FEEDFISH-BASED AQUACULTURE

The nature of aquaculture feeds and feeding regimes plays a major role in determining the degree of environmental impact resulting from semi-intensive and intensive finfish and crustacean farming operations (Tacon and Forster, 2003; Mente *et al.*, 2006). This is particularly true for those intensive farming operations employing open aquaculture production systems (e.g. net cages/pen enclosures placed in rivers, estuaries and open waterbodies, and land-based flow-through tank, raceway and pond production systems) (Black, 2001; Goldburg, Elliot and Naylor, 2001; Brooks, Mahnken and Nash, 2002; Lin and Yi, 2003; Piedrahita, 2003; Muñoz, 2006). The bulk of dissolved and suspended inorganic and organic matter contained within the effluents of intensively managed open aquaculture production systems is derived from feed inputs, either directly in the form of the end-products of feed digestion and metabolism or from uneaten/wasted feed (Cho and Bureau, 2001), or indirectly through eutrophication and increased natural productivity (Tacon, Philips and Barg, 1995).

It follows from the above that the rate of supply and assimilation of aquaculture feeds in fish-fed aquaculture operations (which include the use of fishmeal, fish oil and/or trash fish-based feeds) will play a major role in dictating the nutrient and/or waste outputs from the aquaculture production facility. Moreover, it also follows that these outputs and their environmental impacts will vary depending upon the farming system employed (open or closed systems), on-farm feed/nutrient and water management, and the assimilative capacity of the surrounding aquatic and terrestrial environments (Tacon, 2009). In general, the greater the intensity and scale of production, the greater the nutrient inputs required and the consequent risk of potential negative environmental impacts emerging from the aquaculture facility through water use and effluent discharge.

5.1 Environmental impacts of aquafeed use

For the purposes of this paper, the environmental impacts of fish-fed aquaculture operations can be viewed as follows (Tacon, 2009; Huntington, 2009).

5.1.1 Fishmeal and fish oil

Direct environmental impacts include:

- increased environmental pollution resulting from the rapid growth and expansion of semi-intensive shrimp farming and intensive salmonid farming operations dependent upon the use of compound feeds containing fishmeal and fish oil as major dietary nutrient sources (Tacon, 2002, 2005);
- increased dependence of the aquaculture sector upon marine capture fisheries for sourcing finfish and crustaceans for reduction to fishmeal and fish oil (Goldburg, Elliot and Naylor, 2001);
- increased pressure upon marine capture fisheries for sourcing forage fish species for reduction to fishmeal and fish oil for use by the aquaculture sector (Kristofersson and Anderson, 2006; Skewgar *et al.,* 2007); and
- use of environmentally contaminated fishmeals and fish oils in aquafeeds, and consequent potential risk of transferring contaminants to the cultured species and eventually to the consumer (Hites *et al.*, 2004a, 2004b; Foran *et al.*, 2005).

Indirect environmental impacts include:

- removal of large quantities of forage fish species from marine ecosystems and potential ecosystem and biodiversity impacts upon other dependent piscivorous animal species, including other fish species, birds and mammals (Huntington *et al.,* 2004; Worm *et al.*, 2006; Skewgar *et al.*, 2007); and
- exportation and loss of valuable fishmeal and fish oil resources from one continent and ecosystem (the Americas) to another (Europe, Asia) (Naylor *et al.,* 2000).

5.1.2 Trash and baitfish

In Asia, trash fish is an important dietary component (either fed directly or as part of a farm-made feed), particularly for the extensive culture of shrimp, *Pangasius* catfish, *Macrobrachium*, crabs and snakehead. A recent survey in Viet Nam indicated that farmers perceived trash fish to have a considerable impact on the environment, especially when incorporated into farm-made feeds, possibly due to mixing with chemicals and to prophylactic disease treatments (Sinh, 2006, 2007).

Direct environmental impacts include:

- increased environmental pollution resulting from the use of highly perishable and water-polluting trash fish-based feed items (Tacon *et al*., 1991; Ottolenghi *et al.,* 2004);
- increased biosecurity and disease risks due to the feeding of unpasteurized trash-fish products to cultured fish and their use as bait for wild fish (Gill, 2000; SCAHAW, 2003; Hardy, 2004; anon, 2005);
- increased fishing pressure on wild juvenile target species used for fattening, and the capture of pelagics for feeding and bait use (Dalton, 2004);
- increased risk of over-fishing of available fish stocks due to the use of the captured juveniles of higher-value commercial food-fish species (FAO, 2004b); and
- increased fishing pressure on species that were not previously fished commercially, such as the round sardinella in the western Mediterranean Sea, where the use of trash fish is limited to tuna fattening, with possible consequences for one of tunas' main predators, the common dolphin, as noted by the World Wide Fund for Nature (WWF). In addition, use of trash-fish raises the possibility of

transmitting viruses from non-endemic feed fish to local wild fish populations, as has been experienced in Australia (WWF, 2005).

Indirect environmental impacts include:

- increased trash-fish prices due to high demand for use as aquaculture feed, placing them out of the economic grasp of the poor and needy for direct human consumption as an affordable food source (Edwards, Le and Allan, 2004).

5.1.3 Krill fishery

Despite the fact that there are over 85 known species of krill (Nicol and Endo, 1997) and that total reported krill landings reached over 1 118 165 tonnes in 2004, only one krill species is currently reported, namely the Antarctic krill (*Euphausia superba*) (FAO, 2006a). In view of the important ecological role played by krill in marine food webs, it is imperative that all krill species be reported and quantified by fishers for transparency, traceability and the long-term sustainability of the krill fishery sector (Nicol, 2006; Murphy *et al.*, 2007). Removal of large quantities of krill from the marine ecosystem may have adverse long-term ecosystem impacts on dependent species, and in particular for many protected marine mammals and birds (Reid and Croxall, 2001; Hill *et al.*, 2006).

5.2 Examples of environmental "best practice"

Intensive aquaculture has been driven to improve efficiency by a combination of lower economic margins and an increasingly strict regulatory environment. This efficiency is reflected by the very low FCRs now experienced in salmonid and marine fish culture, as well as the gradual adoption of "bay level" management, where different operators within an enclosed or semi-enclosed area work together to reduce the cumulative impact of their production.

Various approaches have emerged from the salmon farming industry in Europe and elsewhere that provide useful examples of environmental "best practice" that have potential for wider replication, especially in the expanding cage-culture subsector. These include:

- **Modeling of sites to set biomass limits:** Computer modeling can provide assessments of the potential impacts of nutrient loading on a waterbody, on regional algal productivity or on the benthic effects from sub-cage deposition. The particle tracking model Depomod has been extensively used in Europe to determine the theoretical carrying capacity of cage farming areas and to assess the deposition of organic matter beneath finfish cages and mussel rafts. Depomod is limited to near-field predictions through the use of a uniform horizontal flow field – detailed modeling at a waterbody or regional scale requires the capability to represent two or three dimensional flows, depending on the degree to which the waterbody is vertically mixed. Various proprietary models exist, for example Delft3D and Mike21, that can enable detailed assessments of the cumulative effects from aquaculture activity on water quality, such as nutrients and algal activity in a waterbody. While numerical flow and water quality models of this nature require considerable effort to set up and calibrate, and the level of effort required increases with the complexity and scale of the model domain and the water quality processes of interest, they can provide useful predictions on the carrying capacity of sites and thus assist in the planning and licensing of aquaculture development.
- **Setting of Environmental Quality Standards (EQS)**: EQS can be used in assimilative capacity model development. EQS values have to be set for the different environmental quality variables (EQVs) such as dissolved oxygen concentrations defined by regulators and industry bodies. These then provide the

basis for setting environmental quality benchmarks and monitoring targets for aquaculture areas.

- **Joint management of sea, semi-enclosed bay, lake and watershed areas:** In Scotland, the use of Area Management Groups has resulted in greater coordination among different farming interests within a single waterbody that allows joint management actions, such as the complete fallowing of sea areas between aquaculture production cycles. This helps control and reduce the cumulative impacts of intensive aquaculture, especially in areas with limited flushing rates.
- **Waste reduction strategies:** Perhaps the greatest change in intensive aquaculture over the last ten years has been the reduction of wastage through better management and monitoring of feeding. Various approaches have been adopted, including maximizing the bioavailability of feed components through research and trialing, as well as better feed delivery management using computer-controlled, centralized feeding systems. Feeding rates can be further adjusted through the use of underwater cameras and sensors that detect when feed is passing through cage systems and not being utilized by the stock, thus invoking a reduction in feeding rates.
- **Environmental monitoring:** Intermittent monitoring of the benthos and water column will also provide managers with information on the levels of feed utilization, wastage and impact from aquaculture systems, especially when combined with the EQS approach described above.

6. CURRENT POTENTIAL ALTERNATIVE USES OF FISH AND OTHER AQUATIC SPECIES AND THE RELATED MACRO-LEVEL IMPACTS ON FOOD SECURITY AND POVERTY ALLEVIATION

6.1 Current and alternative uses of feed-fish catches

On the assumption that it is more efficient to consume so-called feedfish directly rather than via their inclusion as a component of aquafeed (a premise discussed in Section 6.2), there have been a number of initiatives to develop and market both small pelagic fish and “trash fish” for direct human consumption.

6.1.1 Increased utilization of the “feed fisheries” to supply feedfish for human consumption

An increasing proportion of the catch of Chilean jack mackerel and other pelagics, including the Patagonian grenadier (*Macruronus magellanicus*) and the chub mackerel (*Scomber japonicus*), is being processed for direct human consumption. Despite the fact that the average price of frozen jack mackerel and fishmeal was similar, the reported yield from jack mackerel was about 23 percent for meal production and 5–7 percent for oil production, as compared with 70–75 percent when frozen fish was produced (Wray, 2001). Clearly, under these circumstances selling the fish for direct human consumption is much more profitable than reducing it to fishmeal and oil.

The trend toward increased direct human consumption of traditional feed-fish species (including the use of refined fish oil for direct consumption) is expected to continue in the long run as fish prices continue to rise; national governments actively encourage the direct consumption of potential food-grade pelagic fish species (e.g. Chile, SERNAC, 2007; Peru, Chuquin, 2006); and fish harvesting, processing and stabilization methods improve and consequently fish quality for the consumer improves (Bechtel, 2003; Gelman *et al.*, 2003). At present, around 58.5 percent of jack mackerel is turned into fishmeal, with 23 percent canned, 13 percent frozen and the balance used to produce surimi (Bórquez and Hernández, 2009) (see Box 1).

Similarly, in the case of Peru, the growth in the proportion of the anchoveta harvest destined for direct human consumption has increased markedly since 2000, despite the fact that only 27 065 tonnes or 0.32 percent of the total Peruvian anchoveta harvest in

BOX 1

Benefits of using Chilean jack mackerel for human consumption versus fishmeal reduction

Bórquez and Hernández (2009) examined the advantages of increasing the volume of Chilean jack mackerel used for direct human consumption as opposed to its reduction to fishmeal (currently around 58 percent). They concluded that changing the destination of jack mackerel from fishmeal to the production of food products for direct human consumption might have a positive impact. However, at present, from the point of view of its role in food security and poverty alleviation, the impact of the alternative use of this resource for human consumption might not be very significant, given that it will not have a high demand and will be mainly destined for export.

Reducing the production of fishmeal will not have a negative impact on national salmon aquaculture because at present supplies for inclusion in salmonid aquafeeds are sufficient and there is still a surplus of fishmeal that is generally destined for export.

However, there is a socio-economic impact when fishmeal production is reduced to increase the production of human food products, as the benefit is only translated into an increase in employment for region VIII of Chile, basically via an increase in the number of processing plants. A high demand for new processing plants could result in new investment for construction, but if the existing plants have unused processing capacity, the benefit will translate into only a small increase in the demand for additional labour.

2005 (8 555 955 tonnes) was destined for this use, compared with only 0.01 percent over the period 1991–1995, 0.06 percent over the period 1996–2000, and 0.19 percent over the period 2001–2004 (Flores-Nava, 2007).

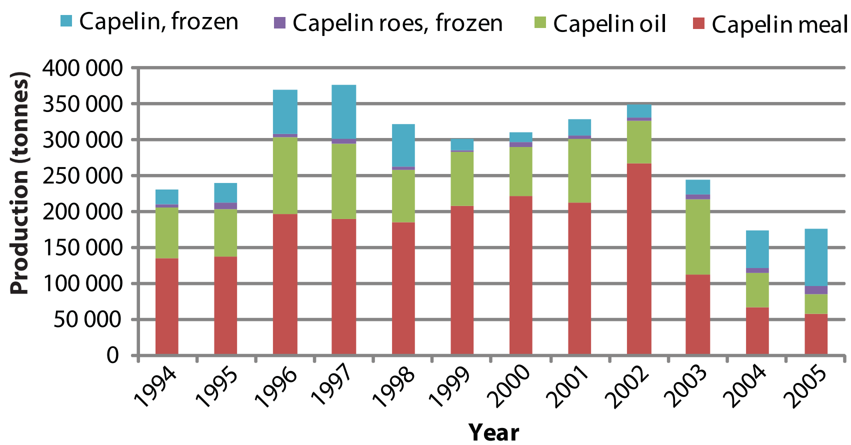
The Peruvian Government is looking to improve national food security through a greater contribution of small pelagic species such as Peruvian anchovy to direct human consumption (Sánchez Durand and Gallo Seminario, 2009). In order to increase the annual per capita fish consumption from 20.8 to 25 kg by 2010, an additional 157 300 tonnes would be required, corresponding to 1.8 percent of the Peruvian anchovy catch in 2005. Sánchez Durand and Gallo Seminario (2009) projected that the use of these catches in the production of food for direct human consumption would add significant value to the resulting products and would increase overall fishery productivity. They highlighted the sale value of a canned product at US$8 100/tonne against that of US$440/tonne for fishmeal and also considered that assigning 1 percent of the fish destined for fishmeal to direct human consumption would generate work for 5 662 people, compared with the 66 positions that are provided by the fishmeal industry.

While some of the European feed-fish species are too small to be used for human consumption (i.e. sand eel and Norway pout), others show some potential for this use, specifically blue whiting and capelin. Although small size, poor flesh colour and high parasite load limit the potential for blue whiting, skinless blue whiting fillets can be produced from chilled or frozen whole fish for the manufacture of frozen laminated blocks for finger or portion production. Another possible product form investigated was blue whiting mince prepared from skinless fillets, which could also be used to manufacture fish cakes, fish pies and cook-freeze dishes. Uptake of these new technologies has been slow, and blue whiting is unlikely to become an important foodfish in the near future. A proportion of capelin is currently used for human consumption. Around 16 percent of the Icelandic catch in 2005 was frozen whole for sale in Japanese and East European markets. During the early part of the 2006 season, 58 000 tonnes (42 percent) of the 135 000 tonnes reported caught by Icelandic vessels were frozen for human consumption and 78 000 tonnes (58 percent) were processed into fishmeal and oil. Such low capelin catches favour a higher proportion of these fish going for human consumption. An examination of the trend in Icelandic capelin usage over the last ten years indicates a recent increase in the volume of capelin used for human consumption (Figure 9).

6.1.2 Trash or low-value fish

There is also an increasing conflict between the use of low-value/trash fish for terrestrial animals/fish and for human consumption, especially in Asia (Funge-Smith, Lindebo and Staples, 2005). Supplies of low-value/trash fish are finite and as indicated by a recent increase in price, demand is outstripping supply. It has been argued that it would be more efficient and ethical to divert more of the limited supply to human food, using value-added products, etc.

FIGURE 9
Icelandic capelin production by product type, 1994–2005



Source: FAO (2006a, 2007)

Proponents of this argument suggest that using low-value/trash fish as food for poor domestic consumers is more appropriate than supplying fishmeal plants for an export income-oriented aquaculture industry producing high-value commodities. In contrast, it can be argued food security can also be increased by improving the income generation capabilities of poor people, and that a large number of people employed in both fishing and aquaculture has a beneficial effect via income generation rather than direct food supply.

Without external interventions (such as incentives and subsidies), it will be the economics of the different uses of low-value/trash fish in different localities that will divert the use of fish in one way or the other. For example, in Viet Nam, as the national demand for fish sauce is predicted to double over the next ten years, there appears to be direct competition for mixed low-value/trash fish between producers of *Pangasius* feeds and producers of low-cost fish sauce. In contrast, operators of culture farms raising high-value marine finfish and lobsters can afford to pay more for anchovy than fish-sauce manufacturers in central Viet Nam.

6.1.3 Non-target bycatch or trimmings that are utilized for fishmeal

A number of food-fish species are also used for reduction to fishmeal and fish oil, either whole fish when market conditions make reduction an economically preferable alternative or trimmings from processing waste.

Stocks of Atlantic herring (*Clupea harengus harengus*) are improving and support a number of economically important fisheries. The majority of herring catches are used as either fresh or frozen whole fish. The EU-controlled herring fisheries (west of the United Kingdom, North Sea, Skagerrak and Kattegat) must offer fish of food grade for human consumption, and fish can only be sent for reduction if they cannot be sold in the market for human consumption. However, all small pelagic fish caught in the Baltic Sea can be offered as feed grade. The proportion of herring processed for fishmeal by the Atlanto-Scandinavian fisheries has decreased from 68 percent in 2001–2002 to 25 percent in 2004–2005 due to a combination of greater land and sea freezing capacity, as well as strengthening prices for the frozen whole product for human consumption.

The Western European catch of sprat (*Spratus spratus*) has largely been used for fishmeal, but it is a popular foodfish in Eastern European Baltic states. However, with the increased awareness of dioxin contamination of oily fish in the Baltic Sea, it may be that the demand for fish for human consumption will decrease and a greater proportion of sprat will be used for reduction (FAO, 2005b). There is the possibility that the countries of Eastern Europe will increase the use of the low-value feedfish from the cleaner waters of the North Atlantic Ocean for human consumption. However, this potential is likely to be constrained by the continued low demand for low-value fish from this region. In 1985, the regional annual consumption of low-value fish[8] was 2.5 million tonnes but dropped to 150 000 tonnes by 1997 and is predicted to increase not more than 161 000 tonnes per annum by 2020 (Delgado *et al.*, 2002).

The demand for Antarctic krill is likely to increase due to its excellent value as a nutrient source for farmed fish and crustaceans (i.e. protein, energy, essential amino acids). Other outstanding properties of krill are their natural pigment content (particularly appropriate for salmon farming), palatability, low content of pollutants, and the likely improvement of larval fish survival. These attributes make krill meal a more attractive feed than potential competitors such as squid meal, clam meal, artemia soluble and fish soluble (Sclabos, 2003). The relatively high prize of krill products may however limit their use in aquafeed in general.

In summary, the use of the main feed-fish species for direct human consumption is driven by market and other economic factors rather than by technical or product development constraints. As a result, there is unlikely to be any dramatic change over the medium term in the proportion of feed-fish species being used directly as food. However, this depends upon a number of extrinsic factors such as the availability and price of other feed-protein commodities such as soya meal.

6.2 Comparative analysis of the use of feedfish in aquafeeds versus for human consumption

As the section above indicates, there are few alternative uses of feedfish for the main feed fisheries supplying fishmeal production in Europe that are not already occurring. In European feed fisheries, a more fundamental question is whether it would be more ecologically efficient if these feed-fish stocks – which are often prey items for commercial fish species and an integral mid-level component of the food chain in many European seas – are left in the sea. Essentially, is it more effective to harvest low-trophic-level species in industrial fisheries and convert the biomass obtained to fish protein for human consumption via aquaculture systems, or is it better to leave low-trophic-level

[8] According to the International Standard Statistical Classification of Aquatic Animals and Plants(ISSCAAP), low-value fish include herrings, sardines, anchovies and mackerels.

fish in the sea where they can be consumed by their natural predators, and then to harvest species from higher trophic levels in fisheries for human consumption? This question was asked of the members of the International Council for the Exploration of the Sea (ICES) by the EC's Directorate-General Fisheries and its response was published in the annual report of the ICES Working Group on Ecosystem Effects of Fishing Activities (ICES, 2004). Its conclusions were as follows:

- The transfer efficiency of both energy and carbon between trophic levels along a food chain is not 100 percent. Energy is required for metabolism and maintenance, and only a fraction of the food consumed by a predator is actually converted to predator biomass. Transfer efficiencies in the range from 10 to 15 percent are generally accepted for predator-prey interactions involving fish predators in marine temperate shelf-sea food webs (Pauly *et al.*, 1998; Jennings, Kaiser and Reynolds, 2001).
- Taking into account the levels of fishmeal inclusion and FRCs, the total conversion efficiency of, say, a sand eel-derived salmon diet in producing a harvestable biomass is around 10–17 percent, which is much in line with natural food webs.
- In addition to the above efficiencies, the energy/material "costs" need to be considered. Additional materials are required for the production of fish feeds, as well as the energy involved in processing. However, while the trophic energy efficiency in marine food chains may be around 10–15 percent, this does not account for natural mortality due to predation, which may reduce this efficacy considerably.

ICES concluded that "if one is only concerned about the efficiency of converting sand-eel biomass to human consumption fish biomass, then the exploitation of sand eels by industrial fisheries for the aquaculture industry is at least as efficient ecologically".

ICES examined the premise that if industrial fisheries are reduced, then gains reflecting 10 percent of the reduction will be made in human consumption landings. Runs of a Multi-Species Virtual Population Analysis (MSVPA) model were used to examine this assumption, as was data on the consequences of a four-year closure of the East of Scotland sand-eel fishery on local gadoid (cod, haddock and whiting) populations. The results provided no evidence to support the contention that ceasing industrial fisheries will stimulate catches in the fisheries for human consumption at the current time and under the prevailing circumstances. ICES goes on to state that so long as the food conversion efficiencies are regularly reviewed, then a closely regulated combination of industrial fisheries and fisheries for human consumption may provide the only solution to the long-term demand for fish protein.

Hecht and Jones (2009) examined the comparative benefits of producing fishmeal for use in the rapidly expanding South African abalone farming industry versus the socio-economic benefits of harvesting the fish directly. They concluded that while the fish that were reduced to fishmeal to supply the abalone culture industry would have sustained around 741 families for a year had they utilized the fish directly, the abalone culture industry employed 814 people in 2004 (Troell *et al.*, 2006) who use their salaries to purchase substantially more than their protein requirement. This example suggests that the "secondary" use of reduction fishery products is able to sustain more families indirectly than primary use is able to sustain directly.

6.3 Risks of utilizing feedfish in the food chain

With global aquafeeds so reliant upon fishmeal from wild sources, the aquafeed industry is potentially vulnerable to economic factors that might change the price of fishmeal traded with significant consequences for what is now a low-margin farming process. The industry is also vulnerable to health issues arising from contamination of fishmeal and fish oil raw materials, either through the concentration of pollutants through the food chain or via the production and distribution process, that affect consumer confidence in the farmed product.

Two potential problems have become particularly important recently (New and Wijkström, 2002). The first problem is the presence of dioxin, polychlorinated biphenols (PCBs) and other persistent organic pollutant (POP) residues in human food products of animal origin and the potential carryover of these substances from animal feeds. The second problem is the relationship between meat and bone meal and the incidence of bovine spongiform encephalopathy (BSE) in ruminants, coupled with the linkage with Creutzfeld Jacob Disease (CJD) in humans.

6.3.1 Persistent organic pollutant (POP) residues

There are also growing concerns about ecosystem function with regard to the potential accumulation of environmental contaminants (including POPs and heavy metals) in wild fish stocks and the possible short- and long-term impacts of these contaminants on the reproduction and health of fish and piscivorous wildlife, including birds and mammals (Ross, 2002; anon, 2003; Falandysz, 2003; Weber and Goerke, 2003; Hinck *et al.,* 2006; Letcher *et al.,* 2006; Shi *et al.,* 2006; FIN, 2007). It follows from the above that there is also a risk of contamination of aquaculture products due to the use of contaminated fishmeals, fish oils and trash fish as feed inputs (SCAN, 2000; Bell *et al.*, 2005; Foran *et al.*, 2005; Tacon, 2005; Bethune *et al.*, 2006; Dorea, 2006).

In general, the lowest contaminant levels have been observed in pelagic fish species, fishmeals, fish oils and farmed salmon originating from South America (Chile and Peru), and the highest contaminant levels have been observed in pelagic fish species, fishmeals, fish oils and farmed salmon from Europe (SCAN, 2000; Joas, Potrykuse and Chambers, 2001; Easton, Luszniak and Von der Geest, 2002; EC, 2002; Hites *et al.,* 2004a, 2004b; Foran *et al.,* 2005). Moreover, as a general rule, since the majority of these contaminants are fat soluble and tend to bioaccumulate in fatty animal tissues, contaminant levels tend to be highest within the longer-lived and more fatty pelagic fish species (anon, 2003; Korsager, 2004; Oterhals, 2004).

As a consequence of the natural accumulation of POPs in fish fatty tissues and fish oil (SCAN, 2000; Bell *et al*., 2005) and the fact that aquaculture is already using over 82.2 percent of total global fish oil supplies, it is believed that dietary fish oil inclusion levels within aquafeeds will decrease in the long run as global supplies remain limited and fish oil prices continue to rise, and by so doing ensure the continued growth of the fish oil dependent marine/brackishwater aquaculture sector (Tacon, Hasan and Subasinghe, 2006).

A similar situation is expected with fishmeal, where rising prices (Pescaaldia, 2007) and decreasing supplies (in the long run, due to the increased use of traditional "forage" fish species for direct human consumption) will force the aquaculture industry (for purely economic reasons) toward the increased use of more sustainable non-food grade feed resources as dietary fishmeal replacements, including the increased use of terrestrial agricultural animal and plant by-product meals.

In order to improve food safety, the EU has adopted a two-fold strategy of (i) reducing POP inputs into the environment and (ii) restricting the level of POPs that can enter the human food chain by setting the maximum and action levels[9] of dioxins in fishmeal, fish oil and aquafeeds over the period 2002–2005 (Table 12). These levels are close to the levels found in fishmeal and fish oil of European origin but much higher than the highest levels found in products originating from Chile and Peru.

The comparisons between different sources of fishmeal and fish oil show very low levels of dioxin. SCAN (2000) commented that "no adverse effects from dioxins would

[9] Action levels act as an "early warning" triggering a proactive approach from competent authorities and operators to identify sources and pathways of contamination and to take measures to eliminate them.

TABLE 12
Current EC limits on dioxins in fishmeal, fish oils and aquafeeds (ng/kg product)

Product	Maximum level	Action level
Fishmeal	1.25	1.00
Fish oil	6.00	4.50
Compounded fish feed	2.25	1.50

be expected in mammals, birds and fishes exposed to the current levels of background pollution". Despite this, a considerable proportion of the population of Europe (and undoubtedly other regions) is exceeding the tolerable weekly intake (TWI) levels for dioxins set by various authorities. As there is a considerable safety factor imposed on TWI, this does not necessarily mean that there is an appreciable risk to individual health. However, exceeding TWI levels erodes the protection of this safety factor. Food contributes more than 90 percent of our daily dioxin intake (EC, 2001). Our exposure to dioxins and PCBs is decreasing (by a factor of about 50 percent over the last 10–15 years) due to improved waste management and restrictions on the use of these materials.

6.3.2 Transmissible spongiform encephalopathy (TSE)

It is important to state that there is no epidemiological evidence for the transmission to humans of a variant of CJD caused by prions that use fish or fish products as vectors.

A temporary EU ban on the use of animal proteins in certain livestock feeds was approved in 2000 (Commission Decision 2000/766/EC over the period to June 2003, since extended to June 2005). The main purpose of the action by the EU was the removal of meat and bone meal from European animal feeds, together with the destruction of stocks of this material, in an effort to contain the spread of BSE. A permanent TSE Regulation (1234/2003) amending regulation 999/2001 covering feed controls came into effect in September 2003 (although the ban on the use of blood products and blood meal was lifted). The ban EU is currently still in force at the time of writing.

The EU ban on the use of animal proteins includes the use of fishmeal in ruminant feeds but does not ban its use in feeds for pigs or poultry or in aquafeeds. The ban on the use of fishmeal in ruminant feeds was initiated because meat and bone meal has unfortunately been used at times to adulterate fishmeal in order to alter its protein content. The ban causes a further problem for feed manufacturers, in that cross-contamination may occur between batches of feeds made for one type of livestock and batches made for other types of animals; the current EC regulation has a zero tolerance and thus manufacturers have been forced to mill ruminant and non-ruminant feeds at different factories.

7. REGIONAL ISSUES ON THE USE OF AQUATIC SPECIES AS FEED FOR AQUACULTURE

7.1 Europe

Given the high level of dependence of European aquaculture on compounded feeds in intensive systems, the issues of regional importance reflect the sourcing of raw materials for feeds rather than the environmental impact of their actual use. Three issues are of immediate concern.

- *Improved sustainable management of feed-fish stocks:* Feed fisheries, which are largely composed of small, bony pelagic fish, require quite distinct management approaches compared with the often larger and slower-growing fish harvested for direct human consumption. As described earlier in this report, management of feed fisheries needs to recognize the dynamic turnover of the stock and the high degree of inter-annual variability that may depend upon extrinsic, often climate-related factors. Furthermore, stocks may be highly migratory and, therefore, often shared among more than one fishing nation. While it is possible to provide science-based precautionary management of feed-fish stocks, political and economic reality may combine to reduce management effectiveness, as typified by the long period which it took to finalize the joint management of the northern blue whiting stock. Furthermore, the ecosystem linkages between feed fisheries and natural predators such as white fish, tunas, sea birds and marine mammals are still not fully understood, and thus further precautionary thinking is necessary in many cases.

- *Increased utilization of feedfish for human consumption:* As mentioned earlier, while feedfish from a number of feed fisheries are not suitable for direct human consumption, other feedfish are. The main barriers to their direct use are not so much technical but more related to market and other economic or cultural influences.
- *Greater substitution by protein and oil substitutes:* Substitutes for fishmeal protein and marine fish oils are continuously being sought, and progress is being made. Protein substitutes are already used in fish feed in the United Kingdom and Norway, with up to 25 percent of the protein in the feed derived from plants. The uptake of fish-oil substitutes has been slower. However, the level of substitution of fish-based meals and oils possible is limited by their lack of essential amino acids (such as lysine, methionine and histidine). Substitution at high levels may limit growth. Another issue facing the plant meal and oil option in Europe is consumer opinion and the affect that may have on the continued acceptance of farmed fish as a "high quality" product similar to its wild counterpart. To produce a product as "near to the wild product as possible", research is also focusing on the "dilution" of vegetable oils in the flesh when fish are fed diets containing 100 percent marine fish oils for six months prior to harvest. In addition, vegetable oil substitutes do not necessarily improve the environmental sustainability of the product (e.g. increased soybean production may lead to further rainforest clearance).

7.2 The Americas

The region is home to three of the top four fishing nations in the world after China, namely Peru (9.6 million tonnes in 2004), Chile (5.3 million tonnes) and the United States of America (5.0 million tonnes). A very high proportion of the fish catch within the region is destined for reduction and non-food uses (average of 47.2 percent), and the region produced 57.3 percent of the total estimated global fishmeal and about 57.1 percent of the total global fish oil in 2005 (Tacon, 2009). According to the FAO, the major pelagic reduction fisheries in the southeast Pacific Ocean have exhibited a general decline in the three most abundant pelagic species: the Peruvian anchoveta, the South American pilchard, and the Chilean jack mackerel. There is a lack of internationally accepted criteria including fishery sustainability criteria, for monitoring ecosystem impacts of reduction fisheries within the region.

Although total capture fisheries production within the region in 2004 was more than 12-times higher than aquaculture production, capture fisheries production has been stagnant over the last decade (landings decreasing by 6 percent since 1995) compared with aquaculture production within the region, which has been growing at an average rate of 8.9 percent/year since 1995.

The domestic aquaculture sector within the region used 469 500 tonnes of fishmeal (13.3 percent of total fishmeal production within the region) and 237 910 tonnes of fish oil (35.1 percent of total fish oil production within the region) in 2004. The largest consumers of fishmeal and fish oil within the region are salmonids and marine shrimp, which accounted for 89.4 percent and 96.1 percent, respectivily, of the total fishmeal and fish oil consumed by the aquaculture sector within the region in 2004. Projections concerning the future market availability and the price of fishmeal and fish oil within the region are that supplies will remain tight and prices high. As in Europe, there is a need to reduce the dependence of the aquaculture sector on fishmeal and fish oil through the use of alternative, locally available feed ingredient sources, the production of which can keep pace with the growth and specific requirements of the aquaculture sector within the region.

The use of low-value (in marketing terms) whole feed-fish species (trash fish) by the aquaculture sector within the region is relatively small and is currently restricted to the on-growing and fattening of tuna in Mexican waters with locally caught sardines (*Sardinops sagax caerulea*), with total use in 2006 estimated at about 70 000 tonnes. However, the use of feedfish as baitfish for commercial and recreational fisheries within the region (primarily in the United States of America and Canada) is believed to be greater than the use of feedfish by the aquaculture sector within the region and is conservatively estimated to be about 100 000 tonnes.

In summary, an increasing proportion of the marine fish catch is expected to be processed for direct human consumption within the region, primarily in the form of easy-to-use and affordable processed fish products, including canned marinates and stabilized surimi-based fish products (Tacon, 2009).

7.3 Africa and the Near East

The main issues of regional importance in Africa and the Near East are those of food security and poverty, and these are not just national problems (Hecht and Jones, 2009). There are 1.1 billion people in the world living in acute poverty, at least 25 percent of whom live in sub-Saharan Africa (World Bank, 2004). While poverty (when people earn less than the local equivalent buying power of US$1/day) in North Africa and the Near East has decreased over the last 20 years and hovers around 2 to 3 percent, the number of people living in poverty in sub-Saharan Africa has nearly doubled over the same period (World Bank, 2004). Countries where more than 50 percent of the population earn less than US$1/day include Zambia, Burundi, the Central African Republic, Nigeria, Niger, Mali and Sierra Leone (World Bank, 2004).

The examples from Morocco and Kenya (Abila, 2003; Naji, 2003; Nyandat, 2007), where fish protein that was affordable to the poor in the past is now no longer available because of "value-adding", raise social responsibility questions and issues. Clearly, where such imbalances exist they need to be addressed by governments and fishing companies such that the distribution of the resources is equitable and does not have a detrimental effect on basic nutritional needs of local communities. The pelagic fisheries for *dagaa* in Lake Victoria and for almost all small-pelagics, for that matter, involve straddling stocks and hence need to be managed using multinational fisheries management procedures. These should take particular cognizance of the social consequences in each country, as the action of one user in a multiuser fishery can affect the returns and, in some cases, the food security of others. Therefore, regional cooperation in managing shared fish resources using principals that promote sustainability is imperative (Hecht and Jones, 2009).

7.4 Asia and the Pacific

It has been estimated that of the 40 million tonnes of fish caught by the capture fishery in the Asia-Pacific region, 9.8 million tonnes (approximately 25 percent) are used directly (e.g. as fishmeal) or indirectly (e.g. as animal food), and contributes to a production of 28 million tonnes of foodfish for human consumption (Funge-Smith, Lindebo and Staples, 2005; FAO, 2007). FAO (2007) also highlighted the potential competing use for trash fish/low-value fish and suggested that the market that will channel this resource to different usages, a contention that is hard to reject. However, the results of the present analysis are contrary to the suggestion that there will be an increase in the channeling of the trash fish/low-value fish resource into aquaculture; overall, by the year 2010, there will be a significant decrease in the use of these resources to support an increase in aquaculture production.

In Asia, there is a need to minimize the direct usage of trash fish/low-value fish and encourage fishfarmers to use formulated feeds, which requiere the use of significantly less trash fish/low-value fish and have higher overall environmental integrity (De Silva and Turchini, 2009). The aquaculture sector in the region has to improve its collaboration with the feed industry. One area of aquafeed development in the region that has not kept pace is the utilization of animal industry by-products in feed formulation. Unlike in the west, in the region, apart from the poultry industry, the animal processing industries are relatively less centralized. Consequently, there is no large-scale producer of blood meal and bone meal. This, however, is not an unsolvable problem, and improved dialogue between sectors and targeted research could facilitate the necessary progression.

In Asia, almost all aquaculture, as is the case for agriculture, is small scale, rural and clustered. These small holdings generate synergies and work in harmony. In the case of marine finfish culture, there is an urgent need for these smallholders to adopt better feed management practices, commencing with a shift from using trash fish/low-value fish as the sole feed source to available formulated feeds. There is a general impression that such changes are difficult to bring about. This is untrue, as exemplified by the recent developments with regard to the adoption of best management practices among small-scale shrimp farmers in India (Umesh, 2007).

Feed development for a wide range of cultured aquatic species, in particular the newly emerging marine finfish species, has lagged behind and is at a far lower echelon than in the animal husbandry sector. With the changing public perceptions on the use of fishmeal and fish oil as well as trash fish/low-value fish for feeding cultured stocks, it is imperative that there be a concerted effort to develop diets with a lower fishmeal/fish oil content and to wean small-scale farmers from using trash fish/low-value fish as a feed source for cultured stocks, perhaps through a regional initiative that brings together researchers, feed manufacturers, raw material suppliers and farming communities. In this regard, there also needs to be an emphasis on the improvement of "farm-made" feeds, an important element in Asian aquaculture. This point has been advocated previously (De Silva and Davy, 1992; New, Tacon and Csavas, 1995), but it is unfortunate that little headway has been achieved. Here again, it may be necessary to adopt a regional approach to determine ways and means of improving the efficacy of farm-made feeds and disseminating appropriate strategies (De Silva and Turchini, 2009).

7.5 On going work of interest

7.5.1 Europe

Improved sustainable management of feed-fish stocks

In Europe, most work on northern stocks is through ICES, which includes a number of relevant working groups:

- Planning Group for Herring Surveys;
- Planning Group on Northeast Atlantic Pelagic Ecosystem Surveys;
- Regional Ecosystem Study Group for the North Sea;
- Study Group on Assessment Methods Applicable to Assessment of Norwegian Spring Spawning Herring and Blue Whiting Stock;
- Study Group on Regional Scale Ecology of Small Pelagics;
- Study Group on the Estimation of Spawning Stock Biomass of Sardine and Anchovy;
- Working Group on Ecosystem Effects of Fishing Activities;

- Working Group on Northern Pelagic and Blue Whiting Fisheries; and
- working group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy.

These working groups feed information into the decision-making process through the ICES Advisory Committee on Fishery Management (ACFM). The ACFM meets twice a year (summer and late autumn) to prepare its advice, which is then translated into operative fisheries management measures by national governments and the European Union. EU fisheries management in the Mediterranean Sea tends to be focused upon coastal fisheries. In general, EU catch limits or quotas are not applicable in the Mediterranean Sea, with the exception of limits on bluefin tuna that have been introduced in response to recommendations by the International Commission for the Conservation of Atlantic Tuna (ICCAT). The work of the General Fisheries Council for the Mediterranean (GFCM), on the other hand, has focused on shared or straddling stocks, particularly those involving demersal and large pelagic species. GFCM's Sub-Committee on Stock Assessment (SCSA) recently assessed the stocks of 11 small pelagic species. This assessment will result in the development of management programmes to control the pelagic trawling and purse-seine fisheries exploiting European anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*) and sprat (*Sprattus sprattus*) (FAO, 2006b).

The EU has produced a strategy and action plan to improve scientific advice and research on stock evaluation in the waters of non-EU coastal states. This plan will combine actions to (i) improve data collection, management and use; (ii) increase the level of research, especially into ecosystem considerations; (iii) strengthen the role of regional fisheries organizations (RFOs); and (iv) provide greater cooperation among European research and advisory organizations, as well as improve the capacity of national fisheries administrations to operate within a regional context.

Ultimately, pressure for improved management of feed-fish stocks must come from both the aquaculture industry and from consumers. One of the barriers to the environmental certification of aquaculture in Europe has been the inability to be assured of the sustainability of fishmeal and fish oils in compound feeds. As mentioned earlier, the sustainable production of fishmeal has become an increasingly important issue, with feed manufacturers looking to FIN for reassurance. There has also been growing pressure for independent certification through such schemes as MSC's standard for responsible fishing.

Impact of fisheries on marine ecosystems

There have been an increasing number of reviews of the impact of fisheries upon marine ecosystems, including:

- ICES/SCOR (Scientific Committee on Oceanic Research) Symposium on Ecosystem Effects of Fishing (*ICES Journal of Marine Science,* 57(3), June 2000);
- The Workshop on the Use of Ecosystem Models to Investigate Multispecies Management Strategies for Capture Fisheries (*Fisheries Centre Research Reports,* 10(2), 2002);
- The International Whaling Commission (IWC) Modeling Workshop on Cetacean-Fishery Competition (*Journal of Cetacean Research and Management*, 6 (Suppl.), 2004); and
- The Workshop on Ecosystem Approaches to Fisheries in the Southern Benguela (*African Journal of Marine Science,* 26, 2004).

Increased utilization of feedfish for human consumption

Small pelagic fish tend to be highly perishable, as the high oil content of their flesh makes them susceptible to oxidative rancidity, making the flesh soft and susceptible to physical damage and faster spoilage than white fish. The presence of zooplankton with high proteolytic activities in the guts of the fish also contributes strongly to the rapid degradation often seen in small pelagic species. The high catch rates also mean that fish to be used for human consumption must be landed, chilled and processed in large quantities, and they must be handled rapidly. Much research was carried out in the 1980s in the United States of America into the use of menhaden for surimi, but uptake was limited, because it was not possible to de-fat the flesh to achieve a shelf-stable product without affecting the taste and texture of the flesh. The Nordic Industrial Fund supported a Nordic network project entitled "Pelagic fish – New Possibilities" during the period 1998–2001 that collated technical, scientific and industrial information about the catching and processing small pelagic fish with the specific aim of facilitating diversification of small pelagic fish products, especially for direct human consumption. There has also been extensive private-sector interest in developing processing techniques to both stabilize small pelagic material and to extract the main protein components for use in more versatile forms such as surimi.

Greater substitution with protein and oil substitutes

The potential for including higher levels of non-fishmeal protein in aquafeeds has been explored for a number of years with gradual but significant success.

As discussed earlier, the proportion of oilseed and legume-derived meals in aquafeed will increase from 17 percent to 24 percent by 2010, resulting in the reduction in the use of Northern Hemisphere fishmeal, while vegetable oils will become an important source of oil in salmonid, accounting for nearly a quarter of the oil content by 2010, again resulting in the reduction in the use of Northern Hemisphere feed-fish supplies.'

Research is currently being conducted by the major aquafeed manufacturers in Europe and is being supported by research initiatives from both individual governments and the EC. Current or recent initiatives of interest include:

- *Perspectives of Plant Protein Use in Aquaculture (PEPPA) project:* This was a €2.5 million (US$3.5 million at current rate of exchange) project over 2001–2004 to (i) replace the greater amount of fishmeal with plant protein sources in fish diets while improving muscle protein growth, fish quality, health, reproductive potential and environmental quality; (ii) understand the metabolic fates of dietary amino acids and carbohydrates as carbon donors and as an energy source; and (iii) strengthen our understanding of the relationships between nutritional factors and endocrine control of muscle growth and adiposity using cellular and molecular approaches.
- *Researching Alternatives to Fish Oils in Aquaculture (RAFOA):* This EU-funded project is studying the effect of substitution of fish oils with plant oils on growth performance, fish health and product quality during the entire life cycle of salmon, rainbow trout, seabream and seabass.
- *The Directorate of the Fisheries Institute of Food and Nutrition in Norway* has also conducted similar research to that of the RAFOA project. In addition, a second project, "Fish Oil Substitution in Salmonids" (FOSIS), is currently investigating whether fish oil can be replaced by vegetable oils in the diet without reducing the nutritional value or the growth performance of the fish, while minimizing fat deposition in the flesh.
- *Two EU research projects* are studying the effects of plant oils on fish digestion and metabolism, "GLUTINTEGRITY" and "FPPARS". In addition to vegetable oils, an EU research project "PUFAFEED" is investigating the use of cultivated marine micro-organisms as an alternative to fish oil in feed for aquatic animals.

7.5.2 Africa and the Near East

In Africa, as far as could be ascertained, there are no organizations that are currently working specifically on the use of wild fish as feed in aquaculture or research as to how this practice may impact on food security and poverty reduction in the region (Hecht and Jones, 2009). However, this issue has been recognized by the Kenya Marine and Fisheries Research Institute and the fisheries departments in both Uganda and Tanzania and no doubt by authorities in most countries. In particular, these three institutions have recognized the impact of the increasing demand for dagaa (*Rastrineobola argentea)* by the animal feed industry on food security around the shores of Lake Victoria. Similarly, the fisheries department in Morocco (Institut National de Recherche Halieutique, INRH) has recognized the impact of reduction fisheries on food security and is strongly promoting improved efficiency in the supply chain so that more fish are available for human consumption (either canned or fresh) instead of being reduced to fishmeal out of necessity, as has been the case in the past. In 2001, some 500 000 tonnes, which represented 60 percent of the Moroccan pelagic catch, were reduced to fishmeal.

7.5.3 Asia and the Pacific

In recent years, the problems associated with the direct use of trash fish as feed in aquaculture have drawn increasing attention in China. During a “National Freshwater Aquaculture Development Planning Meeting” in 2004, the concept of “feed-fish” culture, based on the success of Mandarin fish culture in southern China, was endorsed as a new priority for developing high-value fish culture in the country. Fisheries authorities at the national and provincial levels have received suggestions from advisers for policy development to encourage the use of artificial feeds to gradually replace trash fish use under the marine finfish culture development framework (Xianjie, 2008). These suggestions include:

- Develop grassroot-level extension and training programmes to educate and encourage fishfarmers to use formulated feeds.
- Provide preferential financial and loan/credit support to farmers for shifting from trash fish to artificial feeds. Subsidies could be considered for direct payment to farmers when they purchase artificial feeds, or subsidies could be paid to established feed manufacturers or dealers in an attempt to lower the feed price to reduce initial burden on pioneer farmers.
- Develop fiscal and punitive mechanisms to discourage irrational and irresponsible use of trash fish, especially those practices that cause pollution and damage to the culture environment.
- Identify priority species and key technological areas for public-sector support for research and development.
- Provide guidance, support and coordination services to research institutions and the feed manufacturing industry for artificial feed development.
- Provide incentives to local fishmeal producers to develop quality fishmeal production capacity from low-quality but high-yielding fish species.
- Have stricter fishing regulations of trash fisheries by licensing through mesh-size restrictions and eliminating damaging fishing gears/methods to better protect juvenile fish resources.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

World capture fisheries have reached a plateau catch at around 94 million tonnes, with at least half of stocks fully exploited and a further quarter overexploited or depleted. In order to fulfill the growing demand of a world population that is likely to grow from around the current 6.6 billion people to 9 billion people by 2050, further growth in aquaculture production will be needed. The main issue is whether the use of forage-fish stocks and low-value bycatch (i.e. trash fish) for aquafeeds has environmental, food security and poverty implications and what alternatives exist.

8.1.1 Regional patterns in aquafeed production and use

There is a marked difference among the global regions regarding the sourcing of fish-based protein for aquafeeds. In the Americas and Europe, the intensive culture of salmonids and growing use of carnivorous marine species result in the use of high-performance formulated feeds using fishmeal from dedicated feed fisheries. In general, the histadine-rich meals from South America are preferred, although Europe still depends on regional stocks such as capelin and blue whiting. Given the rising cost of fishmeal and fish oil and the competing demands from Asia, there has been a concerted effort to develop plant-based protein supplements.

In Asia, while intensive shrimp aquaculture uses mainly compound feeds, the majority of marine and finfish aquaculture still depends upon either trash fish or simple farm-made feeds (themselves derived from trash fish). This represents a simple, cheap and readily available source of protein, although conversion ratios and environmental performance are poor. With a decline in many feed-fish stocks fished by China and Japan, there is greater demand for global fishmeal supplies. Furthermore, a combination of increased competition from other demands for key species, such as anchovy for fish sauce production, and wider pressures to reduce environmental impacts and increase productivity means that there is likely to be a partial switch from trash fish to compounded feeds by small-scale producers. However, it is likely that trash fish will continue to be an important feed component for some time to come (De Silva and Turchini, 2009).

In Africa, most small pelagics from both marine and freshwaters are destined for human consumption. In contrast to elsewhere, the majority of fishmeal produced in the region is used for animal feeds rather than for aquaculture, which is still poorly developed in most African countries (Hecht and Jones, 2009). Furthermore, with the exception of Egypt and the Islamic Republic of Iran, most aquaculture cultivates herbivorous/omnivorous species with low fishmeal requirements. Further expansion of aquaculture in the region may see a greater demand for fishmeal produced by small-scale fisheries, and increased demand by aquaculture may have consequences for livestock-dependent communities should the supply become limited (see below).

8.1.2 Scope for greater use of feedfish

There is a general recognition that many of the feed-fish stocks could be better used for direct human consumption. It is possible to can, marinate or otherwise process key species such as Peruvian anchovy and Chilean jack mackerel. To date the resulting products have been destined mostly for export, but there is considerable interest in developing low-cost products for regional consumption, especially in the poorer areas away from the coasts. One product – a risotto product from Peruvian anchovy – looks particularly promising. In Europe, species such as capelin, Atlantic herring and even blue whiting have potential for human consumption, although use of the main feed-fish species for direct human consumption is driven by market and other economic factors rather than by technical or product development constraints. As a result, there is unlikely to be any dramatic change over the medium term in the production of feed-fish species being used directly as food. However, this will depend upon a number of extrinsic factors such as the availability and price of other feed protein commodities such as soya meal.

In Asia, there has been much debate on the alternative uses of trash and low-value fish (De Silva and Turchini, 2009). Trash fish is largely inedible and can only be used for fish and animal feeds. However, there are opportunities for steering the use of low-cost fish towards direct human consumption, either directly or more likely, in some procesed form of (e.g. as a protein mix or a dried, salted or fermented product like fish sauce). However, the potential is limited due to the difficulties in sorting and separating low-value fish from other bycatch and preserving them for subsequent direct consumption.

8.1.3 Environmental issues

Environmental issues can be considered from a number of angles. Fundamental are the status of key forage-fish stocks and the consequences of fishing pressure on their predators. While such stocks are usually resilient to high exploitation levels, their robustness can be compromised by wider climatic and other perturbations. With regards to trash and low-value fish that are mainly caught as bycatch, apart from stock depletion, implications are the wider biodiversity and ecological impacts resulting from the removal of such a large and diverse biomass.

A second category of environmental concern is the impact of aquafeed use. Modern compounded feeds have been developed under increasingly strict environmental regulations and thus tend to be very efficient in conversion terms, with relatively little direct impacts from their non-digestible components. However, the net impact is highly dependent upon the conditions in which they are used and the feeding regime adopted. Of greater concern is the use of whole fish or farm-made trash-fish slurries with low FCRs, poor digestibility and high wastage. For this reason, compounded feeds are preferred for both intensive aquaculture and where there are clusters of farms taking water from the same source.

8.1.4 Food security and livelihood issues

Changing the balance between fish being used for aquafeeds and direct human consumption has implications for food security[10] at both the local and national levels. An important factor is whether the primary product (e.g. the fishmeal itself) or the secondary product (i.e. the fish that result from the aquafeed) becomes available to local populations at an affordable price. In South America, most small pelagic fish are either converted into fishmeal or into export-oriented canned and marinated products. Furthermore, most of the secondary product (e.g. farmed salmon from Chile) is also exported and only available to the affluent urban populations in the region. There has, therefore, been an emphasis on developing low-cost food alternatives, especially in Peru and Chile, to address regional food security needs. For example, the reallocation of 157 300 tonnes (1.8 percent) of the Peruvian anchovy catch from the reduction fishery to human consumption would be sufficient to raise the Peruvian annual consumption from 21 to 25 kg per capita.

In Asia, the situation is less clear cut. Most of the trash/low-value fish used for aquaculture is absorbed by small-scale producers who cannot afford compounded feeds and thus is an important factor in maintaining their livelihoods. As discussed above, there is pressure to intensify production and thus increase the use of compounded feeds. A recent study (Rola and Hasan, 2007) showed contrasting benefits from intensification – while there was a positive relationship between commercial feeding and the cost/benefit ratio (CBR) supported by the data from Thailand, the Philippines and India, data from Bangladesh, China and Viet Nam showed that extensive production resulted in a higher CBR. This suggests that for many small-scale producers – and their dependent communities – the use of trash/low-value fish makes sense from an

[10] "All people at all times have both physical and economic access to the basic food they need" (FAO Committee on World Food Security). Alternate definition: Freedom from hunger. The capability to produce an adequate amount of food for all consumers at affordable prices (FAO, 2009) (FAO Fisheries Glossary, accessed on 31 July 2009 (available at www.fao.org/fi/glossary/default.asp).

economic point of view. However, when one factors in the hidden ecological costs of bottom trawling, this is less certain.

As discussed above, in Africa the major issue appears to be the possible impact of increased demand for small pelagic fish for fish or animal feed, or indeed for export, particularly on lakeside communities traditionally dependant upon these stocks for their own subsistence needs. However, on a wider basis, the potential for increased utilization of the prolific marine forage-fish stocks for aquaculture in Africa and the significant socio-economic gains this might bring are recognized.

In summary, there is no single "answer" as to whether more use of feedfish should be made for human consumption. To anwer this question requires a regional approach that examines all the consequences – economic, social and environmental – of policy change to ensure that inappropriate solutions are not rushed through on the back of simplistic assertions.

8.2 Recommendations

Not withstanding the above, a number of recommendations can be made, which, if acted upon, would help ensure that the moderate forecasted growth in aquaculture can continue – against a background of increased global demand for fishmeal and fish oils – and that the industry improve its environmental performance, in particular with regard to the sustainable sourcing of raw materials for aquafeeds. These include recommendations provided by De Silva and Turchini (2009), Hecht and Jones (2009), Huntington (2009) and Tacon (2009):

- **Improve the management of feed fisheries** through a combination of greater political will and cooperation, as well as the gradual adoption of the ecosystem approach as implementation mechanisms evolve. This could take the form of the provision of technical and other assistance to major feed fisheries through greater cooperation and the strengthening of relevant regional fisheries management organizations. The piloting of innovative management approaches such as the certification of responsibly managed feed fisheries might provide a market incentive to influence fishmeal and fish oil purchasing.
- **Address barriers to the sourcing and use of sustainable fishmeal and fish oils** by (i) adopting feed fisheries sustainability criteria to guide buyers; (ii) improving traceability of materials, especially if blended during manufacture; (iii) encouraging sustainable purchasing strategies through the use of environmental management systems; and (iv) branding of aquafeeds and aquaculture products produced using sustainable raw materials.
- **Further develop plant and other substitutes for fishmeal and fish oil** inclusion in aquafeeds. These substitutes must be cost-effective alternatives to fish-based products, be acceptable to consumers and not raise sustainability issues in their own right. In Asia, affordable alternatives to trash fish/farm-made aquafeeds for small-scale aquaculture that have both improved growth and environmental performance should be developed.
- **Develop food products for direct human consumption** from species that are currently reduced to fishmeal and fish oil. These products should be economically competitive, appeal to domestic and export markets and be resistant to the cyclical nature of fishmeal and oil commodity pricing. In South America, the focus should be on canned, marinated and boneless minced fish products, with the latter having particular potential to address regional food security needs. In Asia, this requires the continued development of techniques to convert existing trash-fish species into low-cost products for direct consumption.
- **Investigate markets for the direct consumption of feedfish and their by-products**. In Europe, an investigation might focus on emerging markets and in particular markets in the Russian Federation, Romania, Poland and Ukraine,

which have been traditional markets for small pelagic products. Such a study would investigate why import levels have remained static over the last five years and determine the role of price, stock availability and other key factors in constraining trade. The study should also recognize the recent falls in capelin availability and the likely impact on investor confidence.

- **Develop alternatives to marine fish-bait species** by reducing the dependency of the commercial and sport/recreation fisheries sector within North America and elsewhere on the use of marine fish-bait species through the development and use of farmed fish-bait species and artificially prepared fish baits using fish processing wastes.

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Use of wild fish and other aquatic organisms as feed in aquaculture – a review of practices and implications in the Asia-Pacific

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SUMMARY

Global and Asian aquaculture have witnessed a ten-fold increase in production from 1980 to 2004. However, the relative percent contribution to production of each of the major commodities has remained almost unchanged. For example, the contribution of freshwater finfish has declined from 71 to 66 percent in Asia but has remained unchanged globally over the last 20 to 30 years. This fact has dictated trends in the use of fish as a feed for cultured stocks. The growth in the sector has gone hand in hand with an increasing dependence on fish as feed, either directly or indirectly. In a number of countries in the Asia-Pacific region, the aquaculture sector has surpassed the capture fisheries sector in its respective contributions to the gross domestic product (GDP). Aquaculture's increased contribution to national GDPs can be taken as a clear indication of the contribution of the sector to food security and poverty alleviation.

The use of finfish and other aquatic organisms as a feed source can be through direct utilization of whole or chopped raw fish in wet form, through fishmeal and fish oil in formulated feeds, and/or as live fish, although the latter is uncommon and the overall amounts used are relatively small. In the first two categories, the fish used are often termed "trash fish/low-value fish". Although attempts have been made to define this term, all definitions have a certain degree of ambiguity and/or subjectivity.

In this regional review, the amount of fish used as feed sources based on the above categories was estimated primarily from the production data, supported by assumptions on the inclusion levels of fishmeal in formulated feeds and observed feed conversion efficiencies for both formulated feeds and for stock fed trash fish/low-value fish directly. A scenario for the use of fish as feed was developed by starting from the levels of aquaculture production recorded in 2004 and assuming increases in production volumes of 10, 15 and 20 percent by 2010, respectively, for the three trajectories. In parallel, the pattern of wild fish use as feed was projected to change as fish and shrimp farmers increasingly replace farm-made feeds by incorporating trash fish/low-value fish with manufactured feeds that include fishmeal. Also, the fishmeal inclusion rates in manufactured feeds are falling slowly, and this has been incorporated into the projections.

The regional review also deals with the production of fishmeal using trash fish/low-value fish in the Asia-Pacific region. Regional fishmeal production as a whole is relatively low when compared with that of major fishmeal-producing countries such as Chile, Iceland and Norway, amounting to approximately 1 million tonnes per year. However, there is a trend towards increasing the use of fish industry waste, such as from the tuna canning industry in Thailand. The fishmeal produced in the region is priced considerably lower than globally traded fishmeal, but its quality is poorer. Total fishmeal use in Asian aquaculture in 2004 was estimated as 2 388 million tonnes, the highest proportion of this being used for crustacean aquaculture (1 418 million tonnes). Based on growth predictions (to year 2010) in the sector and improvements to feed quality and management, it is expected that the quantity of fishmeal used in Asian aquaculture will be slightly less than at present. An estimated 240 000 tonnes of fish oil is used in Asian aquaculture, principally in shrimp feeds.

Based on production estimates of commodities in 2004 that rely on trash fish/low-value fish as the main feed source, this regional review suggests that Asian aquaculture currently uses between 2 465 and 3 882 million tonnes, an amount that is predicted to decrease to between 1.890 and 2 795 million tonnes by 2010. The use of trash fish/low-value fish and fishmeal by the aquaculture sector has been repeatedly adjudicated as a non-sustainable practice, and globally the sector is seeking to reduce its dependence on fish as feed through improved feed management practices and development of better quality feeds and feed formulations using alternative ingredients. Over the next few years, decreases in the use of trash fish/low-value fish are also expected to be achieved through better conversion of raw materials into fishmeal and fish oil during the reduction processes.

The "way forward" in addressing the issue of the use of fish as feed in aquaculture in the Asia-Pacific region includes the need for a concerted regional research thrust to reduce the use of fish as feed sources in aquaculture, as has been achieved in the animal husbandry sector. Secondly, there is a need to increase farmer awareness on the use of trash fish as feed. This is achievable, considering the similar progress that has been made by the region's shrimp farming sector, which almost exclusively involves small-scale practitioners who are often clustered in a given locality.

The analysis also suggests that the use of trash fish/low-value fish in aquaculture may be compatible with improving food security and alleviating poverty. In Asia, trash fish/low-value fish is mostly landed in areas where there are other suitable fish commodities for human consumption. To make the trash fish/low-value fish suitable and available for human consumption would involve some degree of value-adding and transportation costs, which are likely to increase the price to beyond the means of the consumer, particularly in remote rural areas. Under such a scenario, the direct or indirect use of this perishable resource as a feed source to produce a consumable commodity appears to make economic sense and appears to be the most logical use for overall human benefit. In this manner, trash fish/low-value fish contributes to food security by increasing income generation opportunities and hence contributes to poverty alleviation. Another factor that needs to be taken into account is the large numbers of artisanal fishers who harvest this raw material. The continued use of trash fish/low-value fish, therefore, allows these fishers to maintain their livelihoods[1]. Admittedly, this is an area that warrants more detailed investigation, from resource use, livelihoods and economic viewpoints.

[1] The opinion expressed in this paragraph is of the authors and has not necessarily been endorsed by the editors.

1. INTRODUCTION

Aquaculture, an age-old tradition that commenced at least two millennia ago in Asia, has gradually transformed from an art form to a science over the last five to six decades. Aquaculture currently provides over 50 percent of all fish and seafood consumed globally (FAO, 2007). Asia has been in the forefront of most forms of aquaculture development and continues to lead the global production, with a contribution of 54.37 million tonnes in 2004 valued at nearly US$57 billon. In 2004, Asian aquaculture accounted for 91.5 and 80.8 percent of the global production and value, respectively.

As for any other primary production sector, aquaculture, globally or in Asia, cannot be expected to continue to grow almost exponentially. Indeed, a slowing of the growth rate has already been reported (FAO, 2007; De Silva and Hasan, 2007). The question, therefore, is whether Asian aquaculture can, at best, sustain the current growth rate, which over the last five years has averaged 6.8 percent per annum, or at worst, sustain the current level of production. Aquaculture will also need to limit any long-term impacts that it has on biodiversity and adjust to increasing demands on limited natural resources such as water, land and feed ingredients. Simultaneously, aquaculture needs to cater to increasing consumer demands for food safety, improved quality control standards, traceability and associated certification and ethical attributes (Singer and Mason, 2006), particularly in respect of exported aquaculture commodities. As Kutty (1997) pointed out, aquaculture's sustainability is no longer dependent only on economic viability but also on maintenance of environmental integrity.

Feeds and feeding and associated raw material procurement and usage are central to the success and sustainability of any animal farming system, and in this regard the aquaculture sector is no exception. However, aquaculture, a relatively new and emerging food production sector in many regions, is more often than not viewed in light of increasing concerns for and perceptions of environmental integrity, sustainability and prudent use of physical and biological resources. It has been reported that aquaculture development is unprogressive or at least wasteful in its dependence on fishmeal and fish oil (Box 1), two limited biological resources (Naylor *et al*., 1998, 2000), and its use of exotics or alien species (Naylor, Williams and Strong, 2001). However, these propositions have been strongly refuted by Hardy (2001) and Roth *et al.* (2002) and by De Silva *et al*. (2006), respectively. There is general agreement that the growth and sustainability of aquaculture will be significantly impacted by feed availability, efficacy of feed utilization, feeding practices and potential advances in feed manufacture, among others factors. These aspects are not secondary to those related to potential genetic improvements, development of culture technologies and improvements in disease prevention and control and hatchery techniques, all of which are essential for sustaining future aquaculture development.

This study reviews the status of use of trash fish/low-value fish, as well as other aquatic potential feed sources in aquaculture in the Asia-Pacific region and its possible impacts. In this context, an attempt is made to assess the availability of all types of feeds used in aquaculture in the Asia-Pacific region and evaluate the potential needs and constraints associated with feed types, availability and efficacy of utilization. This study is based on literature surveys, dedicated field studies in selected Asian nations and on two case studies dedicated to feeds and feeding in China and Viet Nam. In view of the diversity of the aquaculture practices in the Asia-Pacific region, and based on Food and Agriculture Organization of the United Nations (FAO) production data (FAO, 2007), an initial analysis was undertaken of the sector's production trends as they relate to culture environment, species/commodities cultured and the feed needs and usage.

BOX 1

Fishmeal and trash fish/low-value fish use in the Asia-Pacific region

Asia-Pacific aquaculture currently uses an estimated 2 388 thousand tonnes of fishmeal (equivalent to 10 271 thousand tonnes of raw material) and 2 465 thousand to 3 882 thousand tonnes of trash fish/low-value fish as a direct feed source. The low and high predictions for 2010, respectively, are on the order of 2 000 thousand and 2 191 thousand tonnes of fishmeal (equivalent to 8 386 thousand and 12 829 thousand, and/or 7 338 thousand and 11 225 thousand tonnes of raw material, based on expected improvements in efficiency of raw material to fishmeal conversion rates of 4.0 and 3.5) and 1 890 thousand to 2 795 thousand tonnes of trash fish/low-value fish as direct feed inputs. The estimates of trash fish use are based on production levels of cultured commodities that primarily use trash fish as the major feed source and differ significantly from some previously reported estimates. The estimates indicate that there would probably be a reduction in the amount of fish used as feed sources by the Asia-Pacific aquaculture sector in the ensuing years, even though overall aquaculture production will be higher. These reductions are likely to be brought about through better conversion efficiencies in the reduction industry processes, better feed management and also through a significant reduction of consumption by marine finfish farming through the increased use of formulated feeds.

Photos: Photographs show the use of fishmeal and trash fish/low-value fish in the Asia-Pacific aquaculture industry: A) pelleted feed prepared with fishmeal being the primary source of dietary protein; B) raw fish in farm-made moist feed; C) raw fish cut into pieces to facilitate better feeding.

A)

B)

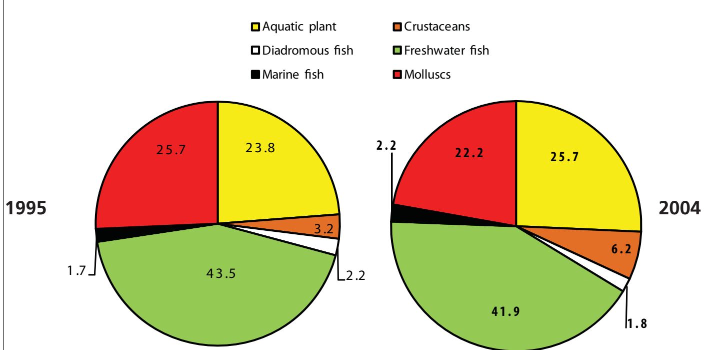
C)

2. MAJOR TRENDS IN ASIAN AQUACULTURE

Global and Asian aquaculture production has been and still is dominated by finfish (Figure 1). If seaweed culture is omitted from the calculations, finfish aquaculture accounted for 62.2 and 61.8 percent of Asian aquaculture production in 1995 and 2004, respectively. The relative contribution of each of the commodity groups has, however, remained almost unchanged over the last decade. The only significant variation recorded was a two-fold increase in the contribution of crustaceans to the total volume (Figure 1). Freshwater species contribute most to finfish production, while the relative proportions contributed by the three culture environments (freshwater, brackishwater and

FIGURE 1

The percent contribution to Asian aquaculture production (in volume) of different commodities, 1995-2004



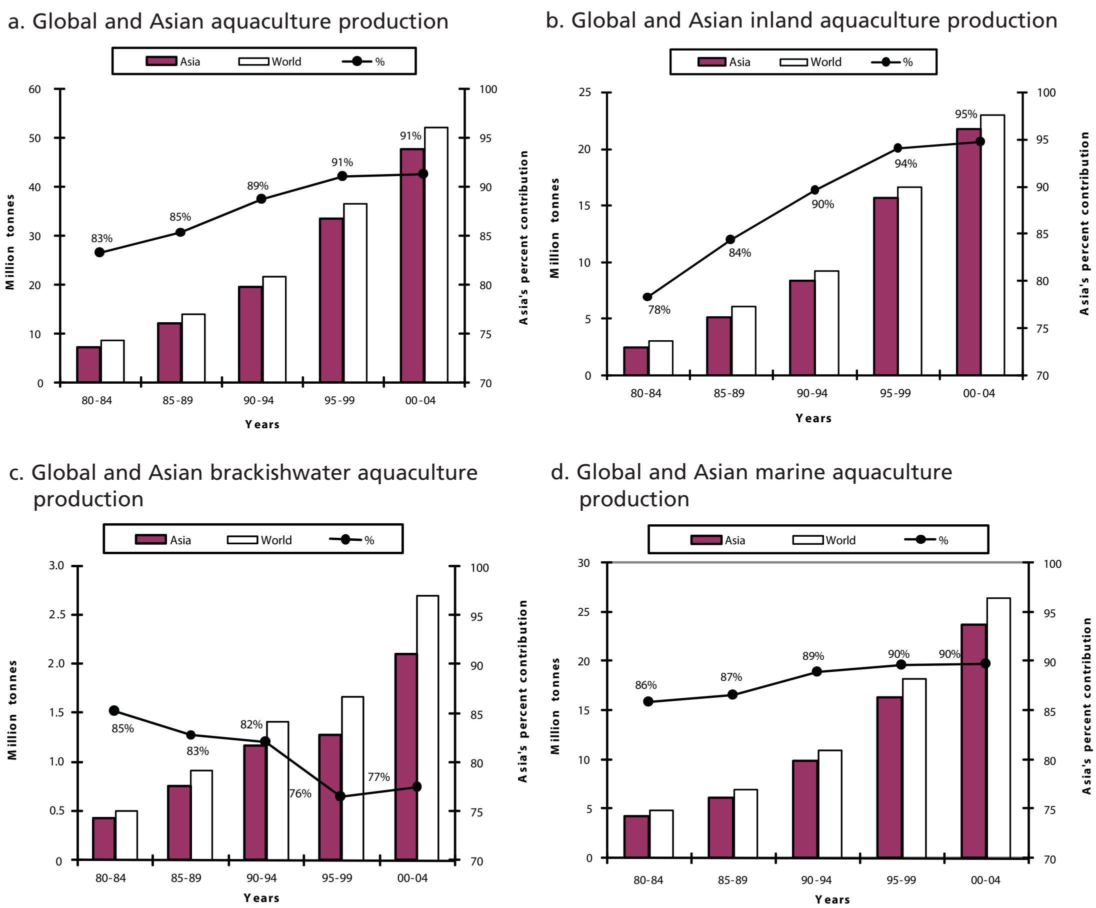
Source: FAO (2006a)

marine) have remained static. This implies that although major strides have been made in increasing the production volumes of the various commodities over the last two decades, the relative importance of each of these in the overall production scenario has remained unchanged.

In this report, seaweeds and molluscs (except for Babylon snail and abalone) are not considered, as the culture of these commodities generally is not based on externally provided feeds. Figure 2 (a–d) depicts the changes in the global and total Asian freshwater, brackishwater and marine aquaculture production from 1980 to 2004 based on five-year averages, together with the percent Asian contribution in each of the cases. Asia clearly dominates all forms of aquaculture, contributing 91, 95, 77 and 90 percent to the total global, inland, brackishwater and marine aquaculture production, respectively, in 2004. It is also evident that throughout the recent history of the sector, when aquaculture began to gain prominence as an aquatic food provider to the global community, Asian aquaculture has been the largest contributor to production volume. Comparable trends (global and Asian) in the total cultured commodities and in each of the environments are evident for finfish (Figure 3a–c) and crustaceans (Figure 4a–c), the two groups of cultured commodities that are dependent on fish as a food source. In all of the above instances, Asia continues to dominate production. Moreover, China is the main aquaculture-producing nation (FAO, 2006b) and also dominates the global fish trade (Kurien, 2005).

FIGURE 2

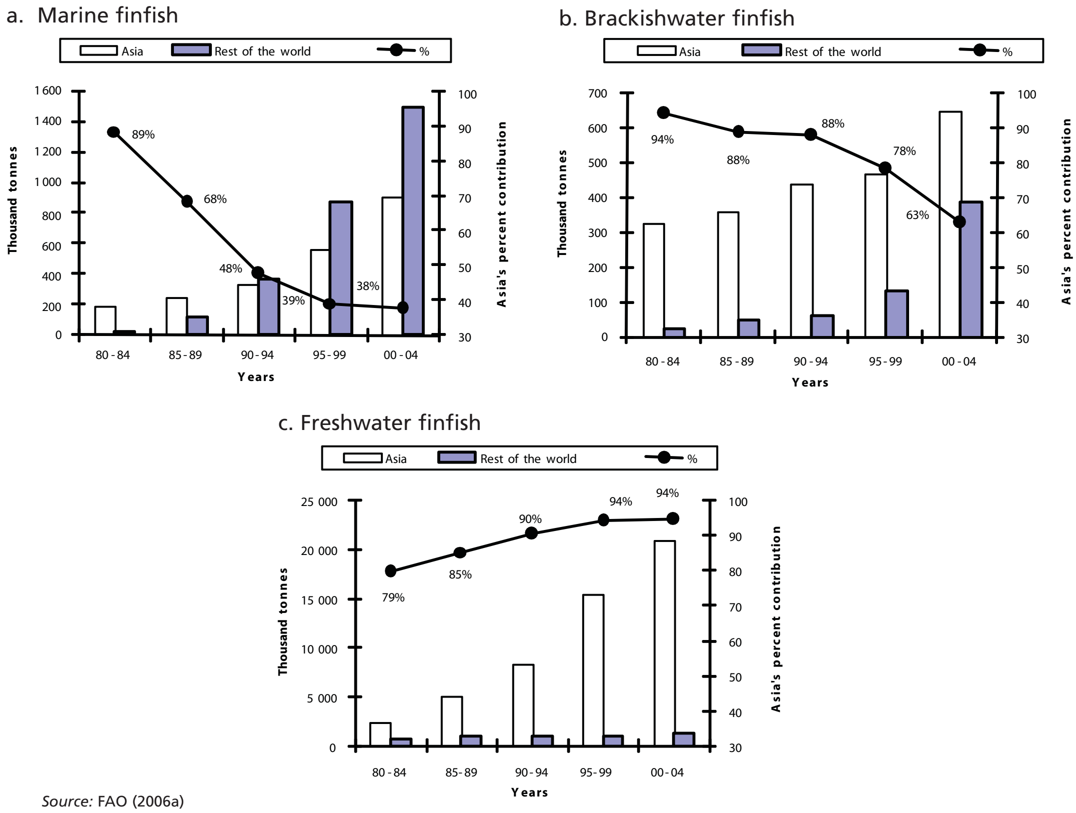
Total global and Asian aquaculture production (mean per year for five-year periods) and the percent contribution of Asian production to the total, 1980–2004



Source: FAO (2006a)

FIGURE 3

Total global and Asian cultured marine, brackishwater and freshwater finfish production (mean per year for five-year periods), 1980–2004

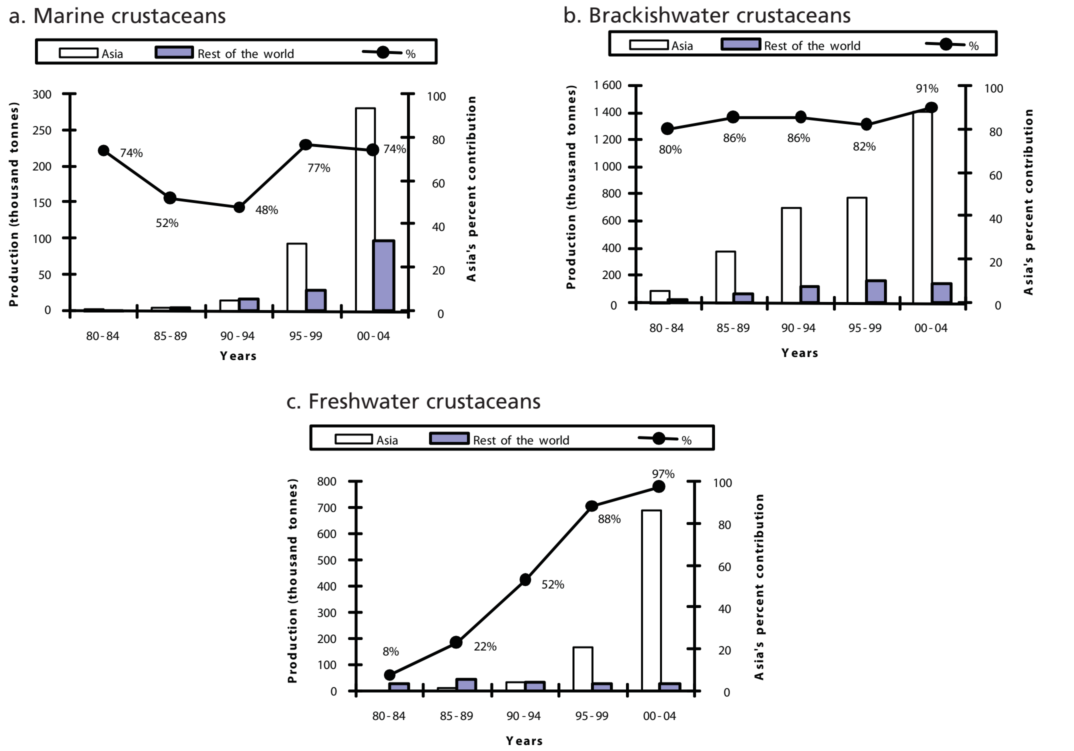


Source: FAO (2006a)

A further analysis of the data taking into account commodities and relevant species groups among finfish that are dependent on fish as food sources exemplifies the point made previously. In Figure 5, the contribution of such commodities to global and Asian aquaculture production (excluding seaweeds and molluscs) in 1980, 1990, 2000 and 2004 is depicted. Although there had been a ten-fold increase in global and Asian production of these commodities from 1980 to 2004, the percent contribution of each of the categories has remained almost unchanged. For example, the contribution of freshwater finfish declined from 71 to 66 percent in Asia, but remained unchanged globally. By contrast, Asian carnivorous finfish production in 2004 was 3 368 956 tonnes (967 348 tonnes from marine, 56 389 tonnes from brackishwater and 2 345 219 tonnes from freshwater aquaculture), while production in 1980 and 1990 were respectively and in order, 173 128 and 272 685 tonnes (marine), 2007 and 13 757 tonnes (brackishwater) and 169 550 and 437 496 tonnes (freshwater). Perhaps the greatest change is observed in crustacean production, which increased from 3 to 12 percent of total aquaculture production during the same period, both globally and in Asia. Another important change in the aquaculture sector (although perhaps less significant in the context of the total volume) is that crab production has increased to 200 000 tonnes per annum, surpassing captured production by almost five-fold.

The production figures *per se* may mask some of the major trends in the growth of the sector. In Figure 6a-d the mean yearly growth rates (percent per year) of finfish and crustacean aquaculture in different environments in Asia and the rest of the world, between 1980 and 2004 are depicted. It is evident that the growth rates in marine and brackishwater finfish aquaculture in Asia have increased somewhat, while the growth rate in freshwater finfish aquaculture has declined over the years, this trend also being

FIGURE 4
Total global and Asian cultured freshwater, brackishwater and marine crustacean production, expressed as the mean per year for five-year periods from 1980 to 2004



Source: FAO (2006a)

reflected in the sector globally. One possible reason for this trend could be the limitations on land and freshwater resources that prevent further expansion of inland aquaculture. Asia, the continent blessed with the greatest amount of freshwater resources, has the least per caput availability (Nguyen and De Silva, 2006). Another possible factor is water quality degradation that has arisen from anthropogenic developments in most watersheds in Asia, in particular, deforestation (Sodhi *et al.*, 2004) and industrial effluent discharge, making water resources unsuitable for aquaculture. Although quantitative data are not readily available, frequent media portrayals of localized fish kills in cages are common, providing indirect evidence.

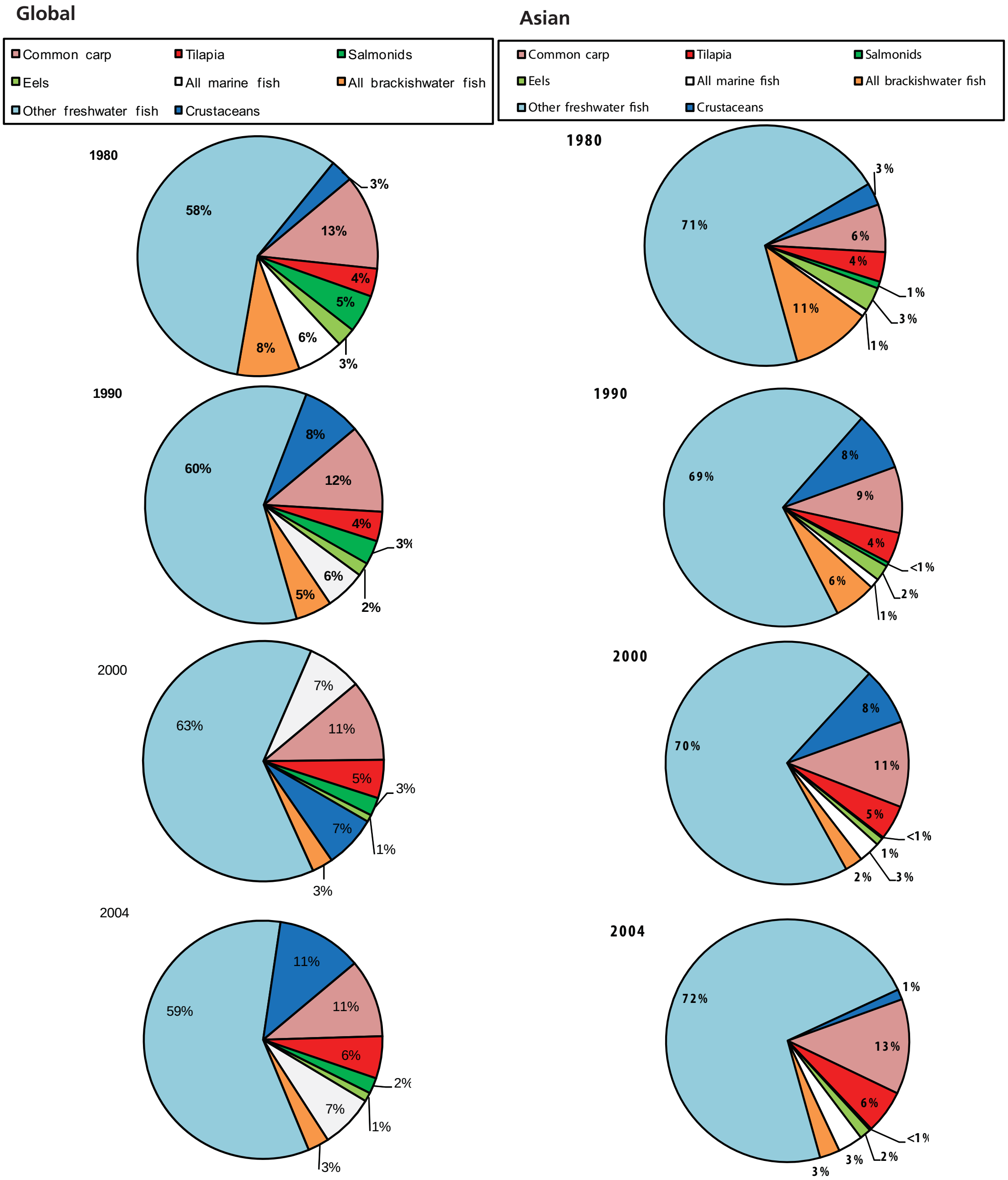
The growth rate of crustacean culture in the rest of the world has declined over the years, as opposed to that in Asia (Figure 6 b, d). It is also important to note that the relative increase was much lower in all instances in Asia, reflecting the fact that Asian aquaculture had reached considerably higher levels of production than the rest of the world prior to the 1980s (FAO, 2006b; De Silva and Hasan, 2007).

2.1 Trends in Chinese mariculture

The economic upsurge in China over the last 10–15 years has resulted in rising living standards and an increase in the proportion of the middle class, with higher disposable incomes. Consequently, this upsurge has impacted on the culinary habits of the Chinese population, leading to an increase in the consumption of high-value seafood species. This trend has been exacerbated by the perception that seafood offers better eating quality and certain health benefits. Driven by these factors, China is increasingly turning to the culture of high-value marine and freshwater fish. In the course of the expansion and intensification of aquaculture of such high-value species (which are

FIGURE 5

Percent changes in global and Asian finfish and crustacean aquaculture production. Freshwater finfish species that are generally fed formulated feed are indicated as separate entities

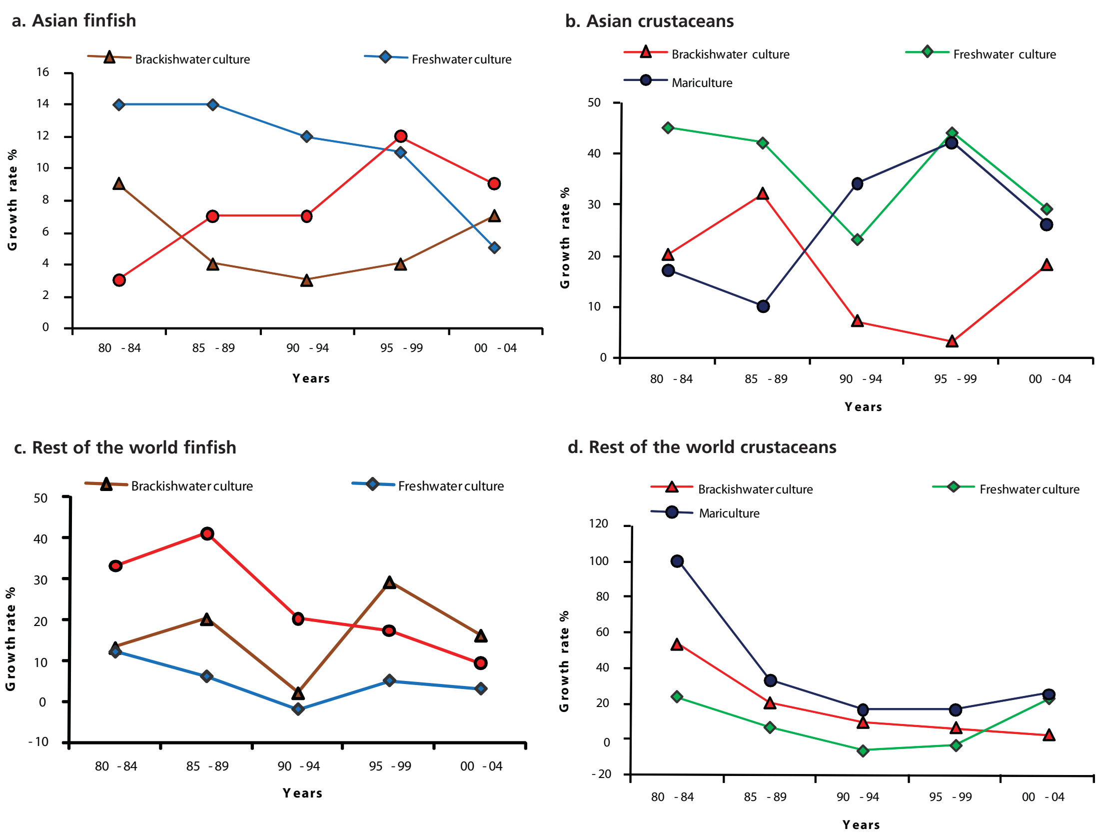


Source: FAO (2006a)

often carnivorous), the supply of aquaculture feeds with a high level and quality of protein emerges as an important factor.

However, the direct utilization of trash fish and low-value and small-sized live fish in growing high-value fish species is relatively new in Chinese aquaculture. It is often perceived that the direct use of large quantities of trash fish as feed by this sector has lead to adverse impacts on the environment and fishery resources, even though explicit scientific evidence is often lacking. In the past, there has been a lack of government policies to adequately guide the development of this type of aquaculture. As a result,

FIGURE 6
The rate of growth of finfish and crustacean aquaculture production in Asia as opposed to the rest of the world over a 25-year period, based on the mean of five-year blocks



Source: FAO (2006a)

some environmentally friendly and technically acceptable practices and techniques relating to the use of trash fish were not sufficiently extended among farms.

Mariculture and coastal aquaculture produced only about 50 000 tonnes of fish and shrimp in 1997, while using an estimated 100 000 tonnes of artificially formulated feeds. The sector has progressed much further since then and in 2005, the mariculture production of finfish and crustaceans, which is dependent on external feed inputs, reached nearly 1.5 million tonnes (Table 1), these practices being spread across an area of 76 680 and 310 742 ha (shrimp, 230 460 ha and crabs, etc., 80 282 ha), respectively.

The rapid growth of marine finfish and crustacean culture in China since the 1990s has been facilitated by the development of marine cage-culture technology (Halwart, Soto and Arthur, 2007), pen culture (Chen *et al.*, 2007), land-based intensive culture techniques and facilities, and the transformation of low-yield coastal shrimp ponds into marine finfish farms. In addition, from the late 1990s, Chinese researchers achieved consecutive successes in the artificial propagation and nursing techniques for a significant number of marine finfish species with aquaculture potential, facilitating the growth of finfish farming in all coastal regions and thereby allowing mariculture to become an important aquaculture subsector in the country.

The national production of marine finfish from aquaculture in 2005 was about 660 000 tonnes (Table 1), and the geographical distribution of this production is summarized in Table 2. Overall, over 60 species/species groups are cultured, the main diversity occurring in southern China, in provinces and regions of the South China Sea coastal areas.

TABLE 1
Mariculture production in China, 2005

Group/Species	Production (tonnes)
Sea perch	87 994
Left-eyed flatfish	76 884
Large yellow croaker	69 641
Red drum	45 742
Breams	44 222
Groupers	38 915
Cobia	18 882
Fugu	18 802
Yellowtails	11 973
Right-eyed flatfish	5 676
Other fish species	240 197
Total finfish	**658 928**
Shrimp	
Pacific white shrimp	407 642
Giant tiger prawn	75 731
Fleshy prawn	49 901
Kuruma shrimp	41 090
Other shrimp species	49 794
Total shrimp	**624 158**
Crabs	
Swimming crab	79 068
Mud crab	111 423
Other crab species	13 805
Total crabs	**204 296**

Source: Xianjie (2008)

TABLE 2
The geographic distribution of cultured marine finfish production in China

Geographical region	Production (tonnes)	Species/species groups
Coastal areas of the Yellow and Bohai Seas	184 000	Flatfish (e.g. introduced turbot and sole)
Shandong province	120 000	Details not available
Liaoning province	47 000	
Fujian province*	150 000	Large yellow croaker (*Larimichthys crocea*), red drum (*Sciaenops ocellatus*), red seabream (*Pagrus major*), black porgy (*Acanthopagrus schlegelii schlegelii*)
Zhejiang province*	40 000	
Jiangsu province*	18 000	
Guangdong province**	223 000	Orange-spotted grouper (*Epinephelus coioides*), Hong Kong grouper (*E. akaara*), flathead mullet (*Mugil cephalus*), Japanese seaperch (*Lateolabrax japonicus*), barramundi (*Lates calcarifer*), (Amoy croaker (*Agyrosomus amoyensis*), *Nibea coibor, Pomadsys hasta*, red seabream, goldlined seabream (*Rhabdosargus sarba*), black porgy, red drum, cobia, (*Rachycentron canadum*), derbio (*Trachinotus ovatus*), four-eyed sleeper (*Bostrichthys sinensis*), *Takifugu obscurus*
Guangxi Autonomous Region**	25 000	
Hainan province**	20 000	

*Coastal provinces of eastern China.
** Provinces and regions of the South China Sea.
Source: Xianjie (2008)

There are three major types of marine finfish farming systems in China: indoor culture, pond culture and cage culture, and the culture techniques used in these systems are being refined continuously. The indoor culture of marine finfish is found mainly in Shandong and Liaoning provinces around the Yellow and Bohai seas in northern China. The major species groups cultured are flatfishes, breams and puffer.

Pond culture of marine finfish is spread along the coast of the East China Sea and the South China Sea (Table 2). Guangdong province is the largest producer, contributing 150 000 tonnes of marine finfish from pond culture. During the mid and late 1980s, Guangdong province pioneered the development of large areas of brackishwater ponds in the Pearl River Delta region, becoming the leader of marine finfish farming in estuarine and coastal areas of China. The major cultured species include Japanese seaperch (*Lateolabrax japonicus*), barramundi (Asian seabass) (*Lates calcarifer*), yellowfin seabream (*Acanthopagrus latus*), goldlined seabream (*Rhabdosargus sarba*), flathead mullet (*Mugil cephalus*), mangrove red snapper (*Lutjanus argentimaculatus*), derbio (*Trachinotus ovatus*), spotted scat (*Scatophagus argus*) and red drum (*Sciaenops ocellatus*).

Cage culture of marine finfish is widespread throughout China's coastal bays (Chen *et al.*, 2007; Halwart, Soto and Arthur, 2007) and is the major sea-farming method. The cultured species are very diverse but are mostly of higher market value. Major cultured species include groupers, flathead mullet, barramundi, sea bream, black porgy, red drum, cobia and puffer (Table 2). The annual output from cage culture is about 300 000 tonnes, out of which Fujian province produces 100 000–110 000 tonnes, Guangdong province produces 70 000–80 000 tonnes, and Zhejiang and Shandong provinces together produce 30 000–40 000 tonnes.

3. USE OF FEEDS IN AQUACULTURE

Aquaculture is an industry whose great diversity is reflected in the range of species cultured, singly and/or in combination, the culture environments (freshwater, brackishwater and marine), the intensity of culture practices, the nature of the containment systems utilized (ponds, cages, raceways, enclosed pens, recirculation systems, substrates (for e.g. net bags, ropes) used in seaweed and mollusc culture), and the socio-economic *milieu* in which the activities occur. All of the above are reflected in feeds and feeding. Fertilization as an indirect "feed" input into aquaculture is not dealt with in this report, and readers are referred to De Silva and Hasan (2007) for the details.

3.1 Importance of feeds in sustaining Asian aquaculture

De Silva and Hasan (2007) pointed out that the efficacy of feeds used in aquaculture has the potential to bring about major changes in culture practices, even in the case of small-scale rural aquaculture enterprises, which collectively make a significant contribution to the total production, economic value and social wellbeing of communities. In this regard, the fast-developing culture of pangasiid catfish, commonly referred to as sutchi catfish, striped catfish or tra catfish (*Pangasianodon hypophthalamus*), in the Mekong Delta is a good example. Feed costs have brought about a significant shift from pangasiid cage culture (once the dominate practice) to pond culture, as feeds account for only 78 percent of total costs in pond culture but for 90 percent when cages are used (Hung and Merican, 2006). Equally, changes in the market chains can bring about significant shifts in aquaculture practices (De Silva, 2008). One of the most notable recent changes, for example, is that of freshwater carp culture in Myanmar. In this instance, the recent opening of an export market to the Middle East and Europe (Aye *et al.*, 2007) has triggered changes in the culture practices of the Indian major carp species, rohu (*Labeo rohita*) and catla (*Gibelion catla*). In these farming systems, a significant amount of formulated feeds is beginning to be utilized, as opposed to the culture practices of five years ago (Ng, Soe and Phone, 2007), which were conducted in a far less intensive manner. Most importantly, however, all evidence indicates that the export of these cultured species has not impacted on their availability and affordability to the local community. This has been achieved to some degree through a government policy that keeps Indian major carps cultured for exportation in production entities that are separate from those that produce the same fish for local consumption (Aye *et al*., 2007).

However, irrespective of the culture practice, the provision of food/nutrients to the cultured stock(s) is a crucial element in the farming activity. In general, the nature of the food availability, among other husbandry practices, will impact on the profitability and viability of the culture operations. An additional factor is the availability of ingredients at a suitable cost, either singly and/or in formulated feeds. In particular, the availability of fishmeal and fish oil at a reasonable price is fundamental to the long-term sustainability of the culture of marine carnivorous finfish species. In this regard, the availability and use of trash fish/low-value fish that forms the basis for the manufacture of feeds has become an issue of public concern and scientific debate (Naylor *et al*., 1998, 2000; Hardy, 2001; Roth *et al*., 2002).

Until recently, attention in respect of the "feeds-ingredients-protein sources-aquaculture" issue chain was mostly directed at fishmeal-related aspects. This is understandable, as until about the mid-1980s mariculture was still in its infancy, and aspects related to fish oil were essentially a non-issue. However, with the relatively rapid development of mariculture and the fact that currently 87 percent of the global fish oil production is used in aquaculture (Tacon, 2007), fish oil usage in aquaculture has become a burgeoning issue, and in most ways a more critical one than the use of fishmeal, as suggested in the early years of aquaculture development (Wijkstrom and New, 1989).

Much research effort has been expended to reduce fish oil use in aquaculture, particularly with respect to the culture of marine carnivorous species, which do not have the ability to synthesize highly unsaturated long-chain fatty acids, such as docosahexaenoic acid (22:6n-3) (DHA) and eicosapentaeonic acid (20:5n-3) (EPA), from the precursors α-linolenic acid (18:3n-3). Efforts to reduce the fish oil content in feeds have been directed, for example, to (a) replacing fish oils with vegetable oils and or blends that mimic the fish oil fatty acid profile (Regost *et al*., 2003; Izquierdo *et al*., 2003; Francis *et al*., 2007) and (b) using "finishing" or "washout" diets, where the stock is fed fish oil diets for a few weeks prior to harvesting, only when this change will enable the stock to achieve the desired flesh quality (Glencross, Hawkins and Vurnow, 2003; Jobling, 2004; Turchini, Francis and De Silva, 2007). These research efforts are complimented with those on new alternative lipid sources rich in long-chain polyunsaturated fatty acids, such as single cell oils or marine invertebrate oils, and/or the genetic manipulation of oilseed crops, to obtain terrestrial vegetable oils rich in EPA and DHA.

Although it is estimated that 87 percent of the total global fish oil production of 800 000 tonnes in 2006 (Jackson, 2007; Tacon, 2007) was used in aquaculture, a rational analysis of this usage (which has a bearing on the culture of marine carnivorous fish in Asia) has not been undertaken. The data from Jackson (2007) suggest that salmon and trout culture accounted for 390 000 and 120 000 tonnes, respectively, or nearly 65 percent of the global fish oil production. The fish species predominantly cultured in Asia (e.g. tilapias, carps, milkfish and eels) accounted for only a small proportion of the fish oil used in Asia (total of about 240 000 tonnes), the bulk being used by other marine finfish and shrimp. The envisaged increase in the use of fish oil in tilapia and carp feeds is surprising, as it is known that these species groups are capable of desaturation and elongation of base 18:3n-3 and 18:2n-6 fatty acids into longer and more unsaturated fatty acids (Kanazawa, Teshima and Ono, 1979; Kanazawa *et al.*, 1980), and as it is also known that these species require small amount of total dietary lipid in their diets. Therefore, it is surprising, as Jackson (2007) argued, that the use of fish oil in feeds for carps and tilapias will increase, while a marked reduction will occur for salmonids, all groups still witnessing an increased production, up to 2012. Apart from the indirect suggestion that tilapia and carp feeds may not need fish oil, there is minimal salmonid culture in Asia (salmonid production in 2004 was limited to only 22 324, 11 869 and 3 502 tonnes for Japan, China and the Republic of Korea, respectively). In essence, therefore, the direct use of fish oils in diets in Asian aquaculture amounts to less than 20 percent of global production, even though Asia accounts for more than 85 percent of total global aquaculture production. However, taking into consideration that the mariculture production of carnivorous finfish and shrimp is witnessing a marked growth, this scenario is bound to change.

The fact that most Asian mariculture is dependent on the use of trash fish/low-value fish entails a minimal demand on global fish oil supplies *per se*. However, with the envisaged changes away from the direct use of trash fish/low-value fish in Asian mariculture, the demand for fish oil in feeds used in this sector is likely to increase.

3.2 Basic feed types

The feed types used in Asian aquaculture are closely related to the intensity of the culture practices and to the species cultured. It is commonly accepted that all aquaculture practices can be categorized as extensive, semi-intensive or intensive. From a feed input/utilization viewpoint, extensive culture practices will not use any external feed input and the stock will obtain all its nutritional needs from the natural foods produced within the system, while in semi-intensive systems, the stock will be provided with supplementary feeds that are not nutritionally complete, and finally, in intensive systems, the stock will depend entirely on external feed inputs that have to be nutritionally complete. These practices are a continuum and it is, at times, difficult to draw a line between intensive and semi-intensive aquaculture. At the lower end of the spectrum, in semi-intensive aquaculture, feed inputs can be single ingredients (such as rice bran) or simple mixes of feed ingredients. At the opposite end of the spectrum will be a more or less nutritionally complete mixture of ingredients that are "cooked" in some form and fed to the stock as a semi-moist dough (Figure 7), as a crude pellet or even as a moist mixture. Farm-made feeds fall into this category.

In contrast is the feeding of whole, chopped or minced trash fish/low-value fish in Asian aquaculture (Box 1). In some cases, low-value fish are prepared in the form of fish meat and fed to high-value cultured species such as groupers. Trash fish/low-value fish are used as the only food source for most cultured marine finfish species (such as groupers, Epinephalidae), as well as mud crabs (*Scylla* spp.), lobsters (*Panulirus* spp.)

FIGURE 7
Sequence of photographs depicting farm-made feed practice on an integrated farm in Myanmar (species cultured: catfishes)

a. Raw ingredient (rice bran)

b. Cooking utensils used to make a dough consisting of poultry waste and rice bran. Poultry waste is generally obtained from the poultry pens

c. Fish feeding by placing feed in containers that are hung in the ponds

BOX 2

Catfish farming in Thailand

Hybrid catfish (*Clarias macrocephalus* x *C. gariepinnus*), the most important freshwater fish cultured in Thailand, accounted for a production of 189 940 and 130 784 tonnes in 2004 and 2005, respectively. However, over the last few years the farmgate price of catfish has declined, which is also reflected in the decreased total production. In an effort to be more cost effective, catfish farmers have adopted new strategies, the foremost of which is a change of ingredients used in farm-made feed, whereby they have shifted from the use of trash fish to wastes from the poultry processing industry. The farm-made feeds use 8 parts of poultry waste (skeletal frames with bits of flesh), 1.5 parts of lard from the cattle slaughter industry and 0.5 parts of salt. The feeds are readily accepted by the stock, and the farmers believe that the production returns have not changed. The cost of feed has been reduced by approximately 30 percent. Of course the nutritional basis behind this change remains unexplained, a situation comparable with that previously described by Wood *et al.* (1992) for shrimp farming in Andhra Pradesh, India, where the traditional farm-made feeds performed far better than feeds formulated on the strict nutritional requirements of the cultured stock. This change among catfish farmers in Thailand has resulted in a significant reduction in the dependence of freshwater finfish culture on trash fish, with apparently no change in consumer acceptability of the product.

Photos: Feed preparation, feeding of cultured fish and voraciously feeding catfish

and Babylon snail (*Babylonia areolata*), providing all the nutritional requirements of the cultured stock. These cultured species are all relatively high-valued and are cultured primarily for export and the local, up-market, restaurant trade. The culture practices used for these commodities would normally fall within the realm of intensive culture, and it is thus an exception to the rule that these stocks obtain their nutrition from a single ingredient.

The other main category of feeds used in aquaculture is formulated feeds. Formulated feeds can be divided into two basic types, viz. “farm-made” or “home-made” feeds and commercial feeds. For the former, the formulations are based on locally available ingredients and, in general, are not strictly in accordance with the nutrient requirements of the cultured stock(s). These feeds, as the name implies, are made on farm (in accordance to the specifications provided by the farmers) or by small enterprises that are locally based and cater to a restricted farming community(ies). These feeds are made in small quantities, at most a week’s supply at a time, based on needs and demand. Bearing in mind that the great bulk of Asian aquaculture, in particular inland finfish culture, is semi-intensive, these feed types are an important entity in the chain of events, and will undoubtedly impact on the long-term sustainability of Asian aquaculture.

BOX 3

Snakehead culture

Snakeheads are difficult to wean on to pellet feed, and hence the industry continues to depend upon moist feeds that include about 70–80 percent trash fish. However, a number of small hatcheries are now beginning to wean the wild-caught snakehead fry on to pellet feed, initially feeding a mixture of pellet feed and minced trash fish and gradually reducing the latter. The fish can be completely weaned on to a dry diet in 10 to 12 days. An increasing number of grow-out farms are beginning to obtain weaned fingerlings, and in a few years, it can be expected that snakehead farming in Thailand will be transformed almost completely, as was seabass farming.

Photos: Feed bag covers and the hatchery set up used for weaning snakehead

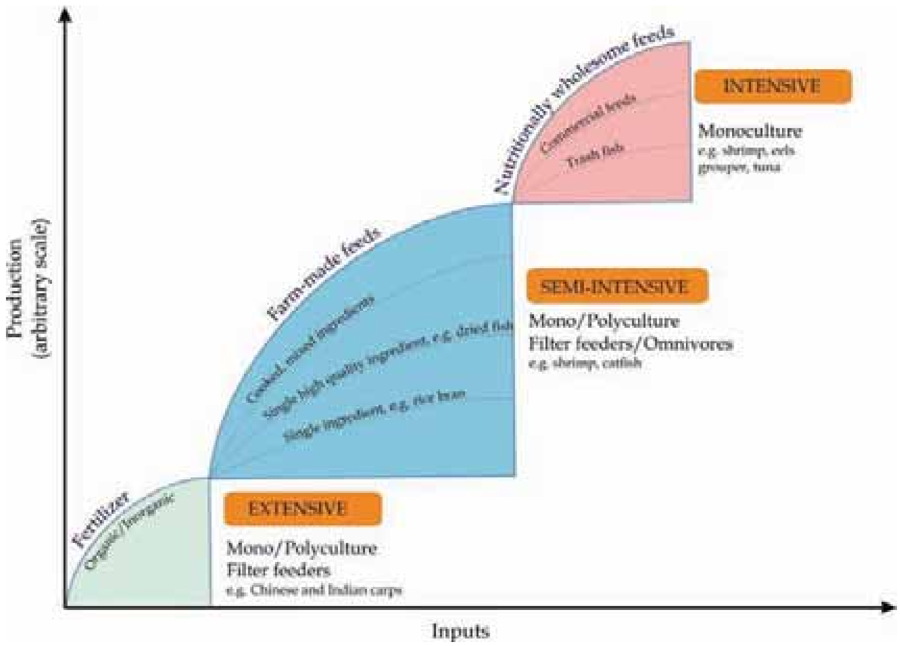
The use of farm-made feeds based on trash fish/low-value fish and/or other animal protein sources (mainly processing waste from poultry) is still a common practice in freshwater and marine carnivorous finfish culture and crab and lobster fattening in Asia. However, in some instances there are trends to change from the use of farm-made feeds to commercial feeds, the most notable of these being in catfish farming in the Mekong Delta, a sector that has witnessed an explosive growth in the last decade and was estimated to have had a production volume of over 1 million tonnes in 2007 (Phoung and Oanh, 2009). The snakehead and catfish farming sector in Thailand is predominantly based on farm-made feeds (see Boxes 2 and 3), but these feeds are predominantly based on the use of poultry processing wastes and in such feeds the amount of ingredients originating from aquatic organisms is often negligible, with exceptions such as in pangasiid culture in Viet Nam (see Section 5.2).

In contrast to "farm made" feeds, commercially manufactured feeds are produced in large quantities in central manufacturing plants and are purported to be in accordance with the dietary requirements of individual species. Rarely, more generalized feeds that are reckoned to be useable and effective for a whole range of cultured finfish are also available in the market. In Asian aquaculture, some of the commonly found feed types are those for tilapias, shrimp, eels, seabass and catfishes. Often such feeds differ marginally in their specifications for different stages of the grow-out cycle of each of the species, and of course, between species. It is not uncommon that in intensive culture systems, the feed costs often account for more than 50 percent of the recurring costs of an operation.

In general, there is very limited quality control of commercial feeds in the region, perhaps with the exception of countries such as Thailand (personal observation). This as an area where investigation is needed, especially in view of the proliferation of small-scale feed mills in the region and the ever-increasing product certification requirements of importing nations. With an exception of a study carried out in Bangladesh (Kader, Hossain and Hasan, 2005), such investigations on feed quality are rather uncommon and have to be intensified and, where appropriate, more stringent regulations introduced with respect to types of feed ingredients and their quality. A schematic representation of the efficacy of the broad feed types on the growth of cultured stocks is shown in Figure 8.

FIGURE 8

A conceptual representation of the effectiveness of fertilizers and different feed types on production



Source: De Silva and Hasan (2007)

3.3 Ingredients used

The ingredients utilized in fishfeed production vary widely depending on the feed type, the cultured stock(s) and the farmers' financial limitations. Basically, they range from agricultural and animal industry by-products to fishmeal and fish oil, among others. A detailed account of the availability of commonly used ingredients and the type of usage in Asian aquaculture, particularly of agricultural by-products, has been presented elsewhere (Tacon, 1987; Hertrampf and Pascual, 2000; De Silva and Hasan, 2007; Hasan *et al*., 2007).

3.4 Use of fish and other aquatic products in aquaculture

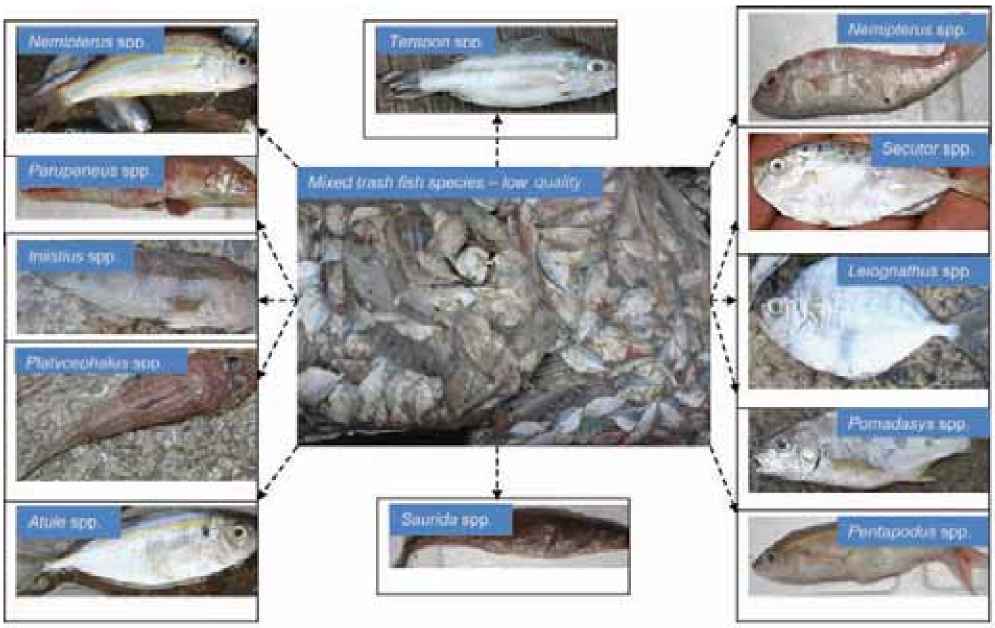
Fish used directly and/or reduced into a form such as fishmeal or fish oil to feed cultured stocks are referred to as trash fish/low-value fish. Recently it has been pointed out that the use of the term "trash fish" is misleading and that a better term would be "low-value fish", which has been defined as *"fish that are generally of relatively low economic value and typically small sized; they can be used for human consumption or as animal feeds (both fish and livestock); they may be used directly in both aquaculture to feed other fish or processed into fishmeal/oil for incorporation into formulated diets; the same is true for human food, where the fish may be consumed directly, or further processed often using traditional methods of processing small fish"* (Sugiyama, Staples and Funge-Smith, 2004). Trash fish/low-value fish have also been defined as: *"Fish that have a low commercial value by virtue of their low quality, small size or low consumer* *preference. They are either used for human consumption (often processed or preserved) or used for livestock/fish, either directly or through reduction to fishmeal/oil"* (Funge-Smith, Lindebo and Staples, 2005).

From an Asian regional viewpoint, based on use in aquaculture, the following categorization is considered appropriate:

- *Trash fish* are generally a mix of species of varying sizes, have minimum commercial value and often are not suitable for human consumption. They often originate from bycatches. When landed, the fish normally appear mushy and have an unpleasant odour (Figure 9). In certain instances, even fish that are suitable for human consumption may become less desirable due to poor capture techniques or poor handling and are thus used for feeding cultured stocks.
- *Low-value fish* normally consist of a single species (such as scad, trevally anchovies or sardines). The quality is relatively good and they may be suitable for human consumption; the flesh is firm and there is no unpleasant odour. These fish originate from targeted fisheries whose catch is aimed for human consumption (Figure 10). However, as their price is low, some farmers who raise higher-value species commonly use these fish as feed for their cultured stock. Also, some fish farmers actively fish in local waters to obtain this resource for feeding their cultured stocks, which practice they believe is cost-effective.

FIGURE 9

Mixed trash fish/low-value fish used in Asian aquaculture and species representations



The methods of capture of trash fish/low-value fish, the price ranges of the produce and its usage in selected Asian countries are discussed by Funge-Smith, Lindebo and Staples (2005). Fish species considered as trash fish/low-value fish vary from country to country, and the price also varies with usage in a given country. Importantly, not all trash fish/low-value fish are destined for use as animal feed in one form or another. A qualitative assessment by Funge-Smith, Lindebo and Staples (2005) indicated that in countries such as Bangladesh, India and the Philippines, and to a lesser extent in Thailand and China, a significant proportion is used for human consumption in fresh, dried and other processed forms. Also in Viet Nam, trash fish/low-value fish are often used for processing into fish sauce, and in some countries such as Cambodia and Viet Nam, these fish undergo "household" processing into a "fish powder" that is used predominantly for poultry feeds at the cottage level (De Silva, 2008).

FIGURE 10
Types of trash fish/low-value fish of single species caught and used in Asian aquaculture

4. USE OF FISHMEAL AND FISH OIL IN ASIAN AQUACULTURE

The preference for the use of fishmeal and fish oil in all forms of diets for cultured stocks is based on their favourable amino acid and fatty acid profiles, respectively, which provide all of these essential nutrients. These products are easily digested by aquatic animals and also provide unknown growth factors, some essential micronutrients and highly unsaturated fatty acids, all of which cannot be synthesized *de novo* in adequate quantities by most cultured stocks, particularly marine finfish.

Fishmeal and fish oil are manufactured from trash fish/low-value fish put through a "reduction process". The raw material used in industrial reduction processes is also referred to as "forage fish". Globally, the main species used on a large scale to manufacture fishmeal and fish oil are small pelagic species such as anchovetta (*Engraulis ringens*), sand eels (*Ammodytes* spp.), Atlantic menhaden (*Brevoortia tyrannus*), capelin (Family Osmeridae, e.g. *Mallotus* spp.), Atlantic herring (*Clupea harengus harengus*), Chilean jack mackerel (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*). On average, 4–5 kg of wet fish will yield 1 kg of fishmeal and 100 g of fish oil (FAO, 1986; De Silva and Anderson, 1995). However, in Asia, as will be discussed later, fishmeal manufacture is based on a species mix, and seafood industry waste is also being increasingly used. In addition, there is a trend to utilize processing waste from cultured fish such as pangasiid catfish in Viet Nam and rohu in Myanmar to extract fish oil and also as a protein source in feeds.

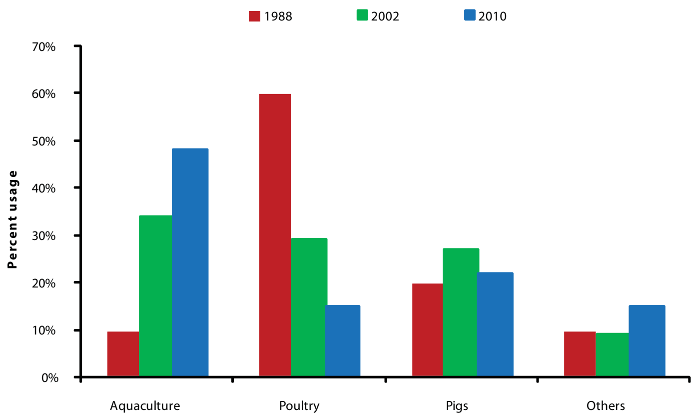
4.1 Historical aspects of the use of fishmeal and fish oil in aquaculture

Prior to the third quarter of the last century, aquaculture was not seen as a major fish-food production sector, the harvest from the oceans was thought to be inexhaustible, and fishmeal and fish oil use in aquaculture was negligible. Most of the global production of these commodities was used by the terrestrial animal husbandry sector. However, with the growth of the aquaculture sector, particularly salmonid culture in the Northern Hemisphere, the demand for fishmeal and fish oil began to increase. The first warning signs were given by Wijkstrom and New (1989) and New (1991, 1997), who suggested that the growth of the aquaculture industry could be limited by the availability of fishmeal.

Over the last 30 years, aquaculture production has grown from 8.52 million tonnes valued at US$12 billion in 1984 to 54.37 million tonnes valued at US$57 billion in 2004, an average annual rate of increase of 6.8 percent (FAO, 2007). As this growth was accompanied by the increased production of carnivorous finfish (such as salmonids) and shrimp, there was a concurrent and very significant increase in fishmeal (Figure 11) and fish oil usage in aquaculture. If this trend continues, aquaculture will become the major user of these commodities (Tacon, 2004), whose production has levelled off but whose prices continue to increase (Jackson, 2006; FAO, 2007). Indeed, the price of fishmeal doubled between 2004 and 2006, rising to almost US$1 600 per tonne, freight on board (FOB) (INFOFISH, 2006).

FIGURE 11

Changes in the proportion of fishmeal usage by different sectors over the years, including a projection for 2010



Source: Pike and Barlow (2002)

As shown in Figure 11, fishmeal usage in poultry farming has declined very significantly, while its use in the pig farming sector has remained static. This is not due to decreased production of poultry and pigs, but is a result of the replacement of fishmeal in the feeds used by these sectors with other ingredients and of improvements in feed utilization efficacy. Admittedly, the protein requirements of poultry and pigs are lower than that of fish (McDonald *et al.*, 2002), which tend to utilize proteins to meet basic metabolic energy requirements (De Silva and Anderson, 1995). Genetic improvements of poultry and pigs, a result of concerted and well-planned research outcomes, have also contributed to better feed utilization, while there have been only limited improvements of aquaculture species in this regard (Gjedrem, 1997). The questions, therefore, arise as to whether the aquaculture sector can achieve likewise results, and if so when, and if not, why, and what are the limiting factors and the pivotal constraints?

In aquaculture, unlike in poultry and pig farming, the number of species cultured is quite high (FAO, 2006b). For example, in the Asia-Pacific region 204 species belonging to 86 families are cultured, while on a global level 336 species belonging to 245 families are farmed. Each cultured species has unique nutrient requirements, and many species must be provided with externally derived food, particularly those reared under intensive culture practices, which often have to be provided with specially formulated feeds that conform to their specific nutrient requirements.

The major increases in aquaculture production have occurred through the rearing of omnivorous fish species and filter-feeding molluscs, while carnivorous fish production, although significant, still only accounts for less than 20 percent of total production. For certain cultured carnivorous species, particularly the salmonids, the fishmeal content of the diets has been significantly reduced without loss of performance and flesh quality or an increase in negative environmental effects. This achievement has occurred in a progressive fashion with the increased understanding of the physiology of the animal and its application through appropriate feed formulations (Åsgård *et al.*, 1999; Hardy, 2000). In the case of salmonids, the renowned "protein sparing effect", the physiological capability to "spare" dietary protein by lipids (De Silva and Anderson, 1995), which is a common trait in coldwater species (Beamish and Medland, 1986), has enabled a gross reduction in the fishmeal (protein) content of the feeds and resulted in the indirect benefit of such diets being more environmentally friendly in that much less nitrogen and phosphorous are discharged into the environment (Hardy, 2000). However, the metabolism differs among finfish species, particularly with respect to traits such as "protein sparing" capability. In general, the protein sparing capabilities of cultured tropical species are not that significant. Therefore, from a feed formulation viewpoint, the prospect of using this physiological trait to reduce the amount of fishmeal in the diets of tropical finfish is relatively remote. These traits, together with the generally poor uptake of research findings by feed manufacturers (De Silva and Davy, 1992; De Silva and Hasan, 2007), have delayed achieving reduction of fishmeal and fish oil use in aquaculture.

There are lessons to be learned from Japan, where large-scale mariculture originated based entirely on using trash fish/low-value fish as the feed source (Watanabe, Davy and Nose, 1989). The development of formulated feeds took a certain length of time, a major breakthrough being the development of a soft-dry diet with high palatability for Japanese amberjack (*Seriola quinqueradiata*). This breakthrough revolutionized feed development for marine cage farming and literally removed its dependence on the direct use of trash fish/low-value fish (Watanabe, Davy and Nose, 1989). Of course, feed formulations and feed manufacturing technology for finfish have now progressed much further (Box 4). Currently, much research effort is being expended on feed formulation for emerging marine cage-farming species in the Asian tropics such as grouper and cobia (Rimmer, McBride and Williams, 2004).

4.2 Fishmeal and fish oil production in Asia

Fishmeal and fish oil are world-traded commodities, with the production dominated by Chile, Iceland, Norway and Peru, all countries that have access to and exploit large single-species stocks such as the anchovetta, sand eel and Atlantic menhaden. Although fishmeal and fish oil production has increased over the years and has somewhat steadied in the last three years, these commodities are often subjected to unpredictable availability and wide price fluctuations due to the influence of climatic changes such as the El Niño events (Jackson, 2006). For example, the fishmeal price increased from approximately US$600 to US$1 600 per tonne from 2003 to January 2006 (INFOFISH, 2006), while the price of a commodity such as soybean meal, for example, remained almost static over the same period (GLOBEFISH, 2005).

BOX 4

Research trends in finfish nutrition

Over the years, the most extensive research on finfish nutrition has been the study of fishmeal replacement in feeds. This research has involved almost all species of cultured finfish and a wide range of potential ingredients ranging from agricultural by-products to single-cell proteins to animal industry by-products. Most recently, the use of krill species (*Euphausia* spp.) as a potential substitute for fishmeal (Olsen *et al*., 2006; Suontama *et al*., 2007) has received considerable attention. However, it should be noted that a reduction in krill populations has been observed (Atkinson *et al*., 2004), possibly as a result of global warming. Moreover, the use of krill may do little more than shift the problem of sustainability from finfish stocks to krill.

Fishmeal production in Asia is dominated by Thailand, China and Japan (Table 3). Chinese production has shown a decline since 2000 (Figure 12) and was only 306 000 tonnes in 2004. Globally, only Japan, Thailand, China, Taiwan POC, Indonesia and Viet Nam are included among the top 16 producers, importers and consumers of fishmeal (IFFO, 2005). It is noteworthy that, other than Japan and China (which produced 68 000 and 13 000 tonnes, respectively, in 2004), Asian countries are not significant fish oil producers.

TABLE 3
Fishmeal production in the Asia-Pacific region

Country	Year	Production (tonnes)	No. of plants	Imports (tonnes)
China[a]	2005	300 000	na*	1 580 000
Taiwan Province of China[b]	2005	16 100[J]	na	220 976
India (Karnataka)[c]	1990 to 2003	8 000–10 000	18	34 000[d]
Myanmar[e]	2005	12 610	14	na
Japan[f]	2004	195 000	na	402 000
Republic of Korea[g]	2005	45 000	na	na
Thailand[h]	2004	403 000	95	4 800
Viet Nam[i]	2004	80 000	15–20	82 000
Total		**1 061 710**		**2 323 776**

*na: not available
Source: [a]Tang (2006); [b]S-Y. Shiau (National Taiwan Ocean University, personal communication, 2007); [c]IMM Ltd. (2003); [d]Chandrapal (2005); [e]Lay (2006); [f]IFFO (2005); [g]US Department of Agriculture (http://www.indexmundi.com/en/commodities/agricultural/meal-fish/2005.html); [h]IFFO (2005); DOF (2006); H. Kongkeo (NACA, personal communication, 2007); [i]Edwards, Le and Allan (2004); Dao, Dang and Nguyen (2005); [J]FAO (2007)

Over the over the last few years, Asian production of fishmeal (notably in the three nations that rank within the top 16 globally) has not increased significantly, while consumption has decreased by about 200 000 tonnes over the period 1999 to 2004 (Figure 12). However, in Viet Nam, which is an emerging aquaculture nation, fishmeal consumption has increased to 82 000 tonnes from almost zero in 1999. By contrast, importations by Thailand have decreased from 10 080 tonnes in 2004 to 4 800 tonnes in 2006 (H. Kongkeo, NACA, personal communication, 2006). Increased domestic fishmeal production is probably the main reason for the decline in imports to Thailand. It is also claimed that there has been a gradual improvement in the quality of the fishmeal produced in Thailand, particularly in those plants owned and/or managed by Charoen Pokphand, one of the world's leading animal feed producers (Gill, 2003).

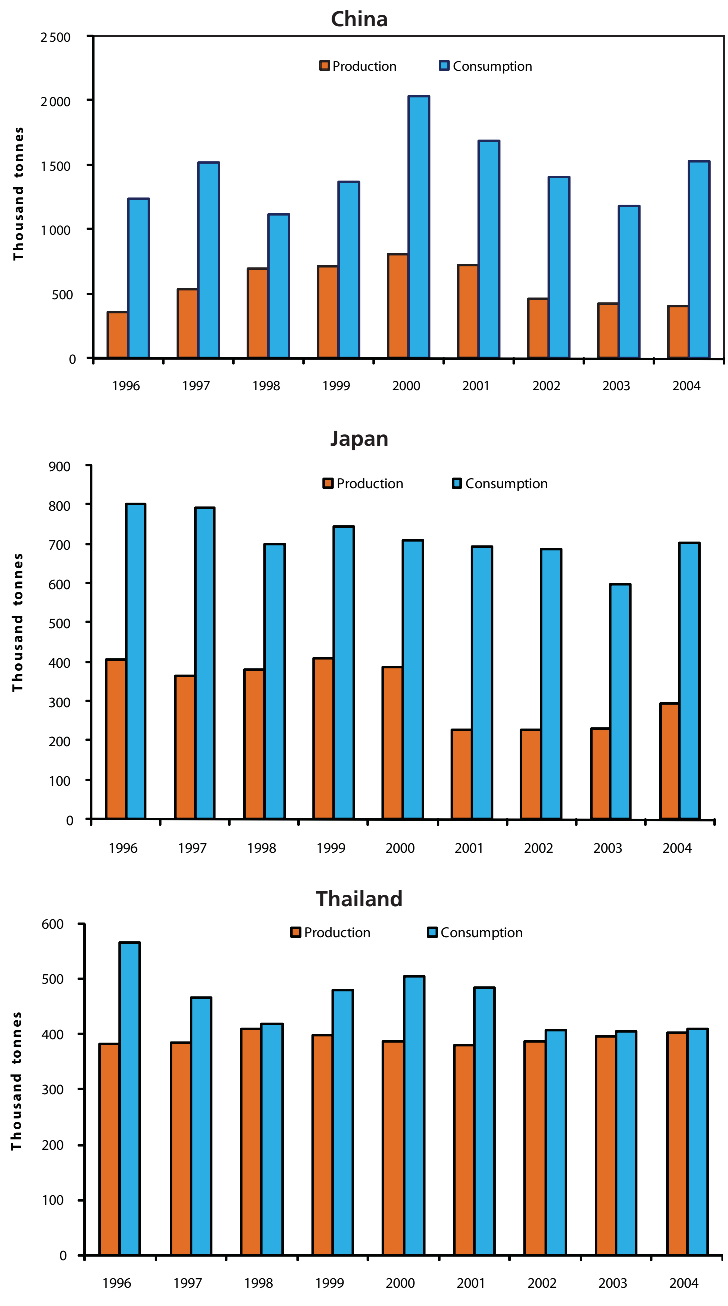
In Viet Nam, it is purported that there is a specialized fleet for catching trash fish, and a total of 300 000 to 600 000 tonnes of trash fish/low-value fish is landed, of which about 280 000 tonnes are used by the fishmeal plants, a conversion rate of 3.5 (Dao, Dang and Nguyen, 2005). By contrast Edwards, Le and Allan (2004) estimated the trash-fish landings in Viet Nam to be 933 183 tonnes in 2001, valued at Vietnamese dong (VND)1 390 416 million (US$99 315 428) (Table 4).

In Viet Nam, the commercial landings of trash fish/low-value fish vary depending on the locality, season, species composition and demand. The price is very variable and is linked to usage (also see Funge-Smith, Lindebo and Staples, 2005). Trash fish/low-value fish used for fishmeal production, fish powder production and direct feeding for cultured fish stocks range in price from VND700 to 1 800, VND500 to 800, and VND 2 000 to 2 500 per kg, respectively (US$1=VND14 500), conceivably reflecting the quality of the trash fish.

In some countries, fishmeal manufacturing also tends to use aquatic food industry waste products. However, the quantities utilized are difficult to obtain, and estimates are restricted to countries that have a major aquatic food industry sector, such as the tuna canning sector in Thailand. In Thailand, the total tonnage used for fishmeal production ranged from 388 987 to 769 361 tonnes from 1997 to 2004, and in 2004 it was 671 641 tonnes (DOF, 2006). The latter amounted to 43.2 percent of the raw material used in the production of 423 866 tonnes of fishmeal in Thailand in 2004.

In India, the coastal state of Karnataka is a major center for fishmeal production (IMM Ltd., 2003), the number of fishmeal plants having increased from two in 1975 to 18 in 1998. However, operations are very seasonal, depending on the availability of the main raw material (oil sardines, *Amblygaster* spp.), both locally and from other states such as Gujarat and Mahashatra. The fishmeal produced is very variable in quality (IMM Ltd., 2003), the average protein content being only about 40 percent. The current market price of the fishmeal produced ranges from Indian rupee (INR)5 000 to

FIGURE 12
Fishmeal production and consumption in three Asian countries (China, Japan and Thailand) that are ranked among the top 16 globally in both these respects



Source: IFFO (2005)

8 000 per tonne (US$1=INR43), considerably lower than the world market price. At present, only about three fishmeal plants are in full operation.

The demand for animal protein feed sources in China is soaring due to the rapid development of aquaculture and the husbandry of other animals. At present, there is an estimated annual supply shortage of 10 million tonnes of animal protein feed material and of 30 million tonnes of ingredients for providing energy. Animal protein sources for aquaculture feed mainly depend on fishmeal, but China produces less

TABLE 4
Estimations of trash fish/low-value fish production in the Asia-Pacific region

Country	Low-value/trash fish (tonnes)	% of total catch	Dominant gear (%)	Year of estimation
Bangladesh	71 000	17	Gillnets (48)	2001–2002
			Set bags (42)	
China	5 316 000	38	Trawl	2001
India	271 000	10–20	Trawl	2003
Philippines	78 000	4	Trawl (41), Danish seine (22) purse-seine (12)	2003
Thailand	765 000	31	Trawl (95)	1999
Viet Nam	933 183	36	Trawl	2001

Source: Funge-Smith, Lindebo and Staples (2005)

than 0.5 million tonnes of fishmeal per annum. In 2004, 1.6 million tonnes of fishmeal were imported into mainland China, accounting for 20 percent of the world's total fishmeal production or more than 25 percent of its traded volume. Fishmeal accounts for 45 percent of the total importation of fisheries products by China. These figures demonstrate the Chinese feed industry's pressing need for animal protein. In China, locally produced fishmeal is of low grade and low price because of the lack of raw materials and the use of poor and out-dated processing technology. China still relies heavily on the importation of quality fishmeal for the manufacture of feeds for marine shrimp and soft-shell turtles.

4.2.1 Localized (non-industrial) fishmeal production

Apart from major fishmeal manufacturing plants, in some Asian countries (e.g. Indonesia, India and Viet Nam) local, small-scale fishmeal plants and fish drying and powdering operations are often located near major landing sites. The produce of these plants caters mostly to the local animal husbandry sector, primarily poultry farming (also see Funge-Smith, Lindebo and Staples, 2005) and to a lesser extent, the aquaculture sector, for inclusion in farm-made feeds.

Locally prepared fishmeal (in essence, a fish powder) is typically manufactured manually in small-scale operations by drying and powdering trash fish/low-value fish. In Viet Nam, the raw material used for fish powder is of poorer grade, as indicated by the price, than that used in fishmeal production and/or for direct feeding to aquaculture stocks. The quantity of fish powder produced is estimated at 185 000 tonnes per year (Edwards, Le and Allan, 2004; Dao, Dang and Nguyen, 2005). In addition, in Viet Nam there are significant quantities of low-value fish of freshwater origin, primarily fished during the flood season in the Mekong Delta, that are sun dried and used for direct human consumption, for making fish sauce and as a substitute for fishmeal (powdered on site) in farm-made feeds in catfish culture (De Silva, 2008).

There is a paucity of data on fishmeal production in India, even though it is the world's second most important aquaculture-producing nation; however, it is common knowledge that production of fish powder in the traditional manner supersedes the industrial production of fishmeal. As early as 1995, Ali *et al*. (1995) estimated that the marine protein sources available for reduction amounted to 335 191 tonnes by dry weight, and consisted of finfish, crustaceans such as mantis shrimp (*Squilla* spp.), cephalopods and molluscs. Ali *et al*. (1995) also acknowledged that the fishmeal produced was of low quality, being mostly pulverized dried fish. Currently, the price of trash fish/low-value fish appears to range from INR2 to 10 per kg (US$1=INR43).

4.2.2 Cost of production of fishmeal

Details on the cost and use of raw material in fishmeal production are not easily accessible. However, some details on fishmeal production that are available for Thailand are summarized in Table 5. The conversion rate of the raw material over the years was consistent, averaging 3.85 over the eight-year period. The cost of Thai fishmeal in 2004 was US$590 per tonne (US$1=Thai baht (THB) 38), considerably less than the average world market price. Assuming that all three types of raw material (Table 5) used in fishmeal production in Thailand result in similar conversion efficiency (CE), in 2004, 771 723 tonnes of trash fish/low-value fish would have produced 207 694 tonnes of fishmeal. The average price of trash fish for fishmeal plants was US$121.5 per tonne of fishmeal produced, accounting for only 20.6 percent of the raw material cost of production of a tonne of fishmeal.

By contrast, in Viet Nam, based on an average price of trash fish/low-value fish used for fishmeal production of VND1 300 per kg and a conversion rate of 3.5, the total cost of the raw material needed to produce a tonne of fishmeal was approximately US$314.

TABLE 5
Summary of fishmeal production in Thailand

Year	Raw materials used (tonnes)			Fishmeal	
	Trash fish	Others	Processing waste	Tonnes	Conversion efficiency (CE)
1997	799 814	45 756	670 187	378 940	3.99
1998	758 465	53 841	511 581	342 438	3.87
1999	755 382	57 464	388 987	309 248	3.89
2000	725 489	62 675	358 927	299 073	3.83
2001	722 109	56 363	659 259	378 352	3.80
2002	679 640	59 908	768 096	391 583	3.85
2003	695 999	63 668	769 361	392 312	3.89
2004	771 723	112 586	671 641	423 866	3.67

Source: DOF (2006a)

Sinh (2007) reported that fishmeal plants in the Mekong Delta bought about 29 916 tonnes/year of trash fish/low-value fish, of which 63.3 percent was from wholesalers and/or other companies, 20 percent was directly from fishers and the remainder was from collectors. The average price of trash fish/low-value fish bought by the fishmeal plants was VND2 800 per kg (±100). The average production of fishmeal was 7 479 tonnes/year and the average selling price was VND13 000 per kg (±500). The average marketing costs were VND284 per kg of this raw material, which provided an average marketing profit of VND166 per kg of raw material. It was reported that 80.6 percent of the fishmeal produced was channelled to feed processing plants, 26.7 percent was distributed through a network of wholesalers and the remainder was exported.

4.2.3 Quality of fishmeal produced in the Asia-Pacific region

The quality of fishmeal is crucial to diet formulation and is affected by the species composition of the raw material, its freshness, the season, the presence of any foreign material (e.g. sand and contaminants) and of course, the reduction techniques employed. In essence, the quality of a fishmeal is partially determined by its protein level (higher the better) and ash content (lower the better). A comparison of the proximate composition of fishmeal of different origins is given in Table 6. It is seen that Asian fishmeal has considerably lower fat content and a very high proportion of ash, both traits that are less desired for formulation of fish feeds. It should be noted that although most fishmeal plants in Asia do not extract fish oil, the fishmeal produced has a significantly lower fat content compared to American and European fishmeals. The use of low-quality fishmeal will result in reduced performance of the cultured stock and also increased feed requirements, which increase the requirement for raw material – trash fish/low-value fish.

With an envisaged increase in the capacity of the reduction industry for fishmeal production in the Asian region, it is imperative that quality control methods be put in place and the efficacy of production improved.

TABLE 6
Typical proximate analysis of selected fishmeal of different origin

Region	% Protein	% Fat	% Ash	% Moisture
South America	65.0	9.0	16.0	10.0
Europe	72.7	9.1	10.1	8.1
United States of America	62.6	10.1	19.2	8.1
Europe/Asia	65.0	5.0	20.0	10.0

Source: Adapted from Pike (2005)

4.3 The use of trash fish/low-value fish for fishmeal production and the potential for direct human consumption

The raw material (much of which is trash fish/low-value fish) used for fishmeal production in Asia is generally in poor physical condition, often literally "mashed", and frequently not suitable for human consumption. While there are no quantitative data available, qualitative data can be derived by visual inspection (the photos in Figure 9 show the physical condition of the fish). These raw materials are landed at sites that have alternative supplies of fish of better quality, with a wide range of species of different sizes and at a range of prices that cater to a broad spectrum of socio-economic groups. If such raw materials were to be transported long distances to areas where availability of fish is significantly less, the quality would further deteriorate. Moreover, the transportation costs would be such that potential prices would not be commensurate to the product quality, and consequently there would be rather limited consumer demand.

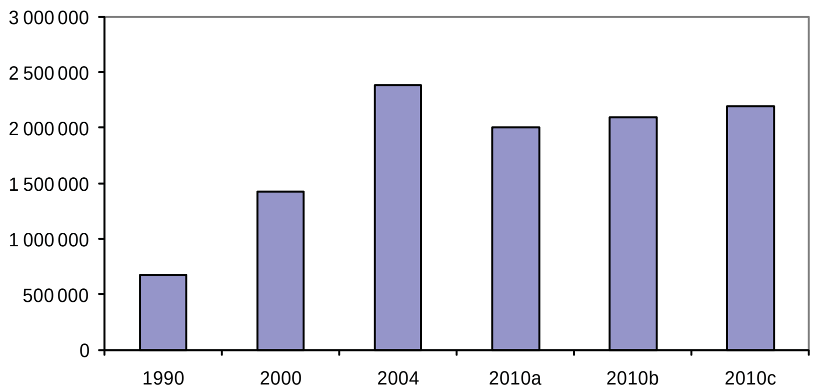
The question "if the raw material used is not reduced, can it be made available to potential consumers in a reasonable state, and at an acceptable price?" is not as simple or straight forward as it is often made out to be (see Funge-Smith, Lindebo and Staples, 2005; FAO, 2007). Although no direct estimates are available, in all probability the costs of transportation and preservation (icing/refrigeration/freezing) far exceed its "real value".

A parallel can be drawn with the very seasonal "dai"[2] fishery of the Cambodian sector of the Mekong River. The overall production from the Mekong fisheries is estimated to be about 1.5 million tonnes (Coates, 2002; Sverdrup-Jensen, 2002). The dai fishery operates for about six to eight weeks, and the bulk of the catch is small migrating species, mostly cyprinids and pangasiids, with yields ranging from 7 000 to 18 000 tonnes per year (Sverdrup-Jensen, 2002). The bulk of the catch is probably too large in volume and too low in value to be transported into neighbouring countries for direct consumption, and hence value-adding has been a traditional best use of the raw material. These value-added products are used for direct human consumption, and their production is related to cultural traits that have evolved in parallel over many hundreds of years.

By contrast, in Asia, value-adding for marine species has been mostly confined drying and to a very small extent, converting into salted fish and fish sauce, the latter particularly in Viet Nam (Phan, 2007). In all these instances, the fish used are of relatively high quality and suitable for human consumption, either fresh or reduced.

[2] The "dai" or "bagnet" fishery is the seasonal capture fishery based on the yearly crop of small fish species migrating out of flooded areas around the Great Lake and Tonle Sap River to the Mekong River.

FIGURE 13
The estimated fishmeal use in compounded feeds in Asian aquaculture



Source: Data from Table 8

Although fishmeal production in Asia is still relatively small, it is growing, albeit slowly. The fact that a nation such as Myanmar produced nearly 12 000 tonnes of fishmeal is of importance to the region, and in this instance the raw material used is considered to be unsuitable for direct consumption. There are 14 reduction plants for this purpose employing over 300 persons (Lay, 2006). The financial gains from this additional employment may well exceed the equivalent food security value of this resource if the fish were used for direct human consumption. In all of the above instances, a potential waste is eliminated and employment is created, indirectly contributing to poverty alleviation and food security (Aye *et al*., 2007).

Asia is the world's major aquaculture producer, and given the current trend towards increased production of species that require feeds with relatively high protein content (i.e. fishmeal) and the relatively limited fishmeal and fish oil production in Asia, Asian aquaculture development is bound to be impacted by global trends.

In Tables 7 and 8, three projections for the growth of Asian aquaculture and the corresponding use of fishmeal by the sector are made based on production increases of 10, 15 and 20 percent from the level in 2004, a corresponding increase in the use of compounded feeds for certain groups, a decrease in the amount of fishmeal used in the feeds and improvements in conversion efficiencies. The latter two criteria are admittedly subjective, but the improvements expected are based on those achieved over the last

TABLE 7
Asian aquaculture production (tonnes) for groups of species farmed on fish feeds that include fishmeal

Species group	1990	2000	2004	Projected 2004–2010 increase in production		
				(10%)	(15%)	(20%)
Crustaceans	618 178	1 644 365	3 338 706	3 672 577	3 839 512	4 006 447
Marine/diadromous fish	964 115	1 586 385	2 158 865	2 374 752	2 482 695	2 590 638
Milkfish	399 554	429 622	514 656	566 122	591 854	617 587
Others*	564 561	1 156 763	1 644 209	1 808 630	1 890 840	1 973 051
Freshwater fish	6 277 800	18 342 611	22 431 118	24 674 229	25 795 785	26 917 341
Anguillidae	163 505	218 035	238 508	262 359	274 284	286 210
Catfishes	74 791	136 388	270 101	297 111	310 616	324 121
Cichlidae	285 561	953 202	1 398 723	1 538 595	1 608 531	1 678 468

*Include all other cultured marine species.
Source: FAO (2006a)

TABLE 8
Estimated amounts of fishmeal used in Asian fish feeds

Species group	Criteria used 1990–2004			Estimated fishmeal usage (tonnes)*****		
	Feed usage (%)**	Fishmeal (%)***	CE****	1990	2000	2004
Crustaceans	100	25	1.7	262 727	698 855	1 418 951
Marine fish*	50	45	1.5	190 542	390 461	554 920
Milkfish	100	12	1.6	76 713	82 488	98 813
Anguillidae	100	50	1.4	114 200	152 625	166 956
Catfishes	80	3	1.4	3 140	5 727	11 344
Cichlidae	85	7	1.4	27 985	97 783	137 074
			Total	**675 307**	**1 427 939**	**2 388 058**
Estimates for 2010				**Estimated fishmeal usage (tonnes)**		
Species group	**Feed usage (%)**	**Fishmeal (%)**	**CE**	**10%********	**15%**	**20%**
Crustaceans	100	20	1.5	1 101 773	1 151 853	1 202 934
Marine fish	70	40	1.3	658 341	688 265	718 190
Milkfish	100	5	1.4	39 628	41 934	43 231
Anguillidae	100	40	1.2	125 933	129 257	137 381
Catfishes	80	4	1.3	7 724	8 076	8 427
Cichlidae	90	4	1.2	66 467	77 176	80 566
			Total	**1 999 866**	**2 096 561**	**2 190 729**

*All marine species as per Table 7.
**Production based on formulated feeds.
***Percent content of fishmeal in feed.
**** CE = conversion efficiency (kg of dry feed required to produce 1.0 kg of fresh fish).
*****Fishmeal use estimated using the production figure of Table 7.
******Increase in production, in percent, for the period 2004–2010.
Source: Fishmeal use in feeds for species groups are based on averages derived from the literature and also used by De Silva and Hasan (2007)

ten years in feeds used in Asian aquaculture and are believed to be attainable through better formulations and improved feed management. Accordingly, in spite of envisaged increases in production, by 2010 the quantity of fishmeal used in compounded feeds in Asian aquaculture is expected to decrease, in terms of percent inclusion in feeds, from the current levels (Figure 13).

In the present analysis, fishmeal usage in the Asia-Pacific region was estimated at 1.427 millon and 2.388 millon tonnes in the years 2000 and 2004, respectively[3]. In this context, the estimates of the present study for fishmeal use in aquaculture appear to be more realistic. More recently, Merican (2006) estimated the feed requirement for shrimp and freshwater fish culture in six Asian countries (Indonesia, India, Malaysia, the Philippines, Thailand and Viet Nam) in 2005 at 2.385 millon tonnes. Assuming the mean protein content to be 65 percent and that 35 percent of the protein is from fishmeal, the total fishmeal requirement is 542 547 tonnes.

4.4 Fishmeal requirements for compounded feeds in Asian aquaculture

Estimates for raw material are computed based on the fishmeal requirements of Asian aquaculture. In this computation, the conversion rate of the raw material (essentially trash fish/low-value fish) is adjusted based on the envisaged increased efficiencies in conversion (details are given in Table 9). Based on the estimates presented in Table 9, by 2010 the raw material required for fish feeds using fishmeal in aquaculture will be at least 6.999 million tonnes and at most 8.762 million tonnes. Considering that in 2004 nearly 10 million tonnes of raw material were required to sustain Asian aquaculture production, the scenario is an optimistic one.

3 Sugiyama, Staples and Funge-Smith (2004) estimated the fishmeal usage in Asia and the Pacific to be 3 726 591 tonnes in 2001. However, it is unclear whether this amount referred to use in aquaculture or the total use.

From a global perspective, the above lower estimate approximates the use of 30 to 33 percent of the raw material used in fishmeal manufacture in Asian aquaculture. However, given that Asian fishmeal manufacturing increasingly tends to use by-products from the fish food industry, it may be that the dependence on trash fish/low-value fish for fishmeal production could decrease further.

A case in point is the example of Myanmar, a newly emerging aquaculture nation where there are 14 fish reduction plants and 28 fish-feed production plants of varying capacity dedicated to producing aquafeeds. Three of these fish-feed plants have their own fishmeal production plants supplying their fishmeal requirements. The aquafeed industry caters to both the shrimp and carp farming sectors. One feed plant that produces 200 tonnes/day of fish feed employed 104 persons (Htoo Thit Fish Feed Plant, personal communication, 2007). Another enterprise, Ayeyarwardy Fisheries Ltd., which specializes in catfish cage culture and the export of fillets, has its own fishmeal plant with a production capacity of 1 tonne/day and employs 18 persons; its output, in turn, is used for fish-feed production (70 tonnes/day), employing 36 persons. The raw material for fishmeal production comes solely from the catfish processing, which in turn employs 400 persons, and the feed is solely used for its own catfish production. As noted earlier, additional data similar to that given above are needed to objectively assess the debate on the use of trash fish/low-value fish in Asian aquaculture.

TABLE 9
Estimated use of fishmeal and raw materials in Asian aquaculture, 1990-2010

Year*	Fishmeal (tonnes)	CE1**	CE2	Raw material (tonnes)	
				CE1	CE2
1990	675 307	5	–	3 376 535	–
2000	1 427 939	4.5	–	6 425 725	–
2004	2 388 058	4.3	–	10 270 894	–
2010[a]	1 999 866	4	3.5	7 999 464	6 999 531
2010[b]	2 096 561	4	3.5	8 386 244	7 337 963
2010[c]	2 190 729	4	3.5	8 762 916	7 667 551

*Three estimates (denoted by the superscripts a, b and c) for use of fishmeal have been derived for 2010. They are based on a projected production increase from 2004 to 2010 of 10, 15 and 20 percent.

**Two estimates of conversion efficiency (CE1 and CE2) were used to calculate 2010 projections of fishmeal use. CE = conversion efficiency of raw material to fishmeal (kg of raw material required to produce 1 kg of fishmeal).

Source: Data from Table 8

5. DIRECT USE OF FISH AS FEED IN ASIAN AQUACULTURE

Although trash fish/low-value fish are used for the feeding of finfish cultured in fresh-, -brackish- and marine waters, as well as for the rearing of crustaceans (such as mud crabs and lobsters) and a few molluscs, the highest usage is in marine finfish culture. Allan (2004) suggested that globally about 5 million tonnes of trash fish/low-value fish are used directly (i.e. as raw ingredients not previously reduced to fishmeal) as feed in aquaculture. D'Abramo, May and Deng (2002) estimated that in 2001 about 4 million tonnes were produced and used in China alone. As the epicenter of all forms of aquaculture, the Asia-Pacific region undoubtedly accounts for the greatest usage of trash fish as a direct feed source. Funge-Smith, Lindebo and Staples, (2005) estimated that while 9.8 million tonnes of trash fish/low-value fish are produced in the Asia-Pacific region, only a part of this volume is being directed for use in animal feeds. It is likely that a significant proportion of the remainder is processed into products such as fish sauce. For example, Edwards, Le and Allan (2004) estimated that the current production of fish sauce in Viet Nam is 80 million litres and is expected to double in ten years.

Fish fed to cultured stocks can be divided into three broad categories:

- Fish landed mostly by small-scale artisanal fishers, usually comprised of a single species at any one time, and which may be suitable for human consumption (Figure 10). This category includes slightly larger-sized fish with firmer flesh and can be and is consumed by local populations. This category is often used in the culture of crabs and molluscs (such as Babylon snail), often filleted or chopped into suitably sized pieces.
- Fish that are evidently not suitable for human consumption, mostly caught by trawlers and often equivalent to the grade of low-value fish used in fishmeal production. The species that fall into this category vary from region to region. In general, the species included in this category are small-sized, often crushed and literally "mushy" (Figure 9).
- Fish of relatively high quality that are used to feed large-sized broodstock (often individuals of over 10 kg) of some cultured marine species such as grouper. This category includes horse mackerel, large oil sardines, etc., and is small in total quantity.

5.1 Use of trash fish/low-value fish in brackishwater and marine aquaculture in Asia

5.1.1 Current use of trash fish/low-value fish in brackishwater and marine finfish aquaculture in Asia and future projections

The very significant increase in marine and brackishwater finfish production in Asia over the last ten years, amounting to an average yearly increase of 9.6 percent, has increased the demand for trash fish as the major food source for cultured brackishwater and marine finfish stocks. These cultured stocks include a range of species belonging to at least eight major families, the family/species group that currently accounts for the highest demand for trash fish species being the groupers (Table 10). In the region, fish is used as feed directly in mariculture in China, Indonesia, Malaysia, Thailand and Viet Nam, and in the farming operations for southern bluefin tuna (*Thunnus maccoyii*) in southern Australia.

Estimates of trash fish/low-value fish usage in aquaculture are available only for Australia and Viet Nam. In the case of Viet Nam, trash fish/low-value fish use in inland and coastal aquaculture ranged from 64 800 to 180 000 tonnes and from 71 820 to 143 640 tonnes, respectively, and the total amount used in aquaculture in Viet Nam was between 176 420 and 323 440 tonnes (Edwards, Le and Allan, 2004). The latter figures amount to approximately 22 percent of all trash fish/low-value fish production in Viet Nam. The bulk of trash fish/low-value fish is used for the production of fish sauce (Dao, Dang and Nguyen, 2005).

Australian southern bluefin tuna fattening, which is based on the on-growing of wild-caught juveniles, is totally dependent on trash fish/low-value fish as the feed source. In 2003, 5 409 tonnes of wild-caught tuna (of average weight 15 to 30 kg) were fattened in cages to produce 9 102 tonnes (processed weight), over a period of three to five months. The tuna were fed solely on pilchard and mackerel, and their farmgate value was Australian dollar (AUD)$266 million (US$1=AUD$0.75) (Primary Industries and Resources SA, undated; EconSearch Pty Ltd., 2004). The approximate increase in fattened weight of 4 000 tonnes required 50 000 to 60 000 tonnes of imported trash fish/low-value fish (Allan, 2004), giving a CE that is, at best, 12.5.

The computations given in Table 11 on the use of trash fish/low-value fish in Asian finfish aquaculture are based on production figures for the major cultured groups over a ten-year period (1995–2004) and at two levels of CE, 6 and 10 based on the best and the average conversion efficiencies observed in practices in Asian countries. Orachunwong, Thammasart and Lohawatanakiul (2006) estimated the conversion efficiencies when trash fish/low-value fish are used in mariculture to range from 8 to 15.

TABLE 10

Changes in total production (thousand tonnes) of cultured marine finfish species in Asia-Pacific from 1995 to 2004 and the estimated trash fish/low-value fish used (ETFU) (% use) for each species at conversion efficiencies of 6 and 10*

Species	% use	1995			1996			1997			1998			1999		
		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU	
			6	10		6	10		6	10		6	10		6	10
Barramundi	40	10	24	40	14	33	54	13	30	50	16	39	65	19	45	74
Amberjack, mackerel, etc.	0	178	0	0	152	0	0	145	0	0	154	0	0	148	0	0
Flatfishes	0	14	0	0	17	0	0	35	0	0	30	0	0	29	0	0
Cobia	30	0	0	0	0	0	0	0	0	0	1	2	3	1	1	2
Seabass	10	4	2	4	6	3	6	6	4	6	9	5	9	13	8	13
Seabream	10	86	52	86	91	54	91	97	58	97	101	61	101	107	64	107
Snappers	50	3	8	13	3	10	16	2	6	11	2	6	10	2	6	10
Groupers	80	5	24	40	5	26	43	6	28	47	6	28	47	9	41	68
Other marine finfishes	50	162	484	809	199	597	996	285	856	1 426	339	1 018	1 695	367	1 100	1 834
Total		**462**	**594**	**992**	**487**	**723**	**1 206**	**589**	**982**	**1 637**	**658**	**1 159**	**1 930**	**695**	**1 265**	**2 108**

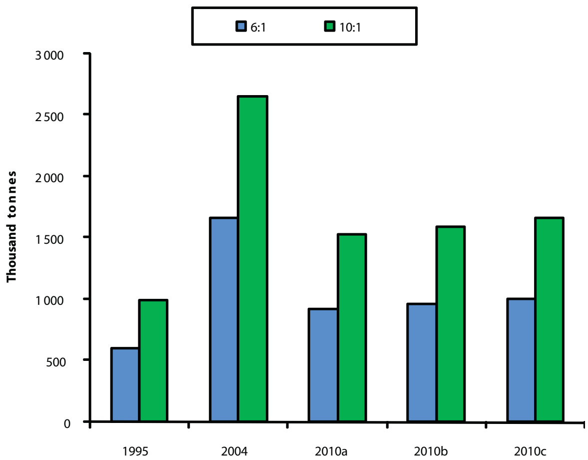
*Fish used as feed in "tuna fattening" in Australia are not included.
Source: FAO (2006a)

TABLE 10 *continued*

Species	% use	2000			2001			2002			2003			2004		
		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU	
			6	10		6	10		6	10		6	10		6	10
Barramundi	40	17	42	69	23	56	93	22	52	87	24	57	95	25	60	99
Amberjack, mackerel, etc.	0	144	0	0	160	0	0	170	0	0	176	0	0	169	0	0
Flatfishes	0	21	0	0	23	0	0	30	0	0	82	0	0	103	0	0
Cobia	30	3	5	8	3	6	10	2	4	7	21	37	62	20	37	61
Seabass	10	19	11	19	17	10	17	17	10	17	104	62	104	110	66	110
Seabream	10	107	64	107	95	57	95	95	57	95	162	97	162	165	99	165
Snappers	50	4	11	18	3	8	14	2	7	11	3	10	16	4	13	22
Groupers	80	10	46	77	13	62	103	23	108	180	53	253	422	58	278	464
Other marine finfishes	50	456	1 367	2 278	525	1 575	2 624	601	1 802	3 003	351	1 055	1 758	370	1 110	1 849
Total		**781**	**1 546**	**2 576**	**862**	**1 774**	**2 956**	**962**	**2 040**	**3 400**	**976**	**1 571**	**2 619**	**1 024**	**1 663**	**2 770**

Source: FAO (2006a)

FIGURE 14
Changes in the estimated trash/low-value fish usage in marine and brackishwater finfish culture in Asia at two conversion efficiencies of 6:1 and 10:1



Note: a, b and c denote three estimates for use of fishmeal for 2010. They are based on a projected production increase from 2004 to 2010 of 10, 15 and 20 percent

Source: The 2010 values are based on increases in production (based on information extracted from Tables 9 and 11)

Estimates of projected needs for trash fish/low-value fish in 2010, based on increases of 10, 15 and 20 percent over the production levels obtained in 2004, with corresponding decreases in the proportion of each major group of finfish fed on trash fish/low-value fish and a marginal improvement in conversion rates resulting from better feed management, are given in Table 11 and Figure 14. The projected increases in production are retained at rather conservative levels for a number of reasons. The main growth phase in the mariculture sector is believed to have already occurred, and most suitable areas for small-scale farming (which is the norm in Asia) are mostly saturated already. In addition, advances in seed production technology have not progressed as expected, with, for example, a survival rate for grouper species of only 10 to 15 percent at best (Rimmer, McBride and Williams, 2004). Finally, the ethical aspects of using trash fish/low-value fish for fish feed instead of directly for human food are likely to remain a bone of contention and possibly a limiting factor for aquaculture. In this context, it is important to point out that offshore cage culture of carnivorous fish has not expanded significantly in Asia over the last decade or more, even though it has been suggested as a potential growth area. Although plausible reasons for this trend have been dealt elsewhere, one factor that is often not taken into account is the relative unsuitability of the hydrographical conditions in most offshore areas in Asia (De Silva, Phillips and Mohan, 2007). Figure 14 portrays a projection of the use of trash fish/low-value fish as fish feed in the year 2010. The amount used will be significantly lower than that reported for 2004, a situation similar to that expected for the use of fishmeal in Asian aquaculture.

5.1.2 Trash fish/low-value fish use in finfish mariculture in Indonesia, Peninsular Malaysia, Viet Nam and China[4]

Indonesia

In Indonesia, four locations (i.e. Lampung, Situbondo, Bali Island, and Batam) were surveyed and conversion efficiencies of trash fish and commercial feed for various marine species are presented in Table 12. Most marine fish farms in the Lampung area produce grouper species. Trash fish/low-value fish use accounts for about 70 percent of the total feed inputs in these farms. The cost of trash fish averages about 40 percent of the total operating costs, ranging from 25 to 65 percent. The farmers' perception is that trash fish are cheaper and easy to obtain, and that stocks perform better than when commercial feeds are given. Trash fish are also the main food source used in barramundi (Asian seabass) as well as grouper farming in Situbondo. The daily trash fish/low-value fish usage for a 15-pond (5 000 m^2) production system is around 150 kg/pond/day for fish weighing more than 500 g. The estimated CE for seabass in ponds is around 6.0, while CE for groupers varies between 7.2 and 8.4. In Batam, trash

[4] This section is based on the findings of Sim (2006) except that of China. Information of China have been extracted from Xianjie (2008)

TABLE 11

Estimated production (thousand tonnes) of cultured marine finfish species in Asia-Pacific for 2010 based on 10, 15 and 20 percent increments and the corresponding prediction on the estimated trash fish/low-value fish usage (ETFU) for each species group at conversion efficiency of 6 and 10*

Species	Trash fish/low-value fish usage (%)		Estimated production and corresponding TF/LV fish use in 2004			Predicted production (at 10, 15 and 20% increments) and corresponding increase in TF/LV fish use in 2010								
	Estimated usage in 2004	Predicted usage in 2010	Production	ETFU		+10%	ETFU		+15%	ETFU		+20%	ETFU	
				6	10		6	10		6	10		6	10
Barramundi	40	20	25	60	99	27	33	55	29	34	57	30	36	60
Amberjack, mackerel, etc	0	0	169	0	0	186	0	0	194	0	0	202	0	0
Flatfishes	0	0	103	0	0	113	0	0	118	0	0	123	0	0
Cobia	30	15	20	37	61	23	20	34	24	21	35	25	22	37
Seabasses	10	5	110	66	110	121	36	61	127	38	63	132	40	66
Seabream	10	5	165	99	165	181	54	91	190	57	95	198	59	99
Snappers	50	25	4	13	22	5	7	12	5	7	12	5	8	13
Groupers	80	40	58	278	464	64	153	255	67	160	267	70	167	278
Other marine finfish species	50	25	370	1 110	1 849	407	610	1 017	426	639	1 063	444	666	1 110
Total			**1 024**	**1 663**	**2 770**	**1 127**	**913**	**1 525**	**1 180**	**956**	**1 592**	**1 229**	**998**	**1 663**

*The production obtained in "tuna fattening" is not included.
Source: Estimated use of trash fish/low-value fish and fish production for 2004 were adapted from Table 10.

TABLE 12
Conversion efficiencies (CE) for marine finfish aquaculture using trash fish/low-value fish and pellet feeds in selected locations in Asia (for comparison, Australian tuna fattening is also included)

Location	Species	Food conversion efficiency	
		Trash fish	Commercial feed
Lampung, Indonesia	Groupers	10.0–12.0	2.0-2.7
Situbondo, Indonesia	Groupers	7.2–8.4	n/a
	Barramundi	6.0	1.5
Bali Island, Indonesia	Humpback grouper	8–10	1.5–2.0
	Brown-marbled grouper	8–10	2.0–2.5
	Coral trout	8–10	1.7–2.5
	Yellowfin tuna (*Thunnus albacares*)	7.0–9.0	n/a
Batam, Indonesia	Groupers	8.0–15.0	n/a
Kukup, Johor, Malaysia	Groupers	10.0–12.0	n/a
	Other carnivorous marine finfish*	n/a	3.0–4.0
South Australia	Southern bluefin tuna	12.5–15.0	n/a

n/a: not available.
*Some farms using farm-made feed with CE of 4.
Source: Sim (2006), Allan (2004)

fish are rather limited and expensive, so many farmers use farm-made feeds, and most of these farms use fingerlings that have been weaned onto such feeds at an early stage. In Bali Island, trash fish are used for grouper (humpback and brown-marbled grouper and coral trout) with CE varying between 8 and 10.

Peninsular Malaysia

In Malaysia, trash fish/low-value fish account for about 30 percent of the total feed usage in marine farming (Kukup, Johor) of groupers (*Epinephelus* spp.), snappers (*Lutjanus* spp.), snubnose pompano (*Trachinotus blochii*), threadfins (mainly fourfinger threadfin, *Eleutheronema tetradactylum*), cobia (*Rachycentron canadum*), trevally (mainly giant trevally (*Caranx ignobilis*) and golden trevally (*Gnathanodon speciosus*)) and barramundi (*Lates calcarifer*). Feed cost generally amounts to about 60 percent of the total operational costs, and trash fish/low-value fish account for about 20–30 percent of the latter.

BOX 5

Mariculture in central Viet Nam

In central Viet Nam, where there is intense mariculture activity in certain areas, the marine fish farms tend to act cooperatively with regard to trash fish purchases and prefeeding preparation as an effective means of saving costs and labour.

Photos: Raw trash fish used in grouper culture and their preparation for feeding to stock


TABLE 13
Trash fish usage in some marine finfish farms in Indonesia, Malaysia and Viet Nam

Region	No. of farms	Trash fish usage		Trash fish cost (% recurring)	
		Quantity (kg/day)	No. of farms	% cost	No. of farms*
Indonesia	20	10–20	2	<20	2
		21–50	8	20–30	4
		100–150	5	31–40	1
		Unknown	5	41–50	5
				51–60	2
				61–70	2
				>70	1
				Unknown	3
Malaysia	2	Unknown	2	20–30	2
Viet Nam (north)	53	5–20	3	<20	2
		10–20	5	20–30	1
		10–25	4	31–40	3
		20–30	6	41–50	20
		20–40	5	51–60	17
		20–50	4	61–70	2
		Unknown	26	Unknown	8
Viet Nam (central)	62	17 –38 **	62	31–40	30
				51–60	20
				61–70	12

*Expressed in percentage in the case of Viet Nam (north).
**There was considerable variation among farms based on the species cultured. Average use ranged from 17 to 38 kg/day, while in some farms, trash fish use of 80 to 200 kg/day was recorded
Source: Sim (2006)

Viet Nam

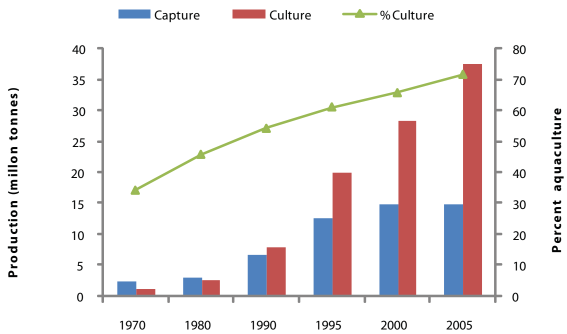
The case study in Viet Nam involved the survey of a total of 68 and 62 small-scale mariculture farms in the north and central regions, respectively (Table 13). In the north, 53 of the 68 farms surveyed used trash fish/low-value fish as the main food source for the stock, while in the central region all farms except those culturing penaeid shrimp fed trash fish/low-value fish. Trash fish/low-value fish usage ranged from 2 to 65 kg per day, and for most farms the feed cost accounted for 41 to 61 percent of the cost of production (for approximately 73 percent of farmers; Table 13). The main species cultured are brown-spotted grouper (*Epinephelus chlorostigma*), cobia, barramundi, snapper and mud crab. In general, the farmers believed that the use of trash fish/low-value fish was cheaper and that the stock performed better.

In central Viet Nam, the survey covered the districts of Van Ninh and Cam Ranh of Khanh Hoa province, and Son Tra district of NhaTrang City (details are given in Phan, 2007). Fish farming in these areas includes the culture of shrimp, marine finfish (mainly groupers and barramundi, and to a lesser extent, Japanese amberjack), lobster (*Panulirus ornatus* and *P. homarus*) and Babylon snail (Box 5). All the cultured stocks except shrimp are fed only trash fish, which are generally considered to be of a quality unsuited for direct human consumption, with the exception of *Stolephorus* spp., which is relatively high-priced among trash fish/low-value fish. In most instances, the trash fish/low-value fish are purchased daily, either directly at the landing sites or from middlemen, there being a well-established market chain for this commodity in areas where mariculture occurs.

China

China has a vast sea area with relatively rich fishery resources, and the fisheries sector has grown since the 1980s. However, with increasing fishing pressure, marine fishery resources have declined sharply, and fish production from aquaculture now exceeds production from capture fisheries, contributing increasingly to the national gross domestic product (GDP) (Figure 15). The catch of high-valued marine fish has dropped gradually, while the catch of medium-valued fish now accounts for 57–59 percent of the country's total marine capture fishery production. Only 30 percent of these less-valued fish are channelled into the food processing industry, and the remainder are mostly used as trash fish/low-value fish for marine finfish culture.

FIGURE 15
Trends in capture fisheries and aquaculture production in China and the percent contribution of aquaculture to the total production, 1970–2005



Source: Data from FAO (2006a)

In recent years, the increased development of mariculture in China, particularly the farming of higher-valued finfish, has resulted in a growing demand for feeds. Most of the cultured marine finfish feed high in the food chain and hence require a higher amount of protein in their feeds. In addition, trash fish/low-value fish remains indispensable for the culture of broodstock of many fish species. For many finfish species that are cultured using pellet feeds, "feedfish" or trash fish/low-value fish are still used during final conditioning to improve appearance and meat quality (such as reducing the fat content in the flesh of large yellow croaker fed with pellet feeds) for better market acceptance and higher price.

This demand places heavy pressure on trash fish/low-value fish supplies and on fishery resources. Farmers still use trash fish/low-value fish because of their relatively low cost, better attraction to the cultured stock and the superior appearance and flesh quality of the final product. Concurrently with the growing demands from aquaculture to feed carnivorous species, the market demand for low-value fish for direct human consumption and for the value-adding processing industry is growing too. This exacerbation of demands on this resource is of increasing concern to all users and primary stakeholders.

In China, trash fish/low-value fish are obtained mostly from trawl fisheries, supplemented by artisanal gillnet fisheries, which operate along most of the coastline. The species composition and availability of the trash fish/low-value fish vary depending on locality, as shown in Table 14.

Trash fish are used in indoor culture, pond culture and cage culture. The annual production in indoor culture is about 100 000 tonnes. Among the marine finfish

TABLE 14
The main trash fish/low-value species of marine origin and their availability in China

Region	Species and availability
Yellow and Bohai Seas	Japanese anchovy *(Engraulis japonicus)* (August–October), common hairfin anchovy (*Setipinna tenuifilis*) (year round)
East China Sea	Bombay-duck (*Harpadon nehereus*) (April–January), *S. tenuifilis* (year round), Commerson's anchovy (*Stolephorus commersonii*) (summer, fall), skinnycheek lanternfish (*Benthosema pterotum*) (year round), *E. japonicus/Engraulis* spp. (autumn, winter), Ammodytidae (year round), yellow croaker (*Larimichthys polyactis*) (April–May, August–September)
South China Sea	Japanese sardinella (*Sardinella zunasi*), *S. commersonii*, chub mackerel (*Scomber japonicus*), large hairtail (*Trichiurus lepturus*), Japanese scad (*Decapterus maruadsi*), Japanese jack mackerel (*Trachurus japonicus*), toothpony (*Gazza minuta*), Konoshiro gizzard shad (*Konosirus punctatus*),Kammal thrissa (*Thrissa kammalensis*), hardyhead silverside (*Atherinomorus lacunosus*), Gunther's lizard fish (*Synodus kaianus*),keeled mullet (*Liza carinata*), bald glassy (*Ambassis gymnocephalus*), brownback trevally (*Carangoides praeustus*), *Equulites rivulatus*, orangefin ponyfish (*Photopectoralis bindus*), deep pugnose ponyfish (*Secutor ruconius*), shortnose ponyfish (*Leiognathus. brevirostris*), whipfin silverbiddy (*Gerres filmentosus*), longtail silverbiddy (*G. longristris*), Japanese silverbiddy (*G. japonicus*), moonfish (*Mene maculata*) (year round except June–August, when a closed season is imposed)

Source: Xianjie (2008)

species cultured, artificially formulated feeds for flatfish and breams are relatively well developed. The use of pellet feeds is rather common in indoor marine finfish culture, formulated feeds accounting for more than 90 percent of the feed consumed. Less than 10 percent of the feed used consists of trash fish or farm-made feeds that include trash fish as a major ingredient. Overall, the indoor culture of marine finfish consumes 90 000 to 100 000 tonnes of trash fish annually.

Pond culture of marine finfish occurs primarily in Fujian, Zhejiang and Jiangsu provinces, with an estimated annual yield of about 250 000 tonnes. In coastal pond culture, which is often in the inter-tidal zone, about 20 percent of the pond area is under extensive culture with very limited feeding. About 50 percent of the ponds culturing bream and other perciform fish use formulated feeds. Most other pond-cultured species depend on trash fish/low-value fish as feed or on farm-made feeds containing trash fish/low-value fish as a major ingredient. Trash fish consumption in marine finfish pond culture is estimated at 750 000 to 800 000 tonnes per year.

The current annual output from cage culture is about 300 000 tonnes. A local survey showed that the use of pellet feeds for cage culture in Zhejiang and Shandong provinces is proportionally higher than in Fujian and Guandong provinces, where most cage operators still use trash fish/low-value fish directly as feed (Xianjie, 2008). Nationally, about 10 percent of marine finfish cage-culture production is estimated to use pellet feeds. Another 30 percent of the production involves the use of trash fish/low-value fish mixed with other feeds or farm-made feeds using trash/low-value fish as the main ingredient. The remaining 60 percent of the production depends solely on the direct use of trash fish/low-value fish as feed. Trash fish consumption by the marine cage-culture industry in the country is estimated at 2 million tonnes per year.

The use of trash fish as feed has a direct bearing on the sustainability of aquaculture development in China. Relying only on fish as feed can cause nutritional imbalance, a lack of minerals easily leading to malnutrition, impaired immunity and reduced growth rates in cultured stocks. Also, the supply of trash fish is inconsistent (seasonal variations in availability impact on price; in China during the closed season, the price of trash fish can rise to more than Chinese yuan (CNY) 3.0 per kg), its quality is often variable, and transport and storage are much more difficult than for artificial feeds. By contrast, the development and use of artificial feeds for the culture of cobia and yellow croaker have demonstrated the following advantages:

- reduced culture period;
- less pollution of the culture environment and hence lower risk of disease outbreaks;
- higher yield and economic efficiency, and
- better resource utilization and environmental friendliness.

5.1.3 Economic aspects of use of trash fish/low-value fish in grouper farming in Indonesia, Thailand and Viet Nam

This section summarizes a recent cost-benefit analysis by Sim (2006) for small-scale grouper farming based on the use of trash fish/low-value fish and commercial feed in three Asian countries. Feed was a major recurring cost throughout a single production cycle. There were two main factors that determined the cost of feed: cost efficiency and feeding effectiveness. In this study, an economic comparison between the use of commercial pellet feed and trash fish/low-value fish was undertaken to reflect the "true" economic benefits of the two feed types. The study dealt with: (i) the economic efficiency of the feed as determined by the level of feed input and production output and (ii) the corresponding CE for each grouper farm.

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[5] CE = [Total feed input (fed wet weight in kg] ÷ [Biomass harvested – Biomass stocked (wet weight in kg)]

To examine the economic efficiency of the two feed types, CE and feed cost were used. CE was calculated for each grouper farm based on the feed and production data collected with a questionnaire and in field surveys. The standard formula for calculating CE[5] was used.

Trash fish is widely used in the studied areas, particularly in Thailand and Viet Nam, where availability of commercial pellet feed and its use in grouper culture are still very limited. Farmers in Indonesia reported that stocks fed commercial pellet feed performed poorly in comparison with stocks fed trash fish/low-value fish and that feed costs were much higher, often becoming unaffordable.

The CE for commercial pellet feed averaged about 2.64 on the four farms in Lampung, Indonesia, producing humpback grouper (*Cromileptes altivelis*) (Table 15). By contrast, the CE for trash fish/low-value fish ranged from as low as 3.1 to a high of 18.8 across the three countries. In Indonesia, CE for trash fish averaged 7.8, in Thailand, it averaged 12.6 for cage culture and 8.1 for pond systems, and in Viet Nam, it was 8.2. Grouper produced using commercial pellet feed cost an average of US$2.64/kg, while fish raised using trash fish cost from US$0.62 to US$4.80/kg to produce, with an average production cost of US$2.20/kg for grouper produced from a total of 21 farms. Table 15 shows the details of CE for various farms on the study sites and the associated feed costs.

The equilibrium price level for trash fish/low-value fish at various price and CE levels of commercial feed is presented in Table 16. At the lowest trash fish/low-value fish price of US$0.20/kg, a CE below 13.2 provides farmers a saving on feed cost if they use trash fish/low-value fish, while at a trash fish/low-value fish price of US$0.26/kg, a CE lower than 10.3 permits farmers to make a significant saving on feed cost.

Based on the current study, nine of the 21 farms that used trash fish/low-value fish had CE greater than 10.0 and three farms had CE below 6.0. It is likely that CE greater than 10.0 is a result of overfeeding or wastage, and six farms in Thailand encountered this problem. Survey observations indicated that farmers in Thailand tend to buy in bulk to obtain a discount, and consequently they tend to overfeed, as they do not have good refrigeration facilities. By contrast, farmers that have CE lower than 6.0 are likely to be underfeeding. These farms are mostly located in Cat Ba Island, Viet Nam, where grouper are not fed on a daily basis during winter.

Feed costs in Indonesia account for 32.2 and 40.2 percent of total production costs for grouper (*Epinephalus fuscoguttatus* and *C. altivelis*) farmers feeding trash fish/low-value fish and commercial pellet feed, respectively. In Thailand, feed accounts

TABLE 15

Conversion efficiency (CE), feed costs and cost of production of humpback grouper in Indonesia (grouper) and humpback and brown-marbled grouper in both Thailand and Viet Nam

Indonesia				Thailand				Viet Nam			
Farm No.*	CE	Cost (US$)		Farm No.	CE	Cost (US$)		Farm No.	CE	Cost (US$)	
		Feed	Production			Feed	Production			Feed	Production
L1	2.63	2.63	11.28	K1**	15.00	3.84	10.00	CB1	4.70	0.94	5.56
L2	2.65	2.65	11.40	K2**	12.50	3.20	8.74	CB2	7.80	1.56	10.18
L3	2.65	2.65	9.43	K3**	11.40	2.93	7.99	CB3	6.70	1.34	8.80
L4	2.63	2.63	8.22	K4**	18.80	4.80	11.04	CB4	10.40	2.08	9.06
S1	7.20	1.80	8.78	K5*	7.80	2.00	5.48	CB5	16.40	3.28	11.32
S2	8.35	2.09	9.42	K6**	12.00	3.08	8.53	CB6	4.00	0.80	7.78
				K7**	10.50	2.69	6.89	CB7	12.70	2.54	9.37
				C1	8.10	2.07	4.40	CB8	8.10	1.62	5.68
								CB9	6.00	1.20	7.37
								CB10	3.10	0.62	6.73
								CB11	10.00	2.00	5.38

*L1 to L4 – farms using commercial compounded pellet feeds; all others use trash fish/low-value fish

**Cage systems

Source: Sim (2006)

TABLE 16
Equilibrium feed costs at various prices (in US$/kg) and conversion efficiencies (CE) for trash fish/low-value fish in comparison with commercial pellet feed

Country	Commercial pellet feed			Trash fish		
	Price	CE	Cost	Price	CE	Cost
Indonesia	1.00	2.64	2.64	0.25	10.55	2.64
Thailand				0.26	10.30	2.64
Viet Nam				0.20	13.20	2.64

Source: Sim (2006)

for 51.8 percent of the total production costs in cage systems and 57.5 percent of the costs in pond systems. By comparison, feed cost in Viet Nam is relatively lower at 23.4 percent. This is mainly due to the lower cost of trash fish/low-value fish (US$0.20/kg), the associated feeding practices, and the fact that farmers often procure their own trash fish/low-value fish, thereby reducing the need to purchase this resource. Farmers in Cat Ba Island tend to withhold feeding if trash fish/low-value fish are not available or when the weather limits active feeding by fish.

As feed accounts for a major portion of the production costs for grouper farming, it is important that the cost is kept as low as possible and that feed efficiency is improved. Figure 16 depicts the trends of CE and cost of production of one kilogram of grouper on farms in Thailand, Viet Nam and Indonesia. Analysis of the available data on CE (X) and cost of production (Y) for Thai and Vietnamese grouper farmers who use trash fish/low-value fish shows a positive linear relationship between these two parameters. These trends are:

Thailand (Figure 16a): $Y = 0.587X + 0.837$ ($R^2 = 0.907$; $P<0.01$), and

Viet Nam (Figure 16b): $Y = 0.292X + 5.536$ ($R^2 = 0.337$; $P<0.05$).

Similar trends were recorded for the three countries (Thailand, Viet Nam and Indonesia) combined (Figure 16c). As expected, these analyses indicate that higher CE results in higher cost of production. There was insufficient data to determine the effect

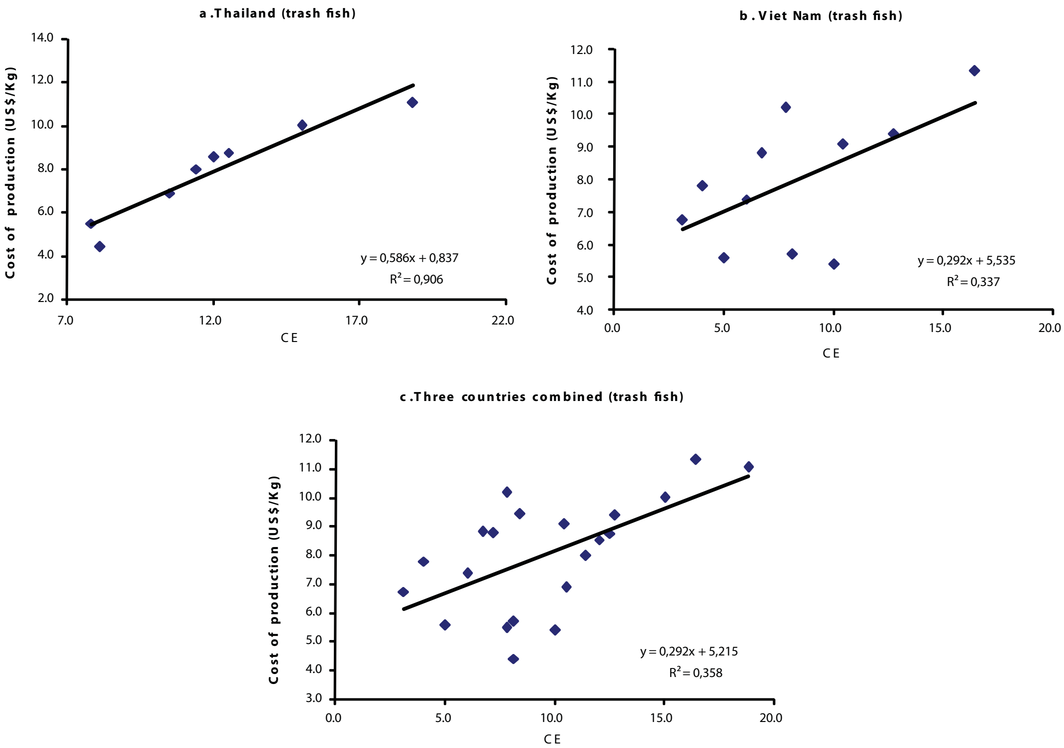
BOX 6

Small-scale farmers and the use of trash fish/low-value fish

From the study by Sim (2006), it is apparent that the only option available to many small-scale farmers in remote areas is to feed their cultured stocks with trash fish/low-value fish, which the farmers often catch on a regular basis. As these practices are linked to local tradition and culture, efforts to change them may jeopardize the livelihoods of many small-scale farmers, fishers and other small-scale operators. Attention should be focused on assisting these farmers to adopt better farming practices, including improved use of the trash fish/low-value fish that they procure themselves through transformation into moist pellet, improved feed management and proper husbandry and health management.

Photo: Fish farmer with fishing gear used to catch trash fish/low-value fish to feed cultured stock

FIGURE 16
Lines of best fit depicting the relationship of the cost of production to conversion efficiency (CE) on grouper farms in three countries (a) Thailand, (b) Viet Nam and (c) Thailand, Viet Nam and Indonesia combined



Note that for Indonesia data for only two farms were available

Source: Sim (2006)

of CE with commercial pellet feed and unit production. Furthermore, CE was not related to farm size in any of the countries.

Based on a simple comparison, trash fish/low-value fish appear to be economically more viable, if issues relative to sustainability and the environment are not taken into account. In Table 16, it is reported that the equilibrium price level for trash fish/low-value fish is at a price of US$0.20/kg and a CE of 13.20 for Viet Nam. If CE level is maintained below 13.0, feed cost saving (although minimal) will result in profitability for small-scale farmers. If the CE falls below 10.0, significant saving in feed cost leads to more a profitable business for small-scale farmers.

Overall, CE is an indicator of the feed efficiency of each farm. Leung, Chu and Wu (1999) reported that areolate grouper (*E. areolatus*) fed trash fish/low-value fish had a CE of 6.52. Although Yap *et al*. (2006) indicated that the CE for trash fish/low-value fish should range from 5 to 10, Orachunwong, Thammasart and Lohawatanakiul (2006) estimated that CE for trash fish/low-value fish ranged from 8 to 15. This suggests that improvements could be made in the efficacy of trash fish/low-value fish usage in grouper farming that would reduce the overall quantity of resource used, which in turn would improve the sustainability of grouper farming in the region (Box 6).

5.2 Trends in the use of trash fish/low-value fish in freshwater aquaculture in the Asia-Pacific region

Compared with the use of trash fish/low-value fish in marine and brackishwater aquaculture in Asia, its use in freshwater aquaculture is relatively less and is also localized. The number of freshwater carnivorous finfish species cultured in Asia

BOX 7

The golden apple snail as feed

The golden apple snail is considered a major invasive species in Asia (Halwart, 1994; Joshi *et al.*, 2005) and is very common in the Mekong Delta floodplain. Annually, some 20 to 25 tonnes of snail are collected and used as feed in giant freshwater prawn farming in the Delta. It is also used in farm-made feeds in pangasid catfish culture.

Photo: Golden apple snail frequently sold as fish and prawn feed in the Mekong Delta floodplain

is rather limited, the most important species being the pangasiid catfishes, walking catfishes and snakeheads. In all these instances and unlike in most mariculture, trash fish/low-value fish are used as a major ingredient to prepare, on farm, moist feeds that are fed to the stock. The greatest use of trash fish/low-value fish in freshwater finfish culture occurs in pangasiid culture in the Mekong Delta in southern Viet Nam, a sector that has grown over the last decade and which contributed an annual production of 1.2 million tonnes in 2007. The individual practices are small holdings with ponds, and the whole sector is estimated to provide employment to 160 000 people, the majority being in processing, of which over 80 percent are women (Nguyen, 2009; Phan *et al.,* 2009).

In the Mekong Delta, in addition to pangasiid catfish, giant freshwater prawn (*Macrobrachium rosenbergii*) and snakehead are also cultured extensively. The types of feeds used in these culture practices vary widely from region to region. However, in general, catfish culture is more dependent on farm-made feeds in which trash fish/low-value fish are a major ingredient (Hung and Huy, 2007). The level of inclusion of trash fish/low-value fish in farm-made feeds varies widely, ranging from 10 to 30 percent by wet weight, the other popular ingredients being rice bran and soybean meal. It should be stressed, however, that over the last two to three years pangasiid catfish culture has undergone a major shift from farm-made feeds to commercial feed use, driven primarily by the logistical difficulties of preparing large quantities of daily feeds on farm.

In giant freshwater prawn and snakehead farming in the delta, yields average 1.8 and 1.43 tonnes/ha/year, respectively. The farming practices are almost entirely dependent on trash fish/low-value fish but also include golden apple snail (*Pomacea canaliculata*) as a feed source (Box 7). According to Sinh (2007), the quantity of feed used in these two farming practices is 39 780 and 25 039 kg/farm/year.

In addition to carps and tilapias, catfishes and snakeheads constitute two important species groups that are cultured in Asian freshwaters. The catfish species cultured vary from country to country; for example, the main species cultured in Viet Nam, which has the greatest catfish farming activity in the region, are the pangasiid catfishes (the sutchi catfish (*Pangasianodon hypophthalmus*) and *Pangasius bocourti*), while catfish culture in Thailand is based on the hybrid of the bighead catfish (*Clarias macrocephalus*) and the North African catfish (*C. gariepinus*) (Na-Nakorn, Kamonrat and Ngamsiri, 2004). In the past, in both these culture practices, particularly during grow-out, trash fish/low-value fish were the main ingredient used for farm-made feeds, and this is still the case in Viet Nam. However, with the decline in the market value of farmed catfish in Thailand, the farmers have become more innovative, remaining viable by almost totally

BOX 8

A vertically integrated catfish farm in Myanmar

An almost complete vertical integration is seen in a Myanmar catfish farming venture. The processing waste in turned into fishmeal that is mixed with other locally produced agricultural by-products such as soybean meal, peanut meal, etc., to produce a pellet feed that is fed to its own catfish cultured in cages in the Nagwun River.

Photo: Bags of pellet feed produced on farm and in catfish rearing facilities

opting out of using trash fish/low-value fish in grow-out feeds.

Snakehead is relished in Thailand and neighbouring countries such as Cambodia and Lao PDR. In Thailand, snakehead production has been increasing steadily and in 2006, 9 800 tonnes were produced, accounting for only 2.6 percent of total inland aquaculture production but about 10 percent of value. Snakeheads are carnivorous, and the farming of snakehead is based mainly on wild-caught young, which are readily available throughout most of the year. Wild-caught fish cannot be easily weaned onto dry feeds in grow-out unless this is done in the very early stages. Almost all grow-out operations depend on farm-made, moist feed, which is dispensed in the form of a dough. The feeds are essentially a mixture of trash fish and rice bran, mixed in 7:3 proportion. For example, a farmer in Suphanburi, Thailand, who produces 3 to 4 tonnes of market-size snakehead uses 20 tonnes of trash fish, purchased at an average price of Thai baht (THB)7.5/kg (US$1=THB38). However, some changes aimed at reducing the dependence on trash fish/low-value fish are also beginning to take place in Thai snakehead farming.

In Myanmar, a number of significant trends in feed development and management that have a bearing on dependence on fishmeal/low-value fish and or fishmeal from external sources are taking place. These changes are related to the recent developments in the farming of Indian major carps, in particular, rohu (*Labeo rohita*) and sutchi catfish (*P. hypophthalmus*) (Aye *et al*., 2007). These trends are in turn associated with the rapid development of the processing sector for these species, which is totally export oriented. Indian major carp are exported whole, and the processing wastes (essentially offal and gonads) are separated and processed to extract oil that is used in fish-feed manufacture. By contrast, a large catfish farming enterprise that produces 740 tonnes of filleted catfish/year uses the offal, the frames and the strips of muscle for its own fishmeal production. On average, one tonne of fishmeal is produced daily in this relatively small-sized plant, and this fishmeal is used in its own feed plant to produce 70 tonnes of pellet feed per day. The feed produced is used exclusively for feeding catfish on its own farm. This is an example of an almost completely vertically integrated aquaculture system (Box 8).

The inland aquaculture sector in Myanmar is in a relatively high growth phase, with relevant patronage and support from the government (Aye *et al*., 2007). For example, the targeted exports of freshwater cultured finfish for 2007 are valued at US$120 million, a two-fold increase from the previous year. Such ventures will increasingly come into being, but they will not be resourcing trash fish/low-value fish and or fishmeal from the market place but will attempt to produce in adjunct facilities using raw material sources available to the farm *per se*. Although the feeds used may not be of the highest nutritional quality, the growth rate of the fish is acceptable to the farmers, as almost all such ventures make substantial profits. Past experience has shown that actual practices may defy nutritional wisdom (Wood *et al*., 1992), and Myanmar's freshwater finfish culture could just be another example.

FIGURE 17
Softshelled crab farm

a. Individual holding facilities

b. Trash fish/low-value fish used for feed

c. Preparation of trash fish/low-value fish to be fed

Courtesy of U Hla Win, Myanmar

5.3 Efficacy of use of trash fish/low-value fish in finfish culture

The use of trash fish/low-value fish as feed in aquaculture may have advantages, particularly for the many small-scale farmers in Asia. One advantage are low cost, resulting in less problems for farmers' cash flows, ready availability of feed in areas where trash fish/low-value fish are caught, perceived and/or real efficiency in feeding, and the possibility of the farmers themselves being able to procure at least a proportion of the daily feed requirements. The main disadvantages in using trash fish/low-value fish are irregularity in supplies and variability in quality, and also higher discharge of nitrogen and phosphorus from indigestible constituents, such as bone, than from pellet feeds.

5.4 Use of trash fish/low-value fish in crab and lobster fattening

5.4.1 Crab fattening

Farmed crab production, almost all of which occurs in Asia, has exceeded wild-caught production. Production has increased from a mere 14 500 tonnes in 2002 to 117 000 tonnes in 2004, the highest growth rate for any of the cultured commodities in the world. Crab farming is predominantly based on the mangrove crabs such as Pacific swamp crab (*Scylla serrata*), purple mud crab (*S. tranquebarica*) and green mud crab (*S. paramamosain*) and swimming crabs (such as *Portunus sanguinolentus*). Although the life cycle of the mangrove species has been closed (Quinitio *et al*., 2001), commercial hatchery production is still in its infancy (Kathrivel, 2007). Consequently, crab farming in Asia is primarily a fattening process, and the main food source is trash fish/low-value fish, often presented by chopping into suitable sizes, depending on the size of the stock. The main mangrove crab farming countries are Thailand, Myanmar, the

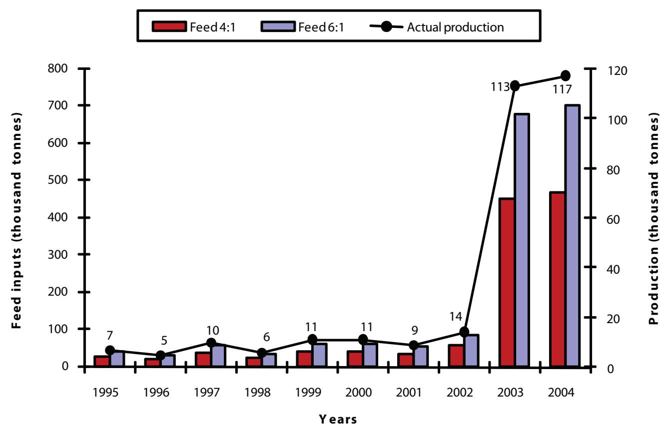
Philippines, China and Viet Nam, and to a lesser extent India and Sri Lanka. The crabs demand a relatively high market price and are almost always sold live even at the end point, the consumer.

The production of softshelled crabs for the up-market restaurant trade is a relatively recent development that enables under-sized crabs to be sold (Figure 17). Wild-caught crablets are farmed in intensive operations in which no more than two crablets are held together and all are checked every other day for molting. This is a relatively labour-intensive farming process, but the economic value of softshelled crabs more than compensates for the increased labour costs. On average, a crablet goes through over eight molts during fattening for the market, whereas a softshelled crab is ready for the market after two molts. Based on the prevailing market price and demand, farms that have the required infrastructure may switch from fattening crabs to a weight of 400 g to producing softshelled crabs weighing up to 150 g.

In all the countries, the number of operations producing softshelled crab is relatively small. For example, in Myanmar there are only two crab fattening farms. In India, crab farming commenced primarily as a means of reviving the livelihoods of 2004, tsunami-affected fishing communities (M. Sakthivel, Aquaculture Foundation of India, personal communication, 2005). A major factor that has encouraged the rapid growth of crab farming along the southeastern coast of India is the ready availability of trash fish/low-value fish at a relatively low price of IDR10 to 12/kg (US$1 = IDR48) during the grow-out period of the crabs (during the northeast monsoon of November to February). Hardshell crabs take eight months to reach a market size of approximately 1 kg or more (price of IDR400/kg), whereas the turnover period for softshell crabs (price of IDR325/kg) is only 25 days. In both cases, the average conversion efficiency is 6.

FIGURE 18

Changes in cultured mangrove crab production over the years and estimates of trash fish/low-value fish required as feed at conversion efficiencies of 4 and 6



Source: Production data is based on FAO (2006a)

In Thailand, softshell crab farms maintain an average of 50 000 individual rearing boxes. Crablets, wild-caught locally, are purchased at approximately THB85 to 90/kg (10 to 15 individuals per kg) (US$1=THB38) and are kept for 45 to 90 days until molting. The molting size ranges from 70 to 175 g, and the farmgate price varies according to the size. For example, 70 to 100 g crabs are sold at THB180/kg, as opposed to crabs exceeding 175 g, which bring THB240/kg. Crabs are fed once every other day with trash fish, and approximately 60 to 70 kg of feed per 10 000 boxes are used at any one feeding.

TABLE 17

Comparison of the production of softshelled crab in Thailand using trash fish and formulated feed[*]

Feed type	% molting	% survival	Feed/crab (kg)	Cost/molted crab (THB)
Trash fish	51.7	52.3	0.292	19.8
Formulated feed	60.7	61.0	0.042	15.6

[*]Softshell crab production trials based on four-month average.
Source: Modified from Wilson (2005)

BOX 9

Production of gravid female crabs for niche markets, Chanthaburi province, Thailand

Crablets weighing about 140–150 g are brought a long distance (travel time of up to 22 hr) from the Adaman Sea area. They are fattened for two to three weeks in a pond by feeding with trash fish/low-value fish that is purchased at THB10–13/kg. The crabs are individually observed at the change of the tide, and when the first signs of eggs appear they are kept in net cages suspended in the ponds. The fully gravid females, determined by using a torch or by making a small incision in the abdomen, and weighing on average 240 to 250 g, are exported weekly. Daily feeding is at a rate of approximately 100 kg of trash fish per 10 kg of crab. The mortality rate is nearly 70 percent during the rearing period; however, the dead crabs are cooked and sold in the local market. An approximate cost-benefit analysis, per cycle of 45 to 60 days, of the practice is as follows (all figures in THB):

Revenue from crab egg production	=	270 000
Revenue from crab meat	=	99 000
Total revenue	=	369 000
Crablet costs	=	282 750
Feed costs	=	16 100
Labour costs	=	10 000
Total expenses	=	308 850
Net profit/loss	=	60 150

Photo: Monitoring of early indications of eggs development in female crabs during low tide in suspended net cages

In general, in both forms of crab farming the wild-caught crablets are fed chopped trash fish/low-value fish. Given an estimated production of about 120 000 tonnes of crab and an average conversion efficiency of 4 to 6, the total quantity of trash fish used in mangrove crab farming is between 480 000 and 720 000 tonnes (Figure 18).

Although crabs are relatively inefficient in feeding on pellet feeds and such feeds are not widely available, evidence suggests that pellet feeds can be more effective than feeding trash fish and that they can significantly reduce the cost of production (Table 17).

In view of the rapid growth in crab farming in the last few years, and taking into consideration that a proportion of crablet supplies is likely to come from hatcheries, an overall growth rate of 25 percent from the current level is expected by 2010. This would mean that a trash fish/low-value fish supply of 600 000 to 750 000 tonnes will be required given an average CE ranging

BOX 10

Lobster fattening in Viet Nam

In addition to finfish, certain aquaculture practices use other aquatic animals that are collected on a small scale and fed to cultured stocks. Among these are various molluscs (also see Phan, 2007). However, the use of non-finfish aquatic organisms as feeds in aquaculture is relatively uncommon and may be specific to certain regions and culture practices. In Viet Nam, a variety of aquatic food sources including trash fish/low-value fish, molluscs, etc., is used in lobster fattening, and the feed material is often processed prior to feeding.

Photos: Cockles used in lobster fattening in central Viet Nam

from 4 to 5. In crab farming and fattening, the use of compounded feeds is relatively insignificant. Another of the more recent developments is the production of gravid females for niche markets, such as in Chanthaburi province, Thailand (see Box 9).

5.4.2 Lobster fattening

Lobster fattening is a relatively recent activity that is most intensely practiced in Viet Nam (Phan, 2007). Two species of spiny lobster are fattened in Viet Nam, *Panulirus ornatus* and *P. homarus,* which are now almost always reared in floating net cages as opposed to net pens, as in the past. It is estimated that the current annual fattened lobster production in Viet Nam is 1 000 tonnes (www.spc.int/aquaculture/site/commodities/rock_lobster.asp?ou=pdt&pdt=rock_lobster&comm_name=Rock%20Lobster).

In lobster fattening, the food source used includes trash fish/low-value fish, as well as molluscs such as blood cockle (*Andara* spp.), small crabs (*Calappa* spp.) and swimming crabs (*Portunus* spp.) (Box 10). In general, the quality of the trash fish/low-value fish fed to lobster is relatively high, with prices ranging from VND10 000 to 13 000 per kg, and often accounting for between 60 to 70 percent of all recurrent costs. However, the farmgate price for fattened lobster is one of the highest among cultured species, averaging VND312 000 and 627 000/kg for *P. homarus* and *P. ornatus,* respectively, of average weights ranging from 0.2 to 0.4, and 0.8 to 1.6 kg. In view of the "mixed" nature of the aquatic feeds used in lobster fattening and also because the total production is relatively small, no attempt was made to estimate the volume of trash fish/low-value fish used in this practice.

5.5 Use of trash fish/low-value fish in mollusc culture

The majority of molluscs cultured are filter feeders, in particular, bivalves. Among other molluscs, feeding is associated with the culture of the high-valued abalone species (*Haliotis* spp.). However, in certain Asian countries, the culture of the gastropod commonly known as the spotted Babylon has developed rapidly, particularly in Thailand, Viet Nam and China (Box 11). Sixteen species of Babylon are known from Indo-Pacific waters. However, the most commonly cultured species is *Babylonia areolata*, which is reared only in Thailand, Viet Nam and China. Little published information is available on culture methods, growth rates, production and other related parameters (Chaitnawisuti, Kritsanpuntu and Natsukari, 2005; Kritsanpuntu *et al*., 2005). The total production of Babylon in Asia is unknown, but is currently conservatively estimated to be 70 tonnes. Babylon is sold live to the restaurant trade, China being the main market.

Babylon is fed trash fish/low-value fish throughout its grow-out phase, which lasts from three to five months depending on the market of destination. In Thailand, the grow-out period is generally longer and the harvesting size ranges from 50 to 60 g/individual

BOX 11

Babylon snail culture

The growth of Babylon snail culture in the region, which commenced about six to eight years ago, has resulted in a marked decline in farmgate/export price. For example, a kg of Babylon produced in Thailand that was exported at THB500–580/kg (US$1=THB40) consisted of 15 to 20 individual animals that were sold live. However, increased Chinese production over the last three years, along with increased production and export from Viet Nam to China, has caused the overall farmgate price to decline markedly. The farmgate price of live Babylon exported to China from Thailand has decreased from THB200–250 kg in late 2005 to THB150–180/kg in December 2006, making the culture practice almost economically unviable, especially within the context of increasing prices for trash fish/low-value fish.

Photo: *Babylonia areolata*

FIGURE 19

Trash fish/low-value fish species used for Babylon snail culture. In some practices, the relatively high-quality trash fish/low-value fish may be filleted, the fillets used for other purposes and the frames fed to Babylon, which feed on the attached bits of flesh, leaving the frame clean

with a shell length of 6 to 8 cm (Kritsanpuntu *et al*., 2005). In China, the harvesting size ranges from 20 to 30 g per individual and a shell length from 4 to 6 cm.

Interestingly, in Babylon snail culture, which tends to involve small-scale, backyard operations, the trash fish/low-value fish are often bought from the fish market and are fish destined for human consumption, such as for example, in Thailand (Figure 19). By contrast, in Viet Nam, the culture practices occur mostly outdoors in net pens, and the stock is fed trash fish/low-value fish that is normally unsuited for direct human consumption. The purchase of fish used for feeding is often done on a daily basis, and the average conversion efficiencies range from 5:1 to 7:1.

5.6 Total direct use of trash fish/low-value fish in Asia-Pacific aquaculture

Using the data provided in the foregoing sections, an attempt was made to estimate the total amount of trash fish/low-value fish used as a direct feed source in aquaculture in the Asia-Pacific region. High and low predictions for the year 2010 were also estimated based on the assumptions on production increases and changes in feed management previously discussed (Table 18). Accordingly, in 2004 the usage of trash fish/low-value fish in aquaculture in the Asia Pacific region is estimated to have ranged from 2 465 000 to 3 882 000 tonnes, and the corresponding low and high estimates for 2010 are 1 890 490 and 2 745 495 tonnes, respectively. Although the range in these estimates is significant, nevertheless, they provide a figure that could be used in planning and development activities that recognize the need to reduce the dependence of Asia-Pacific aquaculture on trash fish resources.

TABLE 18

The total use of trash fish/low-value fish as a direct feed source in Asia-Pacific aquaculture, based on production estimates of the present study

Activity	Country/region	Grade[a]	Quantity (thousand tonnes)		
			2004	2010a	2010b
Marine fish[b]	Asia	A, B	1 603–2 770	913	1 663
Southern bluefin tuna	South Australia	B	50–60	45	50
Freshwater fish	Asia	A, B	332	332[c]	332[c]
Crab fattening	Asia	B	480–720	600	750
Total			**2 465–3 882**	**1 890**	**2 795**

[a]Grade A – low grade, unsuitable for human consumption; Grade B – may be suitable for human consumption.

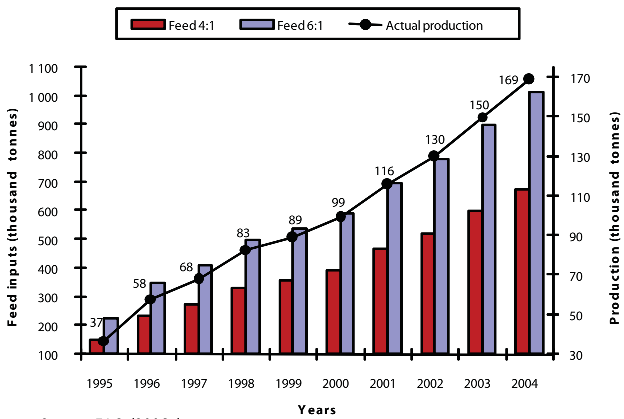
[b]2010 low and high predictions are based on increased production rates (10 and 20% increments) and associated changes in feed management given in previous tables (Tables 10 and 11). For crabs, the predictions are based on an overall increase of 25% production from the current levels and trash fish/low-value fish use calculated at conversion efficiencies of 4 and 5, respectively, for two predictions (2010a and 2010b).

[c]Prediction is not attempted and the value of 2004 is used instead.

Sugiyama, Staples and Funge-Smith (2004) estimated that in China, 3 615 000 tonnes and in the Philippines 144 638 tonnes of trash fish/low-value fish were used as feed for cultured stocks. Edwards, Le and Allan (2004) estimated that in Viet Nam 323 440 tonnes were used in aquaculture, the bulk of them being used in the preparation of farm-made feeds for pangasiid culture in the Mekong Delta.

The above estimates, as well as that of the present analysis, are significantly lower than those of Allan (2004), who estimated that the global usage of trash fish/low-value fish as a direct feed source in aquaculture was 5 million tonnes per year. Assuming that the Asia-Pacific region accounts for 80 percent of the global trash fish/low-value fish usage in aquaculture, it is believed that the current estimates are closer to reality, as these are based on observed production levels and farm surveys. Importantly, the predictions for the future indicate a significant reduction in trash fish/low-value fish use in aquaculture in the Asia-Pacific.

FIGURE 20
Changes in Mandarin fish production in China and the estimated live fish feed needed based on two conversion efficiencies



Source: FAO (2006a)

6. USE OF LIVE FISH AS FEED IN ASIAN AQUACULTURE

Instances of live cultured fish being raised for the sole purpose of feeding to another, generally much higher-valued cultured species are uncommon. There is one such example known from Asia, that of the mandarin fish (*Siniperca chuatsi*). There are also less significant instances where low-value fish such as small-sized tilapias have been used as food for culturing higher-valued species. In addition, there is the farming of species such as milkfish (*Chanos chanos*) to fingerling size for use as live bait for tuna fishing.

The mandarin fish, a percichthyid, is one of the most highly valued freshwater species cultured in Asia. Mandarin fish culture is almost totally confined to a few provinces of China, such as Guangdong and Hubei. This top carnivore cannot be weaned onto dry or moist feed and thus has to be fed on live fish only, unlike the closely related Murray cod (*Maccullochella peelii peelii*), a large Australian iconic freshwater fish. In spite of this limitation, it is cultured extensively in reservoirs (in cages) and in ponds, and the total production from aquaculture has grown from 37 000 tonnes to almost 170 000 tons over the last ten year period (1995–2004) (Figure 20). With the increase in production, there had been a decline in the farmgate price, which dropped from about CNY80 to 120 per kg (US$1=CNY7.85) in the early 1990s to the current price of CNY35 to 60. This decrease in farmgate price, as well as other development demands has resulted in the reduction of the area used for mandarin fish culture. For example, in Hang Lang Township, Zongshan Prefecture, Guangdong

FIGURE 21
Mandarin fish from a culture pond at Hang Lang Township, Zongshan Prefecture, Guangdong Province, China with its live fish feed, mud carp. Prey fish are introduced into the mandarin fish grow-out ponds, on average, every fifth day

province, China, the pond area has decreased from 3 300 ha in the mid-1990s to the current 650 ha (however, production intensity and efficacy have increased).

Species commonly cultured as food for mandarin fish include Chinese mud carp (*Cirrhinus chinensis*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*H. nobilis*) and black carp (*Mylopharyngodon piceus*), all cultured and popular foodfishes. In general, mandarin fish culture goes hand in hand with the culture of its foodfish species, either in cages or ponds, often adjacent to the culture site of the mandarin fish. The live fish are fed at a size ranging from about 2 cm to a maximum of 8–10 cm, depending on the size of the mandarin fish stock (Figure 21). Fish are fed every fourth to fifth day, and the amount of live feed presented is determined by the farmer based on the response of the mandarin fish to the feed, the more aggressive the feeding, the more feed provided. During a culture cycle of 4.5 to 5.5 months, the average yield obtained in pond culture of mandarin fish ranges from 7 500 to 10 500 kg per ha, and the average conversion efficiency is 4. Even though mandarin fish culture demands more space, it remains significantly more profitable than culturing the filter-feeding Chinese carps, based on pond fertilization only, because the market price of Chinese carps is only about CNY12 to 15 per kg at the best of times. A simple cost-benefit analysis (Table 19) indicates that economic gains from mandarin fish culture are, as might be expected, sensitive to market price. Mandarin fish culture typically requires three times the space

TABLE 19

A cost-benefit analysis of mandarin fish culture on a farm in Hang Lang Township, Zongshan Prefecture, Guangdong province, China

Parameter	Unit price (CNY)	Stocking density (no.)	Harvest (kg)	Value (CNY)	Profit (CNY)
Mandarin fish seed (5 cm)	5	15 000	–	75 000	–
Harvest (ave. 700 g; 80% survival)	40/kg	–	4 800	192 000	117 000
	60/kg		4 800	288 000	213 000

The cost of feed is CNY/kg totalling CNY201 600 (US$1=CNY7.85). In mandarin fish culture, mud carp fingerlings are commonly used as a live feed.

Source: Personal observations

(pond and or cage) than the culture of its live food (carps). However, because of the very low market price of carps, the total gains from their culture up to market size are less attractive than the highly demanding but highly profitable culture of mandarin fish. By contrast the risks associated with mandarin fish culture (a form of monoculture), particularly potential mortality from disease, are far greater than for the culture of carps, and more often than not the average farmer is unwilling to take this risk.

7. USE OF FISH IN FEEDS IN ASIA-PACIFIC AQUACULTURE: AN OVERALL ANALYSIS

Fish are used, directly (e.g. as fishmeal) or indirectly (as animal food) in significant quantity in the aquaculture sector in the Asia-Pacific region. This usage falls into three categories that are summarized in Table 20. Overall, fishmeal accounts for the highest usage, and in this regard, Asia-Pacific aquaculture uses the greatest proportion of global fishmeal production.

Tacon, Hasan and Subasinghe (2006) estimated that in 2003, global aquaculture used 2.94 million tonnes of fishmeal (53.2 percent of global fishmeal production), which was considered to be equivalent to the consumption of from 14.95 to 18.69 million tonnes of trash fish/low-value fish, primarily pelagics. These authors also reckoned that nearly 5 million tonnes of such fish were used directly as a feed source for cultured stocks, thereby totalling a consumption of 20–25 million tonnes, primarily for the production of 30 million tonnes of farmed finfish and crustaceans.

In the Asia-Pacific region, an estimated 9.8 million tonnes of the total capture fishery of 40 million tonnes (approximately 25 percent) are used directly (e.g. as fishmeal) or

TABLE 20
A summary of the quantities of fish used, directly or indirectly, in aquaculture in the Asia-Pacific region

Type	Current (tonnes)		Predicted usage in 2010 (in tonnes)	
	Low*	High*	Low	High
Reduced forms (fishmeal)	2 388 058 (10 270 894)	–	1 999 866 (6 999 531)	2 190 729 (7 667 552)
Trash fish/low-value fish	2 465 000	3 882 000	1 890 000	2 795 000
Live fish	675 000	1 012 000	n/a**	n/a

*Based on different food conversion efficiencies as indicated in the relevant sections; the live-weight equivalent, where relevant, is given in parentheses;
**n/a–not attempted
Source: Data derived from Tables 9 and 18 and Figure 20.

indirectly (as animal food), which contributes to a production of 28 million tonnes of foodfish for human consumption (Funge-Smith, Lindebo and Staples, 2005; FAO, 2007). FAO (2007) also highlighted the potential competition for trash fish/low-value fish and suggested that economic considerations will channel this resource to different usages. However, the results of the present analysis contradict the suggestion that there will be an increase in the channelling of trash fish/low-value fish into aquaculture; overall, by 2010 it is predicted that the use of these resources to support an increase in aquaculture will decrease significantly.

8. IMPACTS OF FISH-BASED FEED INPUTS USED IN ASIA-PACIFIC AQUACULTURE

This section deals briefly with four types of impact: impacts on the environment, on wild fish stocks, on human health and on employment and food supplies for the poor.

8.1 Environmental impacts

General treatments of environmental impacts on aquaculture include those of Goddard (1996) and Black (2001). It has been aptly demonstrated that the provision of the most nutritionally wholesome and digestible diet to a finfish species results in, at best, an accumulation of nitrogen in the body of 28–32 percent and an average accumulation of 20–25 percent, the rest being excreted. The excessive discharge of phosphorus and nitrogen via undigested faecal matter in freshwater aquaculture and of nitrogen in mariculture, particularly in areas where water replenishment is inadequate, can lead to serious environmental impacts. In the Asia-Pacific region, such impacts have been observed in freshwater

BOX 12
Environmental impacts of cage culture
Intensive cage culture operations can lead to exceeding the carrying capacity of the waterbody, resulting in fish kills when the bottom anoxic water (resulting from the accumulation of large quantities of nutrients) is upturned by changed weather conditions. Such regular occurrences can lead to abandonment of the facility.

Photos: Intensive cage systems in a reservoir in West Java, Indonesia, and the aftermath of fish kills

systems where clusters of cage farms exceed the carrying capacity of the waterbody. The environmental effects can be both direct and indirect. The direct effects result in fish kills, not only of the farmed fish but also of wild stocks. The latter results in conflicts with the artisanal fishers who make a livelihood from fishing in the waterbody (Abery *et al*., 2005). Moreover, intensive feeding and the accumulation of excessive amounts of nutrients tend to elevate the levels of ammonia and at times, even toxic hydrogen sulphide, which may not cause direct mortalities, but can stress the stock so that it becomes susceptible to disease. The adverse impacts can often be remedied by siting the cage systems in different areas of the waterbody and reducing the feeding intensity (Box 12).

In addition, the feeding of fish as a direct food source to cultured stocks is known to be even more environmentally damaging than feeding of pellet feeds because of the likelihood of lower digestibility. However, there is limited evidence to show the efficacy of pellet feeds as opposed to trash fish/low-value fish as feed. Often, gross conversion efficiencies are used for comparative purposes. However, this approach does not take into account the moisture content of trash fish/low-value fish as feed, which amounts to about 70–75 percent.

Similarly, little is known about the efficacy and resultant environmental effects of the use of farm-made feeds. This is understandable, as the composition, method of preparation and feed management of farm-made feeds are diverse (De Silva and Davy, 1992; De Silva, 1993; Tacon and De Silva, 1997), and more often than not, the quality of feeds used could differ between adjacent farms culturing the same species. As such, comparisons become difficult if not impossible. The environmental effects of the use of farm-made feeds are also difficult to evaluate, and to the authors' knowledge no such studies have been made. However, the small-scale farmers are the best judges of the efficacies and the cost-benefits of the feeds they use. The recent shift to the use of compound feeds in catfish farming in the Mekong Delta and the shift to the use of poultry processing waste in snakehead and catfish farming in Thailand, perhaps are evidence of the increased efficacy that farmers obtain by such changes.

In China, current techniques for finfish culture in ponds and cages are believed to result in 30 percent of feeds being wasted or uneaten by the cultured stock. Compared with artificially formulated feeds, the discharge of nitrogen and phosphorus into the environment by using trash fish/low-value fish as feed is three to four times higher. The uneaten feed together with the excreta of cultured fish impacts the culture environment,

FIGURE 22

A very unhealthy practice in Asia: feeds in drums, improperly sealed and exposed to the elements for a week or more, a practice that could lead to loss of quality and even make the feed rancid, and accordingly result in reduced performance of the stock and lowered feed conversion efficiency

giving rise to fish diseases and the need to use veterinary drugs and chemicals for their prevention and treatment, leading to many problems associated with food safety.

In the Asian context, disease transmission resulting from the use of trash fish/low-value fish in aquaculture is scantily documented (Figure 22). One such example is the reported by Subasinghe and Shariff (1992), who attributed mass mortalities of cage-cultured barramundi (*Lates calcarifer*) in Malaysia to infections of *Pseudomonas anguilliseptica*, *Vibrio alginolyticus* and the spoilage bacterium *Shewanella putrefaciens,* possibly brought about by poor husbandry and the feeding of spoiled coarse fish.

By contrast, the risks and impacts on local fish populations and ecosystems from the use of imported fish to feed the tuna farming industry in the Mediterranean (WWF Mediterranean Programme, 2005) have been highlighted. This report, however, fails to show a direct cause and effect between the use of imported fish to feed the tuna and negative impacts. All in all, it has to be agreed that there are risks associated with using trash fish/low-value fish (particularly imports) to feed cultured stocks and that precautionary approaches have to be applied. However, in most Asian practices, such feed is often obtained from the immediate habitats.

In a recent study on southern bluefin tuna farming in Australia, Fernandes *et al.* (2007) demonstrated that the amount of phosphorous available for leaching from solid waste ranged from 5–6 percent to 17–21 percent from pellet and baitfish [*Sardinops neopilchardus* (syn. of *S. sagax*)]-fed tuna, respectively, and the corresponding nitrogen discharge was 15 and 35–43 percent.

A number of strategies have been suggested to reduce the use of trash fish/low-value fish in aquaculture, and thereby contribute to minimizing the sector's impact on a dwindling biological resource. Among these are reducing fishmeal use in aquafeeds and enhancing the efficacy of trash fish/low-value fish use in aquaculture, culminating in the weaning of stocks to pellet feeds. The limitations on the reduction of fishmeal content in aquafeeds in the region are discussed in Section 4 (also see De Silva and Hasan, 2007).

The environmental gains that are made through the use of trash fish/low-value fish for aquaculture purposes have often gone unnoticed. For example, the live fish restaurant trade, a lucrative upper-end market, was almost entirely dependent on wild-caught reef fish, primarily groupers (Box 13). Destructive fishing methods that not only

BOX 13

Grouper culture and coral reef preservation

Among the major fish species cultured using trash fish/low-value fish are the groupers (family Epinephalidae). In the past, almost the entire market for grouper, especially that of the live fish restaurant trade, was based on wild-caught fish that were often obtained using destructive fishing methods such as poisoning and explosives. These destructive practices resulted in major environmental impacts on aquatic habitats, mainly coral reefs, which resulted in public denunciations. However, this niche market is increasingly being filled by cultured groupers, and this has contributed significantly to the conservation of tropical coral reefs.

Photo: Brown-marbled grouper (*Epinephelus fuscoguttatus*) and humpback grouper (*Cromileptes altivelis*) killed other species but also destroyed the coral environment were often employed to catch these fish (Pet, 1997; Sim, 2005). With the development of grouper mariculture through the closing of the life cycle of many cultured groupers (whose culture is, of course, dependent on trash fish/low-value fish as a feed source), the restaurant trade has switched almost completely to cultured live fish. This change has undoubtedly helped preserve coral habitats and also reduced impacts on biodiversity.

8.2 Impacts on human health

Reports indicating that human health has been impacted because people have eaten cultured fish which were fed unhealthy fish do not seem to exist. However, the public, animal and environmental health impacts of aquaculture have become a relatively controversial issue that has attracted much public attention in recent years from a series of viewpoints (Garrett, dos Santos and Jahncke, 1997; Feare, 2006). It has been speculated that adverse impacts resulting from aquaculture can negatively influence human health and indeed could nullify the relatively well defined health benefits that are known to be derived from fish consumption (e.g. de Deckere *et al*., 1998; Horrocks and Yeo, 1999), at least from a public perspective. The accumulation by farmed stocks of organic and inorganic contaminants from feed and/or the environment is one such issue (Hites *et al*., 2004). The dioxins (which include polychlorinated dibenzo-p-dioxins and dibenzofurans) have attracted the most attention (Lundebye *et al.*, 2004). However, by using properly formulated feeds, the dioxin-like polychlorinated biphenyls (PCBs) can be significantly reduced in farmed fish (Berntssen, Lundebye and Torstensen, 2005).

Legislation on the level of dioxins permitted in farmed fish was introduced by the European Union (EU), while public health concerns such as mad-cow disease (bovine spongiform encephalopathy (BSE) have led to a ban on the use of animal industry by-products in animal feeds. The legislative and regulatory aspects of feeds have been reviewed by Tacon, Hasan and Subasinghe (2006), and it is sufficient to state that Asian aquaculture currently lacks such regulations. Indeed, to make matters worse, some banned animal industry by-products are being exported to Asia and are being used in feeds (authors' personal observations). Unfortunately, very little research on these aspects is being conducted in Asia, where the main thrust is to adopt better management practices (BMPs) for different culture systems, with the expectation that this would avoid extensive contamination of the final product. However, the BMPs have not yet addressed the issue of feed quality, and it is now opportune to introduce this through proper feed certification procedures.

8.3 Impacts on employment and food supplies for the poor

In Asia, which is not a major fishmeal producer but a major consumer (De Silva and Hasan, 2007), two major issues are apparent: (i) Is the trash fish/low-value fish used in the reduction industry sustainable? and, (ii) If so, what are the pros and cons of using the fish for reduction as opposed to direct human consumption? In Asia and the Pacific, all wild fish used in farm-made aquaculture feeds come from Asian fisheries, most being bycatch. However, the fact is that the fish caught as bycatch affect the supply of fish available as food, and bycatch is also of importance for employment and income generation for the poor. The impacts of the use of fish as feeds on employment and food for the poor in Asia are of a much lesser magnitude than elsewhere in the world, the main reason being that much of the fishmeal used in such feeds is imported, mainly from South America.

8.3.1 Food supplies

The great bulk of trash fish/low-value fish landings in Asia are from small-scale artisanal fisheries and may not necessarily be in a state suitable for direct human consumption.

Nevertheless, the degree to which this resource can be used for direct human consumption is difficult to determine. In Asia, trash fish/low-value fish are mostly landed in areas where there are other suitable fish commodities for human consumption. In order to make the trash fish/low-value fish suitable for human consumption, some degree of processing, storage and transportation is needed. However, the costs involved are unlikely to be commensurate to a price that is acceptable to consumers, particularly in remote rural areas.

However, there are situations in Asian fisheries when the use of bycatch as aquaculture feeds pre-empts the use of these fish as food, particularly by the poor. This happens when fish are landed in densely populated areas and then purchased to be used as feed. However, it should be noted that fishmeal is not the only competitor; in several parts of Asia, trash fish/low-value is also a source of raw material for the production of foods based on fish.

In many Asian countries (e.g. India, Bangladesh and part of China) trash fish/low-value fish are sold for direct human consumption. Eating low-value fish caught from the sea has been a tradition for centuries among coastal communities, particularly in Hainan, Guangxi, Guagdong, Fujian and Zhejiang provinces in China. In recent years, increased demand for trash fish/low-value fish as feed in aquaculture has suppressed the supply of seafish to local markets, resulting in higher prices. Furthermore, China has a long history of making surimi-associated products based on trash fish/low-value fish, and there is a wide range of such products in the country. In 2002, China produced 102 400 tonnes of surimi products. Along with technological advances, domestic and overseas markets for surimi products are expected to expand gradually.

Perhaps this is an area that warrants detailed investigations that would generate quantitative information, including data on the socio-economic aspects of the various uses of trash fish/low-value fish. Such information may put an end to the current debate, which is philosophical, moral and/or ethical in nature but rarely, if at all, supported by relevant data[6].

8.3.2 Employment

In parts of Asia, a significant number of artisanal fishers ensure their livelihood by supplying fish as feed to mariculture operations. Moreover, in some remote areas in Asia (e.g. North East Sulawesi, Indonesia), small-scale farmers catch low-value/trash fish for their practices (Aslan *et al*., 2008). Here again, the quantitative data that would allow an objective assessment of the issue of the use of trash fish/low-value fish in aquaculture are lacking.

Fishmeal production plants provide both direct and indirect employment in packaging, transportation and other ancillary inputs for the product. The possibility that more personnel are employed in the reduction industry than would have been the case if the raw material was marketed directly cannot be excluded. However, quantitative information on the employment opportunities in the fishmeal production sector is scant; such information needs to be sought as a matter of urgency.

9. LOOKING AHEAD

In the ensuing decades, fish as a human food source is bound to gain higher global significance. In the developed world, this will occur primarily because of its nutritional benefits (de Deckere *et al*., 1998; Horrocks and Yeo, 1999; Stickney, 2006), whilst in the developing world it will be driven by the fact that fish is the most affordable animal protein source for poorer, rural communities. Most importantly, Delgado *et al*. (2003) have observed that fish consumption among rural, poor communities has increased

[6] In this context, it may be worth recalling that tens of thousands of tonnes of fish are used for commercial production of pet foods (Gooley, Gavine and Olsen, 2006).

significantly over the last decade, and that freshwater fish accounts for about 20–25 percent of the animal protein intake, particularly in rural populations in the developing world. It has even been suggested that farmed fish will become a nutritionally necessary alternative to meat (Sargent and Tacon, 1999). With the near stagnation of wild-caught fish supplies, the increasing demand for foodfish will have to be met by aquaculture; the issue is how much of the shortfall can be met by increased aquaculture production. Currently, 50 percent of foodfish demands are met by the aquaculture sector (FAO, 2006b); but can this proportion grow and if so, by how much?

Fish has become one of the largest exported commodities of developing countries, with exports having shown a continuing rise from US$4.6 billion in 1984 to US$20.4 billion in 2004, an increase that is considerably higher than that shown by traditionally exported commodities such as rice, coffee and tea (Kurien, 2005; FAO, 2007). Among the top-ten fish exporting nations in the world are three Asian countries, China, Thailand and Viet Nam. Viet Nam registered an increase of 17.4 percent in annual growth for the period 1994–2004 (FAO, 2007), the largest contribution being from the aquaculture sector, primarily catfish and shrimp farming. The catfish farming sector in Viet Nam employs an estimated 160 000 to 170 000 people (over 80 percent of them women), within the relatively small geographical area of the Mekong Delta, contributing significantly to food security and poverty alleviation in this region (Phan *et al.,* 2009).

As evident from the data presented previously, aquaculture has shown considerable growth over the last two decades and hence its current importance as a means of addressing global foodfish needs. It was also evident that the proportion of the different cultured commodities has remained relatively static, the increased volumes in each of the commodities meeting the demands of the growing social strata. The Asia-Pacific, overall, has witnessed significant economic growth during the last decade, resulting in a higher proportion of "disposable income" in significant numbers of the population. Such changes result in different consumer demands (Gehlhar and Coyle, undated), including those related to fish consumption (De Silva, 2001).

Cultured marine species (especially groupers) have a high market demand in the region that, barring unforeseen global calamities, is likely to grow (Sim, 2005) by catering to an increasing middle class while also contributing to food security for small-scale producers. In meeting the increased demand for these relatively high-valued species, a certain degree of compromise is needed in the use of exhaustible resources and the potential effects of the sector on the environment. Such compromises may be accompanied by improvements to the technologies and practices that impact natural resource usage, reducing environmental effects to a minimum. There is a need to minimize the direct use of trash fish/low-value fish in marine fish culture by encouraging fish farmers to use formulated feeds, which have significantly lesser dependence on trash fish/low-value fish and higher overall environmental integrity.

The aquaculture sector in the region has to improve its collaboration with the feed industry. One area of aquafeed development that has not kept pace in the region is the use of animal industry by-products in feed formulation. This could be due to the fact that the animal processing industries (apart from the poultry industry) are relatively less centralized than in the west. Consequently, there is no large-scale production of blood meal and bone meal. However, this problem could be solved by improved dialogue between sectors and targeted research.

In Asia, almost all aquaculture, as is the case of most agriculture, is small scale, rural and clustered. These small holdings, which are often farmer owned, operated and managed, generate synergies and work in harmony (Figure 23). In the case of marine finfish culture, there is an urgent need to encourage these smallholders to adopt better feed management practices, commencing with a shift from using trash fish/low-value fish to using formulated feeds, if the use of formulated feed is a more efficient form of resource use. The general impression that such changes are difficult to bring about is untrue, as exemplified by the recent adoption of best management practices (BMPs) by small-scale shrimp farmers in India (Umesh, 2007).

As previously noted, feed development for a wide range of cultured aquatic species, in particular the newly emerging marine finfishes, has lagged behind the progress that has been made by the animal husbandry sector. With the increasingly negative public perception of the use of fishmeal and fish oil by the aquaculture sector, as well as of the use of trash fish/low-value fish for feeding cultured stocks, there needs to be a concerted effort directed towards the development of diets with lower fishmeal/fish oil content and to decrease the use of trash fish/low-value fish by small-scale farmers as feed for cultured stocks. Perhaps this can be accomplished through a regional initiative that brings together researchers, feed manufacturers, raw material suppliers and farming communities. There also needs to be an emphasis on the improvement of farm-made feeds, which are an important element in Asian aquaculture. Although this point has been advocated previously (De Silva and Davy, 1992; New, Tacon and Csavas, 1995; Tacon and De Silva, 1997), little headway has been achieved. Again, a regional approach may be needed to determine ways and means of improving the efficacy of farm-made feeds and the dissemination of appropriate strategies.

In China, the problems associated with the direct use of trash fish/low-value fish as feed in aquaculture have recently drawn increased attention. During the National Freshwater Aquaculture Development Planning Meeting in 2004, the concept of "feed-fish culture", based on the success in mandarin fish culture in southern China, was endorsed as a new thrust for developing high-value fish culture in the country.

The policy of the Chinese fisheries authority is to promote the development and use of complete formulated feeds to gradually replace the direct use of trash fish/low-value fish in marine finfish farming. Apart from the research and development in feeds, feeding and culture technology, the central and local fisheries authorities are now studying the feasibility of launching policies to provide suitable incentives to encourage marine finfish farmers to shift to formulated artificial feeds.

Given the social, economic and technical factors associated with the use of trash fish/low-value fish in China's marine finfish culture, it is unrealistic to expect that trash fish/low-value fish use will disappear in the near future. However, it is envisioned that the use of trash fish/low-value fish for fish culture will come under stricter government regulation and that the general trend in finfish culture will be towards an industry that is more knowledge-based, healthier and more environmentally friendly.

FIGURE 23

An aerial view of cage-culture practices in XinCun Bay, Hainan Island, China, where 570 families conduct marine cage farming. Although each holding is small, the families collectively produce 100 000 tonnes of high-value marine finfish, almost all of which are fed trash fish/low-value fish

10. CONCLUSIONS

The fisheries sector is an important contributor to the GDP of most Asian countries. Interestingly, the percent contribution to the GDP from aquaculture in Bangladesh, the Lao People's Democratic Republic, the Philippines, China, Thailand and Viet Nam has exceeded that from capture fisheries, while the contribution of captured fish is still slightly higher in Cambodia, Indonesia, Sri Lanka and Malaysia (Sugiyama, Staples and Funge-Smith, 2004). However, in the latter group of countries, the contribution to the GDP from aquaculture has also been increasing, but not that from the capture fisheries sector, except in Cambodia.

The increasing predominance of the aquaculture sector is a most welcome sign. However, the aquaculture sector in the Asia-Pacific region is the largest consumer of fish, reduced or otherwise, as feed sources for the cultured stocks (but not the highest consumer of fish oil). Overall, it is predicted that aquaculture will use an equivalent of between 9 228 453 and 13 970 887 tonnes of trash/low-value fish by 2010. This is equivalent to 33 to 50 percent of this global resource. While it can be argued that such a high consumption of these resources for foodfish production in the Asia-Pacific (which accounts for over 90 percent of global aquaculture production), is justified, this is a simplistic stance. A more responsible development of the aquaculture sector in the region necessitates that the availability of foodfish to an ever changing and demanding population is enhanced and that the livelihoods of poor farmers and the associated provisions of food security and poverty alleviation are ensured.

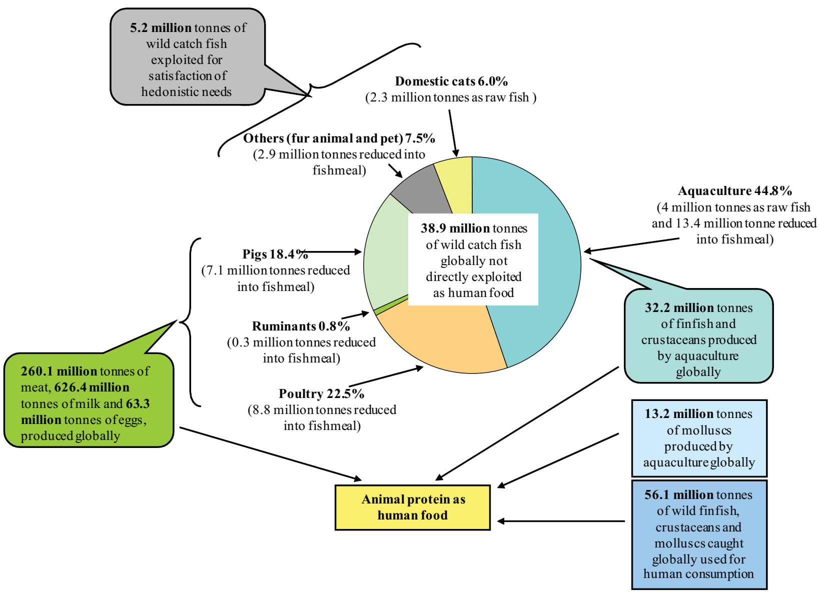
The responsibility of the aquaculture sector in the region is further exacerbated by the decline in wild catches, even if we do not give serious consideration to the rather pessimistic scenarios suggested by some workers. The equation is not straight forward; there are thousands of artisanal fishers who cater directly to the needs of the aquaculture sector and whose fishing methods are probably not destructive as often described. These artisanal fishers mostly use gillnets of appropriate mesh size and which do not negatively impact the sustainability of such fisheries, unlike the case of industrial fishing (e.g. trawling).

It is also important to consider the use of trash fish/low-value fish in aquaculture in relation to the changes that are occurring in the marine capture fisheries in the region *per se*, rather than globally. It has been shown (Sugiyama, Staples and Funge-Smith, 2004) that major changes have occurred in the marine capture fisheries in the region over the last two decades. For example, the landing of trash fish in China rose from 1.3 million tonnes in 1980 to 5 million tonnes in 2002, and in the South China Sea these landings exceeded 60 percent of the total production. Comparable figures are reported from the Gulf of Thailand fisheries and in the western Malaysian trawl fishery, trash fish accounted for 51 percent of the landings. Given that trash fish/low-value fish are generally not preferred for human consumption (particularly near landing sites where better aquatic products are available at an affordable price), and that their distribution to inland areas is hampered by issues related to poor quality and high transportation costs that affect marketability, the question therefore arises: what is the best and most appropriate use of this resource?

The aquaculture sector in the Asia-Pacific region has undergone an unprecedented growth over the last two decades and has done so to a significant degree through an increased reliance on fish as feed, in one form or another. It is important to note that the fish produced via feeding of trash fish/low-value fish are not necessarily destined for high-end markets, e.g. tilapia and catfishes, which generate incomes that in turn ensure food security and contribute to poverty alleviation. It is also important to highlight the contribution of fish culture based on trash fish/low-value fish to the protection of coral reefs, the preferred habitats of groupers.

It is important to note that all predictions indicate that the aquaculture sector in the Asia-Pacific region is becoming increasingly prudent and conscious of the use of

FIGURE 24
The proportion of global trash fish/low-value fish used by different sectors



Source: De Silva and Turchini (2008)

fish, directly and indirectly, as feed sources for cultured stocks. There is clear evidence that such usage will decrease significantly in the future, and this perhaps can be further promoted by better translation of research into feed formulation, adoption of simple but effective feed management practices and improvements to farm-made feeds. The assumption that the use of formulated feeds is better than the direct use of trash fish/low-value fish has to be scientifically substantiated from the viewpoints of both efficacy and primary resource utilization, however, before attempting to encourage resource-poor small-scale farmers to shift to the use of formulated feeds.

Most importantly, the issue of channelling trash fish/low-value fish to the production of food for human consumption as opposed to its use for other purposes needs to be carefully addressed. De Silva and Turchini (2008) endeavoured to show the approximate breakdown of the usages (Figure 24). These authors also point out that with living standards increasing throughout much of the world, the consequent demands for foods that are perceived to be better, and other human recreational needs, all of which impact on the demand of a dwindling biological resource, there is a need for a global approach to the problem.

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Use of wild fish and other aquatic organisms as feed in aquaculture – a review of practices and implications in Africa and the Near East

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SUMMARY

Global aquaculture production has more than tripled over the last 15 years. The 45.6 million tonnes of produce derived from aquaculture in 2004 made a notable (47.7 percent) contribution towards total global fish, crustacean and mollusc production. However, there is concern that the contribution by aquaculture to global food security is misleading because aquaculture is the single largest consumer of fishmeal and fish oil. In 2003, just over 53 percent of the total fishmeal production (i.e. 2.94 million tonnes of 5.54 million tonnes was used by aquaculture). Similarly, 87 percent of world fish oil production was used in aquaculture in 2003 (i.e. 0.8 million tonnes of a world total of 0.92 million tonnes). Hence, there is a growing concern that some of the world's feed-fish fisheries are not being used with adequate consideration for human requirements, and that a portion of these resources could be better used to contribute towards food security in developing nations.

Aquaculture production in Africa grew by 358 percent between 1995 and 2004. As in Asia, this increase is largely attributed to the culture of non-carnivorous species. Therefore, unlike the global average where more than half of the fishmeal is consumed by fish farming, aquaculture is not a major fishmeal consumer in most African countries. To make estimates on fishmeal production and use with any reasonable degree of confidence is difficult because the entire region, except for isolated instances, is extremely data poor, and the actual consumption of fishmeal and fish oil by the animal feed industry (including the aquafeed industry) in almost all African countries is unknown. However, based on available animal feed production figures and average fishmeal inclusion rates it was possible to estimate a fishmeal consumption of approximately 425 000 tonnes. Annual fishmeal production in Africa and the Near East approximates 200 000 tonnes, suggesting that about 47 percent of the fishmeal used in the region is locally produced. Based on aquafeed production data, it was estimated that the total consumption of fishmeal by the aquafeed industries in the region is between 25 000 and 76 000 tonnes.

Although there are adequate species-specific data on small pelagic landings in Africa and the Near East, the majority of fishmeal production is not reported at the species level. It is, therefore, difficult to estimate spatial and seasonal availability of the commodity. Some pelagic fisheries in the region have been subject to unsustainably high levels of fishing in the past. Recent findings suggest that these stocks are not as resilient as previously assumed, which leads to the conclusion that most fisheries in the region are not adequately managed and that this requires urgent attention to ensure the long-term sustainability of the resources. On the whole, except for South Africa and Morocco, fishmeal production in Africa is a relatively minor small-scale type of activity in relation to the rest of the world, hence the region is extremely data poor. South Africa has the only dedicated reduction fishery in the region, although Morocco has the largest small pelagic fishery. Until recently, fishmeal production in Morocco was considered as a surplus activity. It was estimated that up to 40 percent of the small pelagic landings in Africa and the Near East is reduced to fishmeal.

Although much of the world's small pelagic catch is not used for direct human consumption in the developed world, there is a ready and large demand for this fish as food in the developing world. There are numerous examples in Africa where communities that were once reliant on small pelagics as part of their diet no longer have ready access to these resources mainly because of the growing demand by the animal feed industry. In some instances, the increase in animal production (including aquaculture), which is largely reliant on fishmeal, can improve the standard of living and level of food security among poor communities, due to employment opportunities that are created. However, this is only possible if the fishmeal is used locally and the production of the "secondary" product creates employment. Although most of the fishmeal produced in Africa and the Near East is used locally, the production of a "secondary" product does not always create employment among the communities that would otherwise have used the fish for direct consumption. A comparison of post-harvest losses and the proportion of the region's small

pelagic catch that is reduced to fishmeal highlights the urgent need to focus on improved post-harvest technologies, such that spoilage can be avoided.

By way of some examples, the report illustrates that the reduction of fish can either have negative or positive impacts on the poor. Hence, it is difficult to make broad regional recommendations with respect to reduction fisheries and, of course, this is further compounded by the fact that there are no reduction fisheries, *sensu stricto*, in Africa and the Near East, except for South Africa. In conclusion, and principally on the basis that there are only two fishmeal and fish oil-producing countries of substance in the region, it is recommended that steps be taken to; (1) improve monitoring and reporting of fishmeal and fish oil production and consumption; (2) improve monitoring such that analyses to determine the financial benefits of fish reduction versus loss of food security can be undertaken; and (3) create greater awareness of the potential benefits of small pelagic fisheries with respect to food security and poverty reduction, particularly in areas where imbalances already exist and where the reduction of fish may exacerbate the problem of low food security in the future.

1. INTRODUCTION[1]

1.1 Background

World capture fisheries have reached a plateau at approximately 94 million tonnes (FAO, 2006b). Recent estimates suggest that 52 percent of marine stocks are fully exploited, 17 percent are over exploited and 7 percent are totally depleted (FAO, 2005a); however, human population and the demand for marine and other aquatic resources continue to increase. Global aquaculture has made a considerable contribution towards bridging the gap between supply and demand. Total production (excluding aquatic plants, corals and amphibians) in 2004 amounted to just over 45 million tonnes, contributing 47.7 percent to total global fish production (FAO, 2006a, 2006b). Globally, aquaculture production has more than tripled in the last 15 years (FAO, 2006a). Most notable have been the increases in production in China and Chile.

Fishmeal and fish oil are important feed ingredients in aquaculture, and by 2003 the consumption of fishmeal and fish oil by the sector had increased to 2.94 million and 0.80 million tonnes, representing 53.2 and 86.8 percent of global production, respectively (Tacon, Hasan and Subasinghe, 2006). Naylor *et al.* (2000) argue that the farming of carnivorous fishes, in particular, has placed undue pressure on world fishmeal supplies by using up to five times more fish protein than that which is produced. Although there are discrepancies in the ratio of wild-fish consumed to farmed-fish produced, there is general agreement that species such as salmon, trout and other carnivorous marine finfish consume considerably more fish protein than they produce (FIN, 2004). However, this is not the case for herbivorous, omnivorous, detritivorous and planktivorous species, which produce considerably more fish protein than they consume (Naylor *et al.*, 2000). The growth of the aquaculture industry is fortunately skewed in favour of non-carnivorous species, which are produced by more extensive and traditional methods of aquaculture (i.e. with little to no fishmeal in the diet). It is mainly for this reason that the balance is tipped in favour of aquaculture (Roth *et al.,* 2002). Nonetheless, aquaculture is reported to be the single largest user of fishmeal, using in excess of 53 percent of the global supply (Tacon, 2004; Tacon, Hasan and Subasinghe, 2006). This review is a contribution towards the overall goal of the project as outlined in Footnote 1.

2. OVERVIEW OF AQUACULTURE IN AFRICA AND THE NEAR EAST

2.1 Current status and trends

Globally, aquaculture production has almost doubled during the course of the last ten years. Approximately 24.4 million tonnes of fish, molluscs and crustaceans were produced in 1995, and by 2004 production had increased to 45.6 million tonnes (FAO, 2006a). Aquaculture in Africa (particularly in North Africa) and the Near East has also grown substantially over the last decade, and although this region still makes a relatively small contribution to global production, its potential for aquaculture is recognized. This is evident in the increased contribution to global aquaculture (from 0.005 percent in 1995 to 1.19 percent in 2004) (FAO, 2006a) by the region. Growth of the sector in Africa and the Near East exceeds the global growth rate. Total aquaculture production in this region increased from 166 525 to 721 645 tonnes between 1995 and 2004, which represents a growth rate of 334 percent compared to the global increase of 90 percent for the same period (Figures 1 and 2). The greatest proportion of growth in

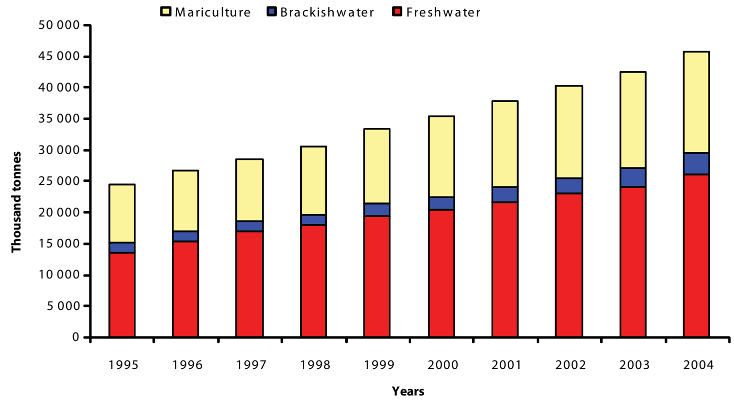
[1] The countries included in this review are listed in Appendix 1 and are limited to those countries of Africa and the Near East that were reported by FAO to have produced aquaculture products and those countries reported to have produced, consumed, imported or exported fishmeal and fish oil. The term "fishmeal" is inclusive of white-fishmeal, oily-fishmeal, tuna meal, clupeoid fishmeal and crustacean meal. The term "fish oil" is inclusive of all fish and marine mammal body and liver oils, fats and solubles. It is important to note that the region is extremely data poor with respect to reduction fisheries, except for Morocco and South Africa. Moreover, in many instances there is conflicting information and data on reduction fisheries such that the reliability of many sources is questionable.

Africa and the Near East has taken place in brackishwater aquaculture (most notably, in Egypt) and to a lesser degree in freshwater (Hecht, 2006). This is not the case for global aquaculture, where most growth has taken place in marine and freshwater (Figures 1 and 2)

Aquaculture in Africa and the Near East is dominated by Egypt, the Islamic Republic of Iran and Nigeria, which collectively contributed 87.4 percent to the region's production, which in 2004 amounted to some 471 535, 104 330 and 43 950 tonnes, respectively (Figure 3). The other main aquaculture-producing countries (i.e. >5 000 tonnes) include Iraq, Saudi Arabia, Madagascar, Syrian Arab Republic, South Africa, Tanzania, Uganda and Zambia, which together produced 63 400 tonnes in 2004 (FAO, 2006a). The balance (i.e. 25 931 tonnes) was produced by 42 countries in the African and the Near East region. However, some of these smaller-producing countries have experienced the fastest rates of growth in production during the last ten years. For example, reported production in Togo grew from 20 tonnes in 1995 to 1 525 tonnes in 2004 (FAO, 2006a), a 76-fold increase, while in Zimbabwe total production increased from 150 to 2 955 tonnes over the same period when one large Nile tilapia cage-culture operation was established on Lake Kariba (Hecht, 2006; Blow and Leonard, 2007). Similarly, Uganda has shown a remarkable 1 058 percent increase in production

FIGURE 1

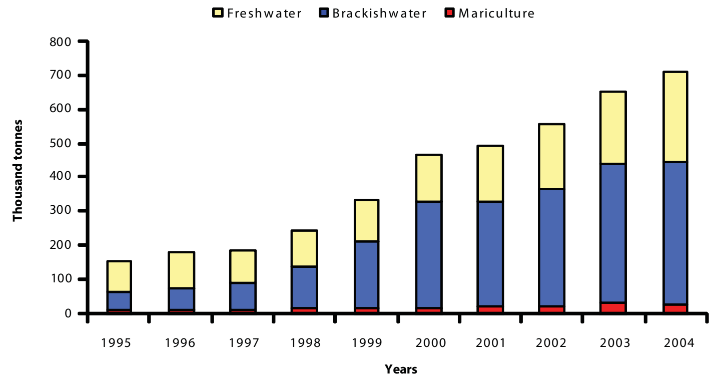
Global aquaculture production (fish, crustaceans and molluscs), 1995–2004



Source: FAO (2006a)

FIGURE 2

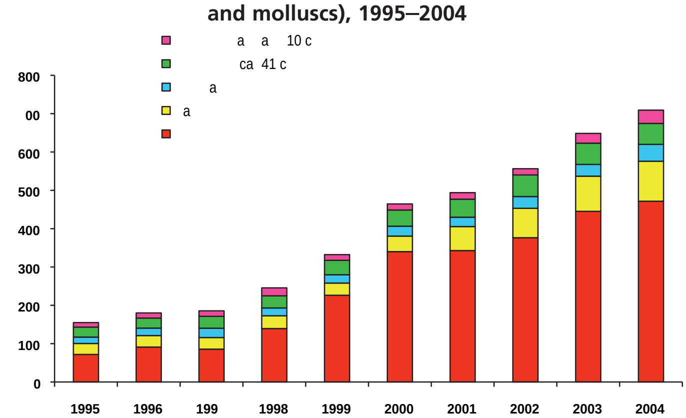
African and Near East aquaculture production (fish, crustaceans and molluscs) by environment, 1995–2004



Source: FAO (2006a)

FIGURE 3

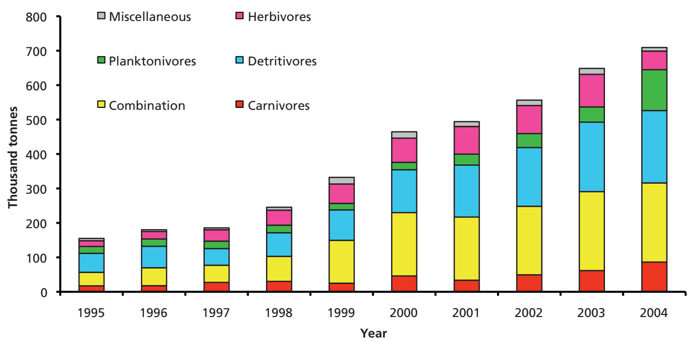
African and Near East aquaculture production (fish, crustaceans and molluscs), 1995–2004



Source: FAO (2006a)

FIGURE 4

Aquaculture production (fish, crustaceans and molluscs) in Africa and the Near East by natural feeding guilds



The "combination" group includes omnivores and fishes that are both detritivorous and herbivorous or detritivorous and planktivorous.

Source: FAO (2006a) and feeding guilds superimposed by authors

between 1998 and 2003, from 475 to 5 500 tonnes (Hecht, 2006).

Similar to the situation in Asia, most of the fish produced in Africa and the Near East are non-carnivorous species. Only 12 percent of production in 2004 was attributed to carnivorous species (Figure 4). The implications of this on fishmeal use are discussed in greater detail later in this report.

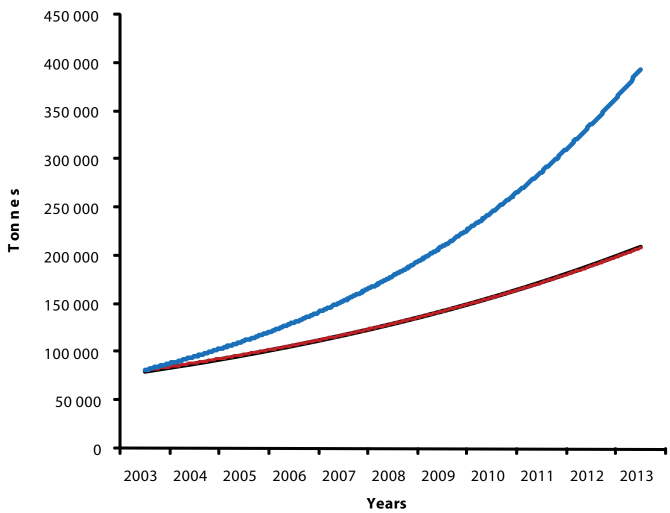
2.2 Future outlook

Food insecurity remains a serious problem in the developing world, particularly in Africa. There have been many attempts to promote aquaculture as a means to address poverty and food security in Africa, although with limited success. There is no reason to dwell on the reasons why the sector has not performed as expected, as these have been dealt with previously (FAO, 1975, 2000; ICLARM and GTZ, 1991; Hecht, 2000; Moehl, Halwart and Brummett, 2005). In looking forward, there have been numerous calls (FAO, 2000; Hecht, 2000, 2006) for a paradigm shift in thinking to strongly promote the commercialization of aquaculture in Africa (Halwart *et al.* 2008; Moehl, 2008). The recent expansion of the aquaculture sector in Africa (Hecht, 2006) and the Near East (Poynton, 2006) is likely to continue. While the value of small-scale or subsistence aquaculture in Africa is recognized as making significant contributions to improved nutrition at the family level (Miller, 2009), it is highly unlikely that this sector will make a noticeable contribution to food security and poverty alleviation at the national level in Africa (Hecht, 2006). However, as commercial enterprises expand and as the industry grows, it will most certainly, as elsewhere in the world, contribute towards improving food security and employment. Some 86 700 people are employed in the aquaculture sector in the Near East, of which the majority (60 000) are employed in Egypt (Poynton, 2006), while in ten sub-Saharan African countries for which data are available, the sector employs around 200 000 people (Hecht, 2006). Clearly, the sector as a whole already makes some contribution to employment and will continue to do so in the future and particularly so when governments in sub-Saharan Africa begin to promote and support commercial aquaculture more strongly (Hecht, 2006).

The potential of aquaculture in Africa was once described as a sleeping giant (New, 1991), and it has been predicted that the developing world is where the bulk of aquaculture production will come from in the future (New, 1991; Hecht, 2000). The growth of the industry in Africa and the Near East over the last ten years is testimony to this potential (see also Aguilar-Manjarrez and Nath, 1998).

On the basis of several assumptions, Hecht (2006) made some projections on the growth of the sector in sub-Saharan Africa and suggested that by 2013 total fish production would be somewhere between 200 000 and 380 000 tonnes per annum (Figure 5). The outlook in North Africa differs from that of sub-Saharan Africa and the Near East, largely due to the impact that Egypt has in the region. Aquaculture in Egypt has already doubled approximately seven times in the last decade, and Egypt is currently ranked the twelfth largest aquaculture-producing country in the world (El-Sayed, 2007). Although there are no projections for North Africa or the Near East, El-Sayed (2007) in his review of Egypt and Poynton (2006) in her regional review of North Africa and the Near East both predicted continued and sustained growth of aquaculture in the region.

FIGURE 5
Two growth scenarios of aquaculture production in sub-Saharan Africa to 2013



Source: Hecht (2006)

3. STATUS ON AND TRENDS IN THE USE OF FISHERIES RESOURCES AS INPUTS IN THE ANIMAL FEED INDUSTRY IN AFRICA AND THE NEAR EAST

3.1 Landings of fish destined for reduction and other uses

Currently, almost 82 percent of global fishmeal production and 55 percent of global fish oil production is not reported at the species level (Tacon, 2004), and there is a more acute lack of information for Africa and the Near East. This makes it almost impossible to determine any spatial or seasonal patterns of availability.

A five-year summary of small pelagic catches for Africa and the Near East is shown in Table 1. Unfortunately the data cannot be disaggregated for reduction, human consumption and other uses.

TABLE 1
Small pelagic landings (tonnes) for Africa and the Near East, 2000–2004*

Country		2000	2001	2002	2003	2004	5-year average
Morocco	Africa	562 684	812 551	707 874	677 635	653 474	682 844
South Africa	Africa	441 650	534 680	528 950	591 399	611 159	541 568
Senegal	Africa	250 715	244 754	210 692	281 723	276 340	252 845
Ghana	Africa	223 624	166 173	139 668	183 069	166 674	175 842
Nigeria	Africa	108 620	92 907	93 519	100 676	97 070	98 558
Algeria	Africa	76 405	99 873	100 750	100 372	99 600	95 400
Other**	Africa	450 075	397 836	408 229	404 570	453 815	422 905
Other***	Near East	81 595	97 624	76 739	71 127	81 396	81 696
Total		**2 195 368**	**2 446 398**	**2 266 421**	**2 410 571**	**2 439 528**	**2 351 658**

*Countries with an annual mean catch of less than 50 000 tonnes were grouped.
**Other African countries (23 countries).
***Other Near Eastern countries (9 countries).

Source: FAO (2006b)

Unlike Peru, Chile and Iceland, among other countries, that have dedicated reduction fisheries (Tacon, Hasan and Subasinghe, 2006), most of the small pelagic fisheries in Africa and the Near East target fish for human consumption. South Africa is the only exception in that it has a dedicated reduction fishery (S. Malherbe, Chairperson, South

African Pelagic Fish Processors Association, personal communication, 2006). While Morocco has the largest small pelagic fishery in the region (Table 1), fishmeal and fish oil production has until recently been considered a surplus activity (Atmani, 2003).

The pelagic fishery in Morocco is based on the European pilchard (*Sardina pilchardus*), sardines (*Sardinella* spp.), the European anchory (*Engraulis encrasicolus*), chub mackerel (*Scomber japonicus*) and horse mackerel (*Trachurus* spp.) (Atmani, 2003; FAO, 2006b). With a catch of 653 474 tonnes in 2004, the Moroccan small pelagic fishery is currently the largest in the region. South Africa's small pelagic fish catch of 614 153 tonnes in 2004 (Table 2) mainly consisted of the South American or southern African pilchard (*Sardinops sagax*), southern African anchovy and Whitehead's round herring (*Etrumeus whiteheadi*) (Fishing Industry Handbook, 2005). The Namibian pelagic catch in 2004 amounted to some 35 506 tonnes of southern African pilchard, anchovy and round herring and 314 538 tonnes of cape horse mackerel (*T. capensis*) (FAO, 2006b). Namibian reduction figures for clupeoid catch are not available (Van Zyl, 2001); however, 10 percent of the 2004 cape horse mackerel catch was reduced to fishmeal (Animal Feed Manufacturers Association of South Africa, personal communication, 2006). Both Algeria and Angola have clupeoid fisheries (FAO, 2006b), although no reliable reduction statistics are available. Landings in Algeria in 2004 amounted to 99 600 tonnes, and Angola landed 58 569 tonnes in the same year (FAO, 2006b). Angola recognizes that reduction fisheries can potentially have a serious impact on the supply of fish for human consumption and proposes to develop its pelagic fisheries such that the potential impact is minimized (S.J.L. Xirimbimbi, Minister of Fisheries, Angola, personal communication, 2006).

TABLE 2
South African pelagic catches, 2002–2004 (tonnes)

Species	2002	2003	2004
Sardine (directed catch)	244 743	271 148	365 792
Anchovy	213 446	258 877	190 093
Sardine (bycatch)	16 141	15 847	8 035
Horse mackerel	8 149	1 012	2 048
Round herring	54 798	42 529	47 234
Chub mackerel	82	250	480
Lantern fish	23	69	471
Total	**537 382**	**589 732**	**614 153**

Source: Fishing Industry Handbook (2005)

In Kenya the most important species destined for reduction is the silver cyprinid (*Rastrineobola argentea*, local name: "dagaa", also known as "omena" and "mukene" in Uganda and Tanzania). To a lesser degree, Nile perch (*Lates niloticus*) trimmings from Lake Victoria are also reduced to fishmeal (Abila, 2003). Between 50 and 65 percent of the Kenyan 'dagaa' catch from Lake Victoria is reduced to fishmeal (Abila, 2003). In 2004, the total recorded "dagaa" catch was 31 659 tonnes (FAO, 2006b), suggesting that 15 800 to 20 500 tonnes of fish were reduced to fishmeal. Significant catches of this species are also made by Uganda (90 000 tonnes per annum; J. Rutaisere, Uganda Department of Fisheries, personal communication, 2007) and Tanzania, although it is not known what proportion of the catches are reduced to fishmeal. Ghana recorded a total anchovy catch in 2004 of 52 629 tonnes (FAO, 2006b). Up to 50 percent of the anchovy catch in Ghana is reduced to fishmeal annually (Directorate of Fisheries, Ghana, 2003), which equates to approximately 26 000 tonnes of anchovy.

The total catch of small pelagics in the Near East region is around 82 000 tonnes (see Table 1) and comprises some 12 species.

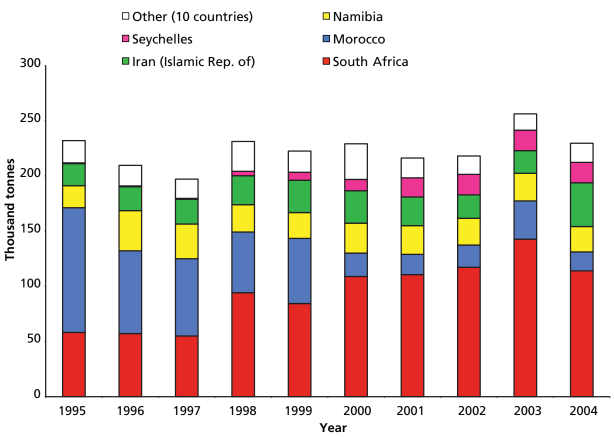
There are no disaggregated data for fishmeal and fish oil production from trimmings, bycatch and whole fish for Africa and the Near East, except for Seychelles and Mauritius, where all fishmeal is made from tuna trimmings. This requires remediation, such that a more accurate picture can be obtained on the use of different fisheries products. Nonetheless, it is reported that 5.6 million tonnes of "trimmings" (i.e. the off-cuts and offal of processed foodfish) and reject foodfish were reduced globally during 2002 (FIN, 2005), which accounts for approximately 17 percent of world fishmeal production over the same period. There appears to be a global trend towards increasing the use of trimmings for the production of fishmeal. For example, it is estimated that on average 33 percent of fishmeal produced in the European Union (EU) is manufactured from food-fish trimmings (Tacon, 2004). In Spain, France, Germany and Italy, 100 percent of fishmeal originates from trimmings, while in the United Kingdom, Ireland, Sweden and Denmark, trimmings accounted for 84, 60, 25 and 10 percent of total fishmeal production, respectively (Tacon, 2004; Tacon, Hasan and Subasinghe, 2006). Similar estimates are not available for Africa and the Near East. However, there are reports that fishmeal is produced from tuna trimmings in Ghana (Directorate of Fisheries, Ghana, 2003), Nile perch frames in Kenya (Abila, 2003) and Uganda (Hecht, 2007), milled dry wastes of smoked tilapia and catfish in Cameroon (Pouomogne, 2007) and tuna cannery by-products in Egypt (El-Sayed, 2007) and, as mentioned above, all fishmeal produced in Seychelles and Mauritius is made from tuna cannery trimmings. There are several smaller plants in South Africa that produce fishmeal from hake and other groundfish trimmings. Hecht (2007) also reports that in many sub-Saharan African countries small quantities of dried fish are reduced to fishmeal for human consumption and for use in fish feeds. Unfortunately, these activities are not quantified.

According to Ames (1992), the physical post-harvest loss of fish in inland fisheries in Africa amounts to between 20 and 25 percent and in some countries may be as high as 45 percent. On the assumption that losses due to spoilage in Africa have been reduced since then to 15 percent for inland fisheries and 5 percent for marine fisheries, this amounts to some 571 362 tonnes of fish that were unavailable for human consumption in 2004 (FAO, 2006b). This scenario can be viewed in two ways. With improved technologies, greater supply chain efficiency and removal of other hindrances, this quantum of fish could either be available for direct human consumption and have an immediate impact on food security, or if not fit for human consumption, could be reduced to fishmeal and used in the rapidly growing animal feed industry and hence contribute to the creation of employment and wealth through the production of secondary products.

3.2 Fishmeal and fish oil production, exports and imports

As mentioned earlier, South Africa has the only dedicated reduction fishery in the region and is also the largest producer of fishmeal in Africa and the Near East. Mean annual production is approximately 100 000 tonnes (Figure 6), with a current value of around US$71 million (S. Malherbe, Chairperson, South African Fishmeal Manufacturers Association, personal communication, 2006). The pelagic fishery is divided into two distinct sectors, a reduction fishery that targets anchovies (*E. encrasicolus*) and round herring (*E. whiteheadi*), and a fishery directed mainly at pilchard (*S. sagax*) for human consumption and bait. Approximately 60 000 to 70 000 tonnes of the pilchard catch is canned, and the value of this component of the pelagic fishery is currently estimated at between US$107 and 125 million, while the bulk of approximately 130 000 tonnes is packed and used for bait in the tuna pole fishery (local and foreign) and in the recreational fishery. The split in the use of the pelagic catch is largely determined by market demand. Currently there are three dedicated fishmeal factories as well as several smaller plants that form part of the demersal fish-processing industry. The pelagic fishery is managed on the basis of an operational management procedure (OMP) that determines the total allowable catch (TAC) and the closed season. On the whole, the fishery is considered to be fairly well managed (D. Butterworth, University of Cape

FIGURE 6
Fishmeal production in Africa and the Near East*,**



*Fishmeal includes white-fishmeal, oily-fishmeal, tuna meal, clupeoid fishmeal and crustacean meal.
** Note that the data shown here varies substantially from the data presented in Table 3, illustrating the discrepancies in data reporting.

Source: FAO (2006c)

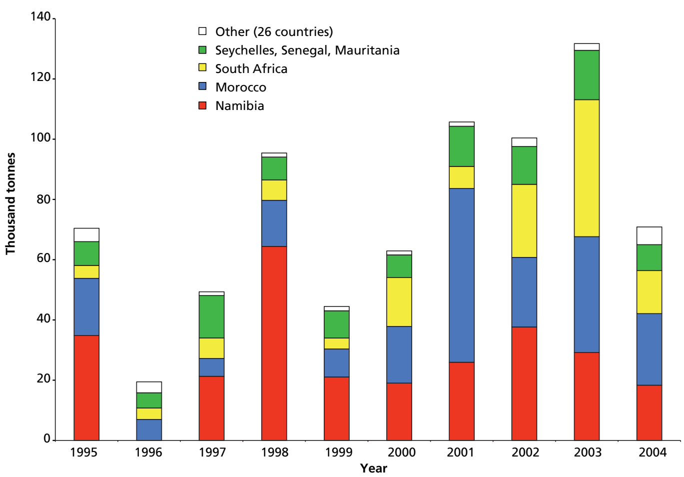
Town, personal communication, 2007). A total of 100 763 tonnes of fishmeal was produced in 2004/2005 (AFMA, 2006) at an average reduction rate of 23 percent (S. Malherbe, Chairperson, Pelagic Fish Processors Association of South Africa, personal communication, 2006), suggesting that ca. 409 476 tonnes of the small pelagic catch were reduced to fishmeal in 2004/2005. As mentioned previously, a small, although unspecified, portion of the South African fishmeal originates from groundfish trimmings.

In 2004, Morocco produced approximately 63 000 tonnes of fishmeal, which at a reduction rate of 24 percent equates to around 40 percent of the total pelagic catch of 653 474 tonnes. Fishmeal and fish oil production in Morocco was until recently considered a surplus activity to absorb fish that cannot be canned due to inefficiencies in canning, inadequate storage facilities and poor fish quality due to inappropriate handling (Atmani, 2003). For example, 70 percent of the catch landed at Laayoun (one of the main pelagic fishery ports in Morocco) was reduced due to insufficient canning infrastructure, even though the fish were fit for human consumption (Atmani, 2003).

South Africa, Morocco, Namibia, the Islamic Republic of Iran and Seychelles collectively produced 91 percent of the reported fishmeal production in the region over the last ten years (Figure 6). Over this period, Morocco, Namibia, Seychelles and Senegal were, in that order, the largest net exporters of fishmeal (Figure 7). Similarly, the Islamic Republic of Iran, South Africa, Egypt, Israel, Syrian Arab Republic and Saudi Arabia were the largest net importers of fishmeal (Figure 8). The Islamic Republic of Iran is the largest producer of fishmeal in the Near East region and in 2003, produced approximately 10 300 tonnes, while all other countries for which data are available produce less than 300 tonnes per annum (Poynton, 2006).

Morocco was the largest producer of fish oil in Africa and the Near East, with an annual average of 16 606 tonnes between 1995 and 2004 (Figure 9). Morocco, South Africa and Namibia were the only significant producers and together produced 94.3 percent of the fish oil in Africa and the Near

FIGURE 7
Fishmeal exports from Africa and the Near East



Source: FAO (2006c)

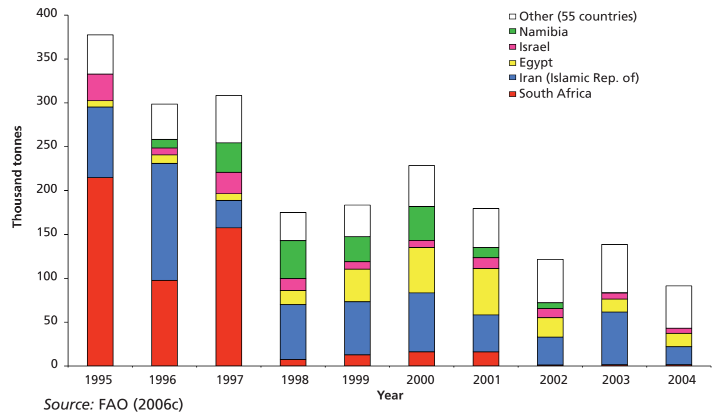
East (Figure 9). South Africa, Algeria, Israel, United Arab Emirates, Saudi Arabia, Syrian Arab Republic, the Islamic Republic of Iran and Nigeria were (in that order) net importers of fish oil, while Morocco, Namibia and Angola were (in that order) net exporters (FAO, 2006c).

The quantity of oils and solubles exported from the region increased during the course of the ten year period from 1995 to 2004, primarily due to increased exports from Morocco (Figure 10). The opposite trend was observed for imports, with a considerable drop in the volume of marine oils and solubles imported into South Africa and Algeria during the late 1990s (Figure 11).

The fishmeal production figures and the volume of fish reduced to fishmeal for Africa and the Near East are summarized in Table 3. Overall, the available information and data suggest that just over 200 000 tonnes of fishmeal were produced per annum or that just under 860 000 tonnes of pelagic fish were reduced to fishmeal and fish oil at a reduction rate of 24 percent. The data used to develop this summary table consisted either in published information on the quantum of fish reduced to fishmeal or the volume of fishmeal production. This allowed for the calculation of fishmeal production or alternatively, back calculating the quantum of fish that was reduced to fishmeal.

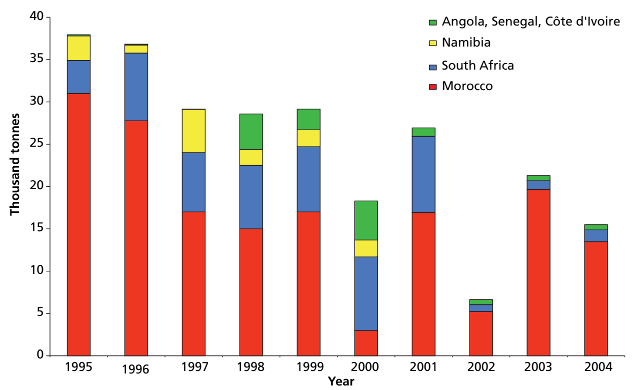
There are significant differences between the data presented in Figure 6 and in Table 3 that reflect the considerable inconsistencies in the reported production, export and import figures for fishmeal and fish oil in the region. For example, the Ministry of Fisheries in Ghana reported that

FIGURE 8
Fishmeal imports into Africa and the Near East



Source: FAO (2006c)

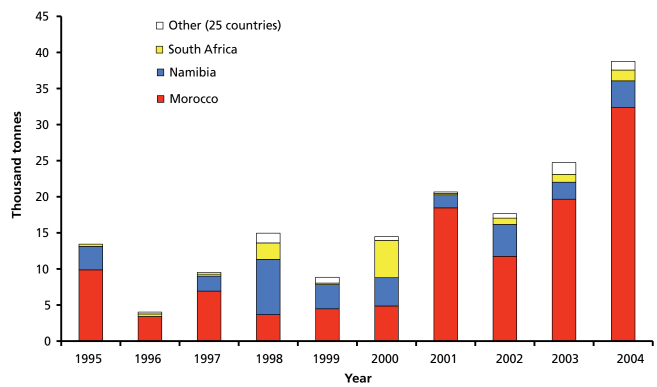
FIGURE 9
Fish oil production in Africa and the Near East*



*Fish oil includes all fish and marine mammal body and liver oils, fats and solubles.

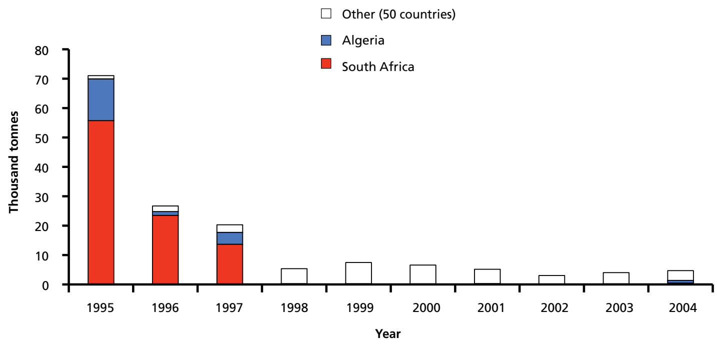
Source: FAO (2006c)

FIGURE 10
Fish oil exports from Africa and the Near East



Source: FAO (2006c)

FIGURE 11
Fish oil imports into Africa and the Near East



Source: FAO (2006c)

anchovy is a widely consumed commodity by low-income communities in the country and, even so, as much as 50 percent of the anchovy catch is reduced to fishmeal (Directorate of Fisheries, Ghana, 2003). Since the anchovy catch in Ghana totalled 52 629 tonnes in 2004 (FAO, 2006b), this would equate to the reduction of approximately 26 300 tonnes of anchovy during the same year. However, there is no record of fishmeal production in Ghana in the FAO statistics (FAO, 2006c). These inconsistencies are problematic in undertaking a review of this nature. While both data sets should be viewed with circumspection, it is likely that the data presented in Table 3 are closer to reality than the data reported to FAO. Similarly, FAO (2006c) reports that fish oil production in Morocco totalled 13 474 tonnes in 2004, whereas the Fishmeal Information Network estimates the production for Morocco at around 25 000 tonnes for 2004 (FIN, 2005), which is almost double the figure cited by FAO (2006c).

Similarly, there are inconsistencies in reported export quantities of fishmeal. For example, Atmani (2003) reports that fishmeal used to be exported from Morocco to Europe. However, because of the demand by the domestic animal feed industry, fishmeal exports have been suspended. FAO statistics, however, show that an average of 21 831 tonnes per annum was exported from Morocco over the last ten years (FAO, 2006c) and, although there is considerable annual variation, there was no evidence of a reduction. Furthermore, FIN (2005) reports that fishmeal was exported from Morocco for the first time in 2000 and that 34 000 tonnes were exported in 2004. This is 43 percent more than that cited by FAO (i.e. 23 766 tonnes; FAO, 2006c) and moreover, fishmeal exports from Morocco have been reported as far back as 1976 (FAO, 2006c).

TABLE 3
Reduction of small pelagic fish to fishmeal and fish oil in Africa and the Near East, 2004–2005 (tonnes)

Country**	Wet weight fish	Fishmeal production
Morocco	262 500*	63 000
South Africa	449 013*	107 763
Ghana	26 300	6 312*
Namibia	31 454	7 548*
Egypt	521*	125
Kenya	18 150	4 356*
Angola	20 833*	5 000
Senegal	2 950*	708
The Islamic Republic of Iran	42 937*	10 305
Yemen	3 212*	771
Libyan Arab Jamahiriya	1 629*	391
Total	**859 499**	**206 279**

*Calculated figure based on a reduction rate of 24 percent.
** Excluding countries that produce fishmeal from tuna cannery trimmings (e.g. Seychelles and Mauritius).
Source: Directorate of Fisheries, Ghana (2003); Fishing Industry Handbook (2005); AFMA (2006); El-Sayed (2007); FAO (2006c); Poynton (2006); Hecht (2007)

These are just a few examples, among many, of inconsistent information. Contradictory data obstruct efficient management and decision–making, particularly when there are considerable differences between sources, as has been shown here. It also makes it very difficult to undertake credible reviews of reduction fisheries, unless one has direct access to industry facts and figures.

3.3 Current use of and demand for fishmeal and fish oil in aquafeed and in animal feed

The available data do not allow for a reliable summary of current use and demand patterns for fishmeal and fish oil in the region. At best it is possible to provide some estimates based on extrapolations when reasonable data are available. However, these estimates should also be viewed with circumspection. Overall, it is fair to state that the contribution by feed-fish fisheries to the economies of the countries is important only on a local basis, but their contributions to gross domestic product (GDP) are negligible. For example, the total processed value of the pelagic fishery in South Africa and Morocco contributes 0.000098 percent and 0.000074 percent to GDP, respectively.

It has been reported that some 20 000 tonnes of fishmeal were used by the Egyptian aquafeed industry in 2004, of which less than 200 tonnes were produced locally from sardine, anchovy, mackerel and tuna cannery by-products (El-Sayed, 2007). However, there is some doubt as to the accuracy of this estimate, and there are no reliable fishmeal consumption data for the aquafeed industries in the other countries. Hence, this had to be estimated using an alternative approach. The available aquafeed production data (Table 4) and fishmeal inclusion rates of between 5 and 15 percent suggest that the total use of fishmeal in aquaculture for Africa and the Near East ranges somewhere between 25 000 and 76 000 tonnes per annum. The relative proportion of fishmeal used in aquafeeds and in the poultry and pig feed industries in six African countries (for which relatively good animal feed data are available) was calculated on the basis of average fishmeal inclusion rates of 15 percent for fish feed, 3 percent for poultry feed and 6 percent for pig feed (Tacon, Hasan and Subasinghe, 2006). The results are shown in Table 5, from which it is evident that total fishmeal consumption by the animal feed industry in these African countries amounted to some 424 872 tonnes per annum of which 69 440 tonnes were attributed to aquafeeds, 276 647 tonnes to poultry feed and 78 777 tonnes to pig feed. On the assumption that the figures are a realistic reflection of the situation on the ground, then aquaculture accounts for approximately 16 percent of the total quantity of fishmeal used in animal feeds in the region.

TABLE 4
Estimated fishmeal consumption by the aquafeed industry in Africa and the Near East

Region	Total aquafeed production	Fishmeal inclusion rates		
		5 percent	10 percent	15 percent
North Africa and Near East	462 600	23 130	46 260	69 390
Africa (8 countries)*	42 027	2 101	4 202	6 304
Total		**25 231**	**50 462**	**75 694**

* Cameroon, Ghana, Kenya, Malawi, Nigeria, South Africa, Uganda and Zambia, which collectively contributed approximately 70 percent to the total sub-Saharan aquaculture production (FAO, 2006a).
Source: Poynton (2006); Hecht (2006, 2007)

TABLE 5
Estimated volumes of fishmeal used in animal feeds produced in African countries that are the major aquaculture producers (tonnes)

Country	Cameroon	Egypt	Kenya	Nigeria	South Africa	Zambia
Year	2004	2004	2004/2005	2001	2000/2001	2005/2006
Aquafeed	40[1]	420 000[2]	104[1]	35 570[1]	3 263[4]	750[5]
Poultry feed	52 910[1]	3 148 000[3]	256 440[1]	2 591 732[1]	3 109 828[4]	62 700[5]
Pig feed	15 120[1]		32 630[1]	1 084 214[1]	177 407[4]	3 600[5]
Fishmeal – aquafeed	6[a]	63 000[a]	16[a]	5 335[a]	978[d]	113
Fishmeal – poultry feed[b]	1 587	94 440[d]	7 693	77 752	93 294	1 881
Fishmeal – pig feed[c]	907		1 958	65 052	10 644	216
Fishmeal country total	**2 500**	**157 440**	**9 667**	**148 139**	**104 916**	**2 210**

[a] Assumes average of 15% fishmeal inclusion level.
[b] Assumes 3% fishmeal inclusion level.
[c] Assumes 6% fishmeal inclusion level.
[d] Assumes 30% fishmeal inclusion rate.

Source: [1] Hecht (2007); [2] Poynton (2006); [3] El-Sayed (2007); [4] Animal Feed Manufacturers Association of South Africa (www.afma.co.za) and Abalone Farmers Association of South Africa; [5] Bentley and Bentley (2005)

3.4 The potential use and demand of reduction fishery products for direct human consumption

The international fishmeal industry reports that 90 percent of the fish that is reduced to fishmeal is "feed grade", for which there is little or no demand for human consumption (FIN, 2004). This is a developed-world perspective. In many African countries, small pelagic fish, if fresh, would be readily accepted for direct human consumption (Kurien, 1998). This is substantiated by the fact that large quantities of frozen small-pelagics, particularly horse mackerel, are imported into almost all African countries from Namibia (Van Zyl, 2001) and in particular, by Nigeria, Cameroon, the Democratic Republic of Congo and the Republic of the Congo. Moreover, in many African coastal and island states, the small pelagic catch is often simply not available for human consumption (Abila, 2003), as it is processed into fishmeal on board or is piped or trucked directly to land-based fishmeal processing plants.

In Kenya, the production of fishmeal limits the availability of low-value pelagic fish to rural communities. Silver cyprinid, *Rastrineobola argentea*, locally known as dagaa or "omena" is a small, pelagic, "sardine-like" fish that is caught in Lake Victoria. It is readily eaten by low - to middle-income communities and when available, 89 to 95 percent of rural households in the vicinity of the lake consume this fish (Abila, 2003). During the early 1990s, the entire catch was used for human consumption. However, due to increasing demands for fishmeal by the animal feed industry, it is estimated that between 50 and 70 percent of the catch is now reduced to fishmeal (Abila, 2003; Nyandat, 2007; Hecht, 2007). The animal feed industry is capable of paying more for the fish than the local people, leaving limited and insufficient quantities for human consumption (Abila, 2003). The capacity for Kenya to absorb the dagaa that is reduced to fishmeal is substantiated by reports that all of the fish caught during the rainy season (when catches are high) and when factory trucks are unable to reach the beaches is sold on the local markets for human consumption (Abila, 2003). This situation is no doubt mirrored in Uganda, where annual dagaa landings are in the region of 90 000 tonnes. The fact that Uganda does not permit the importation of fishmeal means that the animal feed industry is totally reliant on dagaa, which as reliance continues to grow, will reduce the availability of the fish for human consumption (J. Rutaisere, Uganda Department of Fisheries, personal communication, 2007).

The views expressed so far are one sided and somewhat simplistic. For example, the needs of the animal feed industry, upon which the poultry industry is dependent, also should be considered, particularly in view of the fact that the demand for meat in many African countries exceeds the demand for fish (Hecht, 2006). Moreover, industry inefficiencies such as those that occurred in Morocco (Atmani, 2003) and most likely in several other countries, also need to be considered. Where such inefficiencies exist, it is better to reduce the fish to fishmeal than to write them it off as a post-harvest loss. This point is clearly illustrated by Naji (2003), who noted that each kilogram of fish exported from Morocco, in whatever form, generates sufficient foreign revenue to allow for the importation of 3.92 kg of staple foods. However, despite this fact, Naji (2003) recommends that fish resources would be better directed towards human consumption than for inclusion in animal feeds.

The use of the pelagic resource is, however, largely driven by market forces. For example, Namibia has significant horse mackerel resources, yet only 10 percent of the catch is reduced to fishmeal, while the bulk is exported to other countries in Africa as a frozen product for human consumption (Van Zyl, 2001). The reason for this is that there is little demand for fresh or frozen horse mackerel on the local market and export profit margins are higher than those for fishmeal. Similarly, the processing of the pelagic catch in South Africa is also entirely market driven, which, in essence, is no different from the use of the "dagaa" resource in Kenya, although it does not have the same social consequences. This implies that if small pelagic fish are to make a greater contribution to food security, then this can only be achieved through legislation. This in turn would be against free market principles to which many African countries are now committed, either by choice and/or by international design.

The FAO *Code of Conduct for Responsible Fisheries* (FAO, 1995) advocates that: "States should encourage the use of fish for human consumption and promote consumption of fish whenever appropriate..." and countries should discourage the use of fish for feeding animals when it is fit for human consumption (FAO, 1995). While governments no doubt recognize and promote the principles of the code, it is often not possible to give effect to the required practicalities due to inadequate local infrastructure. Thorpe *et al.* (2004) on reviewing the *Poverty Reduction Strategy Papers* of African countries (these documents remain one of the main conditions for concessional lending to developing countries by the International Monetary Fund and World Bank), suggest that "… most [but not all] African governments generally do not regard fisheries as one of the sectors that could assist in the achievement of national food security and the reduction of poverty". As such, the reduction of edible fish to fishmeal does not appear to have been identified as a problem in many countries. Food security is a serious problem in many African countries. For example, in Ghana where 25 percent of children below five years of age are undernourished (Kurien, 2003), as much as 50 percent of the anchovy catch is reduced to fishmeal (Directorate of Fisheries, Ghana, 2003). However, the possible benefits of redirecting a portion of the anchovy catch for direct human consumption are not mentioned in the *Post Harvest Fisheries Review* prepared by the Directorate of Fisheries, Ghana (2003).

In summary, there appears to be a dichotomy with respect to the use of small-pelagics in the region. In some countries (e.g. Kenya and Morocco), the small pelagic catch is reduced to fishmeal, even though the fish would have been absorbed by local markets for direct human consumption had they been available. That there is a need for more fish to improve food security is unquestioned. Per capita fish consumption in sub-Saharan Africa fell from 9 to 7 kg (i.e. 22 percent) between 1990 and 1997, due to dwindling fish stocks and increased competition with fish exports (Teutscher, 2000). Similarly, Hecht (2006) reports a decline of 2.1 kg per capita in sub-Saharan Africa for the period 1980 to 2002. Conversely, in other countries (e.g. Nambia and South Africa) the variable use of the small pelagic catch is largely determined by demand and, therefore, the catch appears to be used for optimal economic and social benefits. Unfortunately, the paucity of data on the use of small pelagic fish in Africa and the Near East precludes a more detailed analysis and prognosis. This can only be achieved if local authorities acknowledge that pelagic fisheries can contribute to alleviating food security and if more detailed records of fish use are collected and disseminated. In reality, however, it is the market that dictates the fate of fish. If profit margins from reduction products such as fishmeal and fish oil exceed those of selling fresh fish into the market, there is little that governments can do other than by direct intervention into free-market systems that are encouraged by the World Bank, donors and development agencies. As alluded to earlier, central to the contribution by fish to food security and poverty reduction in many African countries is the need for a concerted effort to reduce physical and economic post-harvest losses. The conservative estimate of around 571 000 tonnes of fish lost due to spoilage in Africa (see above) is significant on a continent where food security and poverty still prevail in the twenty-first century. Hecht (2006) showed that the average price of fish in 16 African countries is around US$2.43 per kg. Even an average price of US$2 per kg translates into an estimated economic loss of around US$1.4 billion. The recent initiatives by NEPAD (The New Partnership for Africa's Development) and the WorldFish Center (NEPAD, 2005) to address the problem of post-harvest losses are to be welcomed and must be supported.

3.5 "Trash fish" and other fishery by-products used as feeds in aquaculture

Unlike Asia where trash fish is a major feed in aquaculture (Tacon, Hasan and Subasinghe, 2006), the use of this commodity in Africa is extremely limited. There are some records of trash fish being used as fish feed in Cameroon, Nigeria and Ghana (Hecht, 2007). However, the absence of any substantive data suggests that the use of trash fish in aquaculture in Africa is negligible. Similarly, Poynton (2006) in her review of aquaculture in the Near East concludes: "From the limited data available on use of trash fish and raw fish, it appears that these resources are relatively little used in aquaculture in the Near East and North Africa. In the major producer country, Egypt, there is limited use of raw fish (sardines, silversides, small shrimp and tilapia) for seabass and meager (*Argyrosomus regius*) farming, where the raw fish are used to enhance the final flavour of the cultured stock. In Libyan Arab Jamahiriya, sardines are used in bluefin tuna farming. In Saudi Arabia, trash fish or raw fish are used as additional feed supplements for broodstock of some cultured marine species; for example, fresh mackerel are fed to seabass, and fresh squid are fed to shrimp. In the United Arab Emirates, trash fish (Carangidae, Lethrinidae, Haemulidae, Sparidae and tuna) from the Dubai fish market are collected and used to produce fishmeal."

In South Africa, approximately 30 percent of the pilchard catch (130 000 tonnes in 2004/2005) is destined for use as bait in tuna pole and longline fisheries and the recreational fishery and exported as feed for tuna in cages (G. Christy, Christie and Sons Fishing Enterprises, St Francis Bay, South Africa, personal communication, 2007). Although it was not possible to obtain any specific figures for other countries in the region, there is no doubt that a proportion of the small pelagic fisheries catch is used for similar purposes, e.g. in Angola, Libyan Arab Jamahiriya, Morocco, Mozambique, Mauritania, Senegal and Ghana.

4. SUSTAINABILITY ISSUES OF REDUCTION FISHERIES

The effects of over fishing on ecosystem health are well documented (Pauly *et al.,* 1998). Until recently, small pelagic fish populations, because of life history characteristics such as high fecundity, early sexual maturation and rapid growth rates, were considered to have the ability to bounce back rapidly from periodic collapses (Adams, 1980). While there are examples of small pelagic stocks bouncing back rapidly, others have collapsed. More recently, however, the important role of ecosystem functioning, climate variability, El Niño Southern Oscillation events and species dominance shifts on stock abundance of small pelagic species has been highlighted (Sharp, 1987; Lluch-Belda *et al.*, 1989; Patterson, 1992). In a seminal paper on the subject, Freon *et al.* (2005) state that: "The majority of small pelagic exploited stocks are threatened by exploitation, often out of phase with strong and not always well understood variations in abundance, in relation to environmental variability (short- and long-term) and/or the internal dynamics of the ecosystem. Environmental changes can affect fisheries either at the level of catchability or at the level of resource abundance. The lack of understanding of most of the processes still limits short-term forecasts of abundance. Process-oriented studies (modelling approach interacting with orientated data collection and experiments, etc.) and emphasis on combined analysis of different sources of spatialized environmental, ecological, and fishery data are required to improve our knowledge." Their review paper highlights the extreme complexity of factors that effect short-, medium- and long-term variability in abundance of small pelagic stocks and clearly shows that small pelagic fisheries appear to be as vulnerable to overfishing as demersal fish stocks, which is also highlighted by Sadovy (2001), and are highly sensitive to meso-scale ecosystem disturbances and climate variability and may take a long time to recover. The review by Freon *et al.* (2005) suggests that none of the present management options are fully adapted to both the short- and long-term variability in abundance of most small pelagic fish stocks, and hence, recommends a two-tier approach. The first step would be "based on simple modifications of the existing management plan, based on a total allowable catch (TAC) that will vary annually according to current estimation of fish stock biomass from direct (e.g. acoustic survey; preferred for short-lived pelagic fish) and/or indirect (e.g. Virtual Population Analysis (VPA); preferred for medium- and long-lived species) stock assessment methods". The second tier should address the problem of interdecadal variations in the abundance of pelagic fish that induce counterproductive investments in the fishing sector. Their excellent review clearly illustrates the need for more comprehensive research to adequately manage pelagic fish stocks on a sustainable basis.

For example, many Namibian fisheries were severely overfished by foreign fishing fleets between 1968 and 1990, and even though strategies were implemented to rebuild the stock, the pilchard fishery in Namibia has still not recovered (FAO, 2005b). Similarly, the South African pilchard fishery collapsed in 1966 due to overfishing and environmental factors and has only recovered in recent years, i.e. in 2003 and 2004, 40 years down the line (FAO, 2005c). The collapse of the pilchard fishery saw a rise in anchovy catches during the mid-1960s, which resulted in a fairly constant total pelagic catch in South Africa over this period. The complex dynamics of species dominance shifts in the South African small pelagic fishery that occurred between 1967 and 1996 is discussed by Lluch-Belda *et al.* (1989) and De Oliveira and Butterworth (2004). In lieu of the complex population dynamics and the value of the fishery, among other reasons, the fishery is now managed on the basis of an Operational Management Procedure (OMP). Recognizing the complexity of managing pelagic fisheries has more recently led South Africa and Namibia (and now Angola through the Benguela Current Large Marine Ecosystem (BCLME) programme) to adopt an ecosystems approach to fisheries management. With respect to the small pelagic fisheries of north and west Africa, it has been recommended (FAO, 2002) that the precautionary approach be adopted towards managing the stocks on a sustainable basis and that the basis for setting the TAC and fishing capacity for the next year should not exceed the average annual catch during the last five years. More recently, Senegal has also recognized the need to adopt an ecosystems approach for fisheries management (Samb, undated). Unfortunately, it would appear from recent reports that the pelagic resources in Morocco are being overfished by foreign fleets (FAO, 2005d), and it has been suggested that the FAO *Code of Conduct for Responsible Fisheries* should be implemented more rigorously to better manage these fisheries.

Industry and consumer bodies also play an important role in promoting the sustainable use of small pelagic fisheries. *The Fishmeal Information Network*

Sustainability Dossier (FIN, 2001) compiled by the fishmeal industry aims to provide factual information regarding the industry and the fisheries upon which the industry depends, and is based on independent documented evidence. The sustainability of the fish stocks that are described and discussed in the dossier is crucial to the sustainability of the fishmeal industry, so it is in the interest of the industry to provide accurate assessments and reporting and to manage itself according to sustainable principles. The dossier contains information that is useful and applicable to the sustainability of reduction fisheries. Understandably, the focus of the dossier is on the major reduction fisheries of the world and, therefore, unfortunately contains no information on the reduction fisheries in parts of the world that do not contribute significant proportions to global supply. The dossier plays a very important role in developing and maintaining sustainable reduction fisheries. However, it would be of great value if the Fishmeal Information Network (FIN) were to expand its mandate and also consider the competition that exists for small pelagic resources in the developing world. In addition, the Marine Stewardship Council (MSC) is an independent non-profit organization that promotes responsible fishing practices, which it does through a document entitled *Principles and Criteria for Sustainable Fishing* (MSC, 2002). This document, as well as the promotion of sustainable reduction fisheries by the FIN, is founded on the FAO *Code of Conduct for Responsible Fisheries* (FAO, 1995). The MSC principles are similar to those of FIN (2001) and are comprised of a set of broad principles based on sustainable management practices and the social responsibilities of fisheries worldwide. Further, the MSC offers certification and accreditation to fisheries that adhere to its principles and criteria, and these now play an ever increasing and important role in the global marketing of fisheries products in the developed world, although fisheries in the developing world are somewhat disadvantaged by the current principles (Uwe Scholz, Gesellschaft für Technische Zusammenarbeit (GTZ), Germany, personal communication, 2007).

Briefly summarized, the principles and criteria of the MSC (2002) rebuke overfishing and promote sustainable exploitation only. They endorse strategies that aim to restore depleted stocks and that focus on a holistic ecosystems approach to fisheries management. To ensure that the primary principles are achievable, the MSC makes use of local, national and international institutional structures. In addition to its ecologically sustainable approach, the principles published by the MSC Executive (MSC, 2002) also consider social sustainability and responsibility. This is of particular importance to resource users in parts of Africa and the Near East where there appear to be imbalances in access to small pelagic fish resources by rural communities and fishmeal producers. More specifically, the criteria state that management systems should "observe the legal and customary rights and long term interests of people dependent on fishing for food and livelihood" (MSC, 2002). There is evidence to suggest that the interests of people that depend on the small pelagic fisheries for food in parts of Africa and possibly the Near East are not always taken into consideration. The implementation of the principles and criteria advocated by the MSC would address these imbalances, although the localized nature of the market of some of these fisheries may make it difficult for the resource users to accede to certification and accreditation.

5. ENVIRONMENTAL IMPACTS OF AQUACULTURE IN AFRICA AND THE NEAR EAST THAT RESULT PRIMARILY FROM REDUCTION FISHERIES AS FEED INPUTS

Compound aquafeeds with a high fishmeal content contribute to nitrogen and phosphorus loading in the immediate environment (Tacon, 2004). The way in which nitrogen and phosphorus wastes enter the environment and their impact, which may be positive or negative, depends on the nature of the aquaculture system. For example, effluent water from land-based aquaculture systems enters the environment either periodically (during flushing or harvesting) or continuously (in the case of flow-through systems). All effluent, however, enters the environment at a point source. This is different under cage-culture conditions, where soluble wastes are often subject to rapid dissipation, although solids may accumulate below the cages, with serious impacts on the environment and which may also affect the operator. For aquaculture to be sustainable requires that whatever wastes are returned to the environment need to be matched by the carrying capacity of the environment. However, the assessment of environmental carrying capacity is an expensive exercise requiring high-level expertise that is not available in most African and Near East countries. Despite the fact that most countries in Africa and the Near East have legislation pertaining to aquaculture, there are, as far as could be ascertained, no specific waste management standards for aquaculture (see http://www.fao.org/fishery/nalo/search/en for National Aquaculture Legislation Overviews). South Africa is the only country that has a set of water quality guidelines that specify the requirements for cultured organisms (Department of Water Affairs and Forestry, 1996). However, depending on the type and size of operation, an Environmental Impact Assessment is required in most countries, which is then considered in relation to other relevant legislation, e.g. that dealing with pollution, environmental conservation, health or water. Several countries (e.g. Mozambique) have developed innovative ways to ensure environmental standards and sustainability. Because of the high cost of monitoring water quality in remote areas of the country, the Mozambique Department of Fisheries (Aquaculture Division) has restricted shrimp farmers to operate only at extensive or semi-intensive stocking densities, which ensures environmental sustainability (F. Ribeiro, Instituto de Investigação Pesqueira, Maputo, personal communication, 2007).

The addition of either phosphorus or nitrogen to aquatic systems may cause eutrophication and algal blooms. Phosphorus is usually the most limiting element for plants (i.e. algae) in freshwater systems, whereas nitrogen is more limiting in the marine environment (Cho and Bureau, 2001). It is possible to directly measure the amount of nitrogen and phosphorus levels that enter the environment in the effluent of pump-ashore and land-based aquaculture systems. This is almost impossible in cage-culture, where there is no steady flow of effluent out of the system. However, it is possible to predict the volume of waste produced in these systems by formulating a nutrient budget, which is based on biomass carried by the aquaculture system and the dietary ingredients of the feed, which is the primary source of phosphorus and nitrogenous waste. Simplified, the nutrient load in farm effluent is estimated by subtracting the protein, lipid and carbohydrate requirements of the fish for maintenance, growth and reproduction from the total available nutrients in the diet, the difference of which is excreted as by-products of metabolism as either solid or dissolved waste (Cho and Bureau, 2001).

For example, the effluent that is produced by growing 1 tonne of salmon under intensive aquaculture conditions includes 240 kg of total solids, 10 kg of solid nitrogen, 4 kg of soluble nitrogen, 4 kg of solid phosphorus and 2 kg of dissolved phosphorus (Cho and Bureau, 2001). However, these volumes vary considerably with the quality of the feed (Cho and Bureau, 2001). Similarly, different species farmed under different culture conditions produce varying levels of waste. For example, the volume of nitrogen discharged per tonne of channel catfish (*Ictalurus punctatus*) is similar to that produced during salmon production, i.e. approximately 9 kg of nitrogen/tonne of catfish (Lucas and Southgate, 2003); however, the volume of phosphorus is considerably less at 0.6 kg per tonne of catfish, while the intensive production of 1 tonne of gilthead seabream (*Sparus aurata*) in earthen ponds results in 48 kg of nitrogenous discharge, 3 kg of phosphorus and 9 105 kg of total suspended solids (Lucas and Southgate, 2003).

Irrespective of the culture system used, there is an intricate balance between the volume of phosphorus and nitrogenous waste that is produced and the capacity for the environment to maintain the system without any negative environmental effects. This balance is determined by the physical properties of the environment (for example, water depth, current or drawdown in the case of cage culture and water availability and volume and natural down stream biological filtration in the case of land-based systems), which in turn governs the nature and size of the aquaculture operation. Provided environmentally responsible aquaculture practices are employed and environmental carrying capacities are not exceeded, the impact that nitrogenous and phosphorus wastes from aquaculture have on the environment can be minimized.

Aquaculture in most of Africa and the Near East is pond based. For example, in Egypt only 10.6 percent of the 450 000 tonnes was produced in cages in 2003 (El-Sayed, 2007). Throughout the region pond-based aquaculture ranges from extensive to semi-intensive and approximately 88 percent of the fish produced are non-carnivorous. By implication, therefore, the overall total nitrogen and phosphorus waste from the use of fishmeal in Africa is currently still considered to be negligible. However, local impacts can be severe and have led to the closure of some operations in South Africa. While most countries, as mentioned above, have regulations in place to ensure that aquaculture development is environmentally sustainable, very few have the resources to monitor the growing commercial aquaculture sector (Hecht, 2006). Given the increasing interest by the industrial sector in aquaculture in Africa, there is a need to develop appropriate water quality legislation for aquaculture.

6. CURRENT AND POTENTIAL ALTERNATIVE USES OF FISH AND THE RELATED MACRO-LEVEL IMPACT ON FOOD SECURITY AND POVERTY ALLEVIATION

The global fishmeal industry claims that there is no demand (i.e. for direct human consumption) for 90 percent of the wild-caught fish that is reduced to fishmeal (FIN, 2004). From a global perspective this is probably correct. However, on a regional or on an individual country basis evidence is presented that suggests that a good proportion of the reduction fishery products are simply not available for human consumption (Abila, 2003), although if available, they would certainly have been consumed (Kurien, 1998). Moreover, the available data for Africa and the Near East show that 60 percent of the small pelagic catch is used for food and only 40 percent is reduced to fishmeal. In several countries and in particular in Morocco and South Africa, a sizeable proportion (see above) of the small pelagic catch is canned, while in other countries the fish is sold fresh on the market.

Nonetheless, the fish that is reduced to fishmeal generates revenue, which in turn contributes to job creation. The questions that, therefore, need to be asked are: *Does the revenue that is generated from the sale of fishmeal filter back to the people who would have benefited by eating the fish had the fish not been reduced?*; and *Do the people who no longer have access to the reduced fish for direct human consumption receive any benefit from the reduction fishery and, if so, how does this benefit compare to that from direct human consumption?*

These questions, which require detailed data from farmers, the fishmeal industry and the fisheries authorities, are answered by way of an example. Such detailed data could only be obtained for the South African abalone farming industry. The South African abalone culture industry is the fastest growing industry in the local aquaculture sector, and the majority of the employees in the industry are people who no longer have access rights to local fisheries. Although abalone (*Haliotis midae*) are herbivorous, the industry is partly dependent on a fishmeal-based artificial diet and will become more so as it grows and ocean-harvested kelp becomes limiting (Troell *et al.,* 2006). South Africa is a net consumer of fishmeal and was ranked the thirteenth largest consumer in the world in 2004 (101 000 tonnes) (FIN, 2005). It produces the bulk of its own consumption: in 2004, South Africa produced and imported 114 000 and 1 599 tonnes of fishmeal, respectively, and exported only 23 766 tonnes (Figures 6, 7 and 8).

The abalone culture industry in South Africa used approximately 320 tonnes of artificial feed in 2005 (Jones and Britz, 2006), which equates to ca. 96 tonnes of fishmeal. The fishmeal reduction yield that is accepted as an industry standard in South Africa is 23 percent (S. Malherbe, Chairman, South African Pelagic Fish Processors Association, personal communication, 2007), meaning that ca. 420 tonnes of live fish were reduced to produce the 96 tonnes of fishmeal for the abalone culture industry. The minimum daily protein requirement for a person is 1.38 g dry protein/kg/day (Scrimshaw, 1977). Assuming that the average employee supports a family of four with a total average weight of 180 kg (i.e. a minimum dry protein requirement of 248 g/family/day) and that the protein content of fresh fish is 16 percent (Miles and Jacob, 2003), then it is possible to estimate that the fish that were reduced to fishmeal to feed the abalone culture industry would have sustained ca. 741 families for a year had they utilized the fish directly. However, the abalone culture industry employed 814 people in 2004 (Troell *et al.*, 2006), who use their salaries to purchase substantially more than their protein requirement. This example suggests that the "secondary" use of reduction fishery products is able to sustain more families indirectly than it would have sustained directly.

The example shows that the fish were not "wasted" by reducing and feeding them to abalone. However, *would the community have been better off selling them for human consumption?* Had the fishmeal not been reduced and had the farm workers retained their fishing rights, the catch would have realized US$1.5 million, i.e. US$1 778/worker/year, before fishing expenses are taken into account. If it is assumed that abalone farm workers earn the minimum wage for South African farm labourers (i.e. ZAR871.58/month; Hall, 2004) they would have earned a net salary of US$1 687/ worker/year (this assumes an exchange rate of ZAR6.20 to US$1.00). From this it may be concluded that the reduction fishery has not placed the abalone farm workers at an economic disadvantage.

Can the above example be extrapolated and used to estimate the beneficial or detrimental effects of reduction fisheries on livelihoods in the rest of Africa and the Near East? The example assumes that (1) the fishmeal is utilized locally and (2) that the production of the "secondary" products (i.e. the animals to which the fishmeal is fed) results in local employment among sectors of the populations that might have benefited from the fishery pre-reduction. The first assumption is largely met in most African and Near East countries, because most locally produced fishmeal is not exported; with the exception of Morocco, Senegal and Saudi Arabia, all countries that were recorded as fishmeal producers produced considerably more fishmeal in 2004 than they exported during the same year (FAO, 2006c). However, it is in the second assumption that the application of this example will differ considerably between countries and even areas within a country, and there is no evidence to suggest that this assumption is applicable for all African and Near East countries. Fish processing activities create substantial employment in some countries while not in others (Kurien, 2003). Similarly, employment created through the production of secondary products differs in different parts of the region, suggesting that the poor in some countries will benefit from reduction (e.g. people employed in the abalone culture industry in South Africa are better off receiving a wage than they would have been had the fish that was fed to the abalone been consumed directly by the farm workers), and those in other countries will remain worse off as a result of these fisheries (e.g. the reduction of fish, which was previously consumed by them, left them without a protein source and has not created employment in these communities). The model presented here can be adjusted and could be used to determine the beneficial or detrimental effects of reduction fisheries for all areas in the region with reliable employment statistics.

From the above example, it could be concluded that the reduction of fish had a net benefit for the employees in the abalone farming industry and this is no doubt similar to other industries, including the fishmeal processing industry. Therefore, it would be erroneous to collectively condemn all reduction fisheries on the grounds that they perform a “social injustice”. At the same time, the costs of some reduction fisheries in the developing world probably outweigh the benefits, as production of the “secondary” product does not always result in employment, leaving the poorest of the poor worse off without access to protein or a monetary income. Further investigations are required to seek ways in which to reduce social conflict among potential users of the resource, where this exists.

7. REGIONAL ISSUES ON THE USE OF FISH AND/OR OTHER AQUATIC SPECIES AS FEED FOR AQUACULTURE

The main issue of regional importance in Africa and the Near East is that of food security and poverty, and these are not just national problems. There are 1.1 billion people in the world living in acute poverty, at least 25 percent of whom live in sub-Saharan Africa (World Bank, 2004). While poverty (people that earn less than the local equivalent buying power of US$1/day) in North Africa and the Near East has improved over the last 20 years and hovers around 2 to 3 percent, the number of people living in poverty in sub-Saharan Africa has nearly doubled over the same period (World Bank, 2004). Countries where more than 50 percent of the population earn less than US$1/day include Zambia, Burundi, Central African Republic, Nigeria, Niger, Mali and Sierra Leone (World Bank, 2004). Directly linked to poverty is a lack of food security and child mortality. In 2002, there were 15 countries in the world that experienced more than 200 infant deaths per 1 000 live births; 14 of these countries were in sub-Saharan Africa (World Bank, 2004). Furthermore, in low-income countries one child in eight dies before reaching five years; this compares to one in 143 in high-income countries (World Bank, 2004).

The examples from Morocco and Kenya (Abila, 2003; Naji, 2003; Nyandat, 2007), where fish protein that was affordable to the poor in the past is now no longer available because of “value-adding”, raise social responsibility questions and issues. Clearly, where such imbalances exist, they need to be addressed by governments and fishing companies such that the distribution of the resources is equitable and does not have a detrimental effect on basic nutritional needs of local communities. The pelagic fisheries for dagaa in Lake Victoria, as for almost all fisheries for smallpelagics, involve straddling stocks and hence, need to be managed by way of multinational fisheries management procedures. These should take particular cognisance of the social consequences in each country, as the action of one user in a multiuser fishery can affect the returns and, in some cases, the food security of others. Therefore, regional cooperation in managing shared fish resources using principals that promote sustainability is imperative.

7.1 National, regional and international organizations/institutions working in the region on related issues

As far as could be ascertained, there are no organizations that are currently working specifically on the use of wild fish as feed in aquaculture or on how this practice may impact on food security and poverty reduction in the region. However, as indicated elsewhere in the study, the implications of the practice have been recognized by the Kenya Marine and Fisheries Research Institute and the Departments of Fisheries in Uganda and Tanzania and no doubt, by authorities in most countries. In particular, these three agencies have recognized the impact of the increasing demand for “dagaa” (*Rastrineobola argentea*) by the animal feed industry on food security around the shores of Lake Victoria. Similarly, the Institute Nationale de Recherche Halieutique (INRH) in Morocco has recognized the impact of reduction fisheries on food security and is strongly promoting improved efficiency in the supply chain such that more fish are available for human consumption (either canned or fresh) instead of being reduced to fishmeal out of necessity, as has been the case in the past. In 2003, approximately 75 000 tonnes of fishmeal were produced in Morocco (Poynton, 2006), and at a reduction efficiency ratio of 24 percent, this amount equates to about 312 500 tonnes of fresh fish that was not available for human consumption. This estimated amount of fresh fish used for reduction is equivalent to 46.1 percent of the Moroccan pelagic catch (677 635 tonnes, Table 1) and 34.9 percent of total capture fisheries production (896 262 tonnes in 2003) (Poynton, 2006).

As mentioned elsewhere in this report, the available information suggests that the discarding of bycatch, particularly from shrimp trawling and shark finning, and physical and economic post-harvest losses through spoilage may have a much greater impact on food security and poverty than any or all of the reduction fisheries in the entire region. This problem has been recognized and addressed by various international agencies such as the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the Department for International Development of the United Kingdom (DFID), and the WorldFish Center, among others. Fortunately the flurry of good work that was undertaken by many organizations in collaboration with national fisheries departments and academic institutions in Africa during the 1990s until around 2001–2002 has recently been revived. For example, the Canadian International Development Agency (CIDA) and the Association of Canadian Community Colleges (ACCC) have recently (2005) provided funding to the Memorial University of Newfoundland to initiate several projects to address the problem in Malawi and Mozambique (anon., 2006). Moreover, the "Fish for All" summit in Abuja, Nigeria (22–25 August 2005) adopted the Declaration on Sustainable Fisheries and Aquaculture in Africa, whose action plan identified the reduction of post-harvest losses as an urgent investment need. Unless there is a sustained long-term commitment by development agencies to holistically address these issues, including legislation and fish trade, the gross wastage of fish and its negative impact on food security will persist. This is of greater urgency in the region than the impact of reduction fisheries on poverty and food security.

8. CONCLUSIONS AND RECOMMENDATIONS

Global aquaculture makes a considerable contribution to world fish supply. Although the contribution from Africa and the Near East remains small, this region has shown phenomenal growth over the last decade. This underpins the potential of the region to contribute significantly towards meeting its own future demand for fish.

The global aquaculture industry is now the single most important consumer of fishmeal. However, the bulk of fish production in Asia, Africa and the Near East is composed of species low in the food chain. It is for this reason that the formal and informal aquafeed industry only uses approximately 16 percent of the total fishmeal consumed by the animal feed industry in the region.

Several examples have been provided that show fishmeal production competing with poor people for fish in parts of Africa. Historically, the predominant use of small pelagic fish in Africa was for direct human consumption. Competition from the animal feed industry has now reversed the situation in some countries, resulting in an imbalance in resource allocation. In some cases the secondary use of fishmeal has improved the standard of living and level of food security among poor communities, due to the employment that is generated. However, this is only so if the fishmeal is used internally in the country of origin and the production of the secondary product creates employment among the poor in that country. Although most of the fishmeal produced in Africa and the Near East is used in the countries in which it is produced, the production of secondary products does not always create employment among the communities that would otherwise have used the fish for direct consumption.

Therefore, in countries where rural people now have reduced access to fish as a result of reduction, it is incumbent upon governments to invoke the FAO *Code of Conduct for Responsible Fisheries* (FAO, 1995). However, the state of fisheries management and the generally data-poor nature of the region make it very difficult to implement the code. It has been shown that the reduction of fish into fishmeal can have a net benefit for the poor. However, there are instances where people are worse off as a direct result of fishmeal production. In instances where reduction of fish exacerbates the problem of low food security, steps should be taken to redress the imbalances.

It has been shown that post-harvest losses and bycatch discards globally and in Africa are enormous (Ames, 1992; Alverson *et al.*, 1994) and may very well have a larger net impact on food security and poverty than reduction fisheries in Africa. Hence, it is recommended that the initiatives to address post-harvest losses by NEPAD, WorldFish Center and FAO be strongly supported.

8.1 Recommendations

The following actions are recommended:

- Where appropriate, governments need to be made aware of the impact of fishmeal production in countries where there is a net deficit in food security.
- Where appropriate, governments need to be made aware of the potential that small pelagic fisheries have to improve national food security.
- Where necessary, sustainable fisheries management procedures need to be implemented, with particular emphasis on inland pelagic fisheries.
- Tertiary-level training must be provided to improve fisheries management.
- Governments should encourage fisheries to adhere to the FAO *Code of Conduct for Responsible Fisheries* (FAO, 1995) and the *Principles and Criteria for Sustainable Fishing* of the Marine Stewardship Council (MRC, 2002) and where appropriate, should aim to achieve MSC certification and accreditation.
- Government are strongly encouraged to collect and record fishmeal and fish oil production statistics.
- National fishmeal and fish oil production statistics need to be recorded and reported according to source, i.e. dedicated fishery, bycatch, trimmings, spoilt foodfish, overproduction, etc.
- Governments are strongly encouraged to record statistics of fishmeal use in the animal feed industry.
- FAO aquaculture production statistics should also be compiled according to feeding guilds (i.e. carnivorous, herbivorous, omnivorous, detritivorous and planktivorous) to better understand, interpret and predict the demand for aquafeeds in the future.
- Where appropriate, governments should be encouraged to develop policies regarding the use of water for aquaculture and aquaculture effluent.

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APPENDIX

Countries in Africa and the Near East that are aquaculture producers or that have produced, consumed, exported or imported fishmeal and fish oil between 1950 and 2004.

A.1. Aquaculture-producing countries in sub-Saharan Africa

Benin	Kenya	Rwanda
Burkina Faso	Lesotho	Senegal
Burundi	Libyan Arab Jam.	Seychelles
Cameroon	Madagascar	Sierra Leone
Central African Republic	Malawi	South Africa
Congo, Democatic Republic	Mali	Swaziland
Congo, Republic	Mauritius	Tanzania, United Republic of
Côte d'Ivoire	Mayotte	Togo
Ethiopia	Mozambique	Uganda
Gabon	Namibia	Zambia
Gambia	Niger	Zimbabwe
Ghana	Nigeria	
Guinea	Réunion	

A.2. Aquaculture-producing countries in North Africa

Algeria	Liberia	Sudan
Egypt	Morocco	Tunisia

A.3. Aquaculture-producing countries in the Near East

Bahrain	Kuwait	Saudi Arabia
Iran, Islamic Republic of	Lebanon	Syrian Arab Republic
Iraq	Oman	United Arab Emirates
Jordan	Qatar	

A.4. Countries in Africa that either produce, consume, import or export fishmeal and/or fish oil

Algeria	Gambia	Réunion
Angola	Ghana	Rwanda
Benin	Guinea	Saint Helena
Botswana	Kenya	Sao Tome and Principe
Burkina Faso	Lebanon	Senegal
Burundi	Libyan Arab Jamahiriya	Seychelles
Cameroon	Madagascar	Sierra Leone
Cape Verde	Malawi	Somalia
Comoros	Mali	South Africa
Congo, Democatic Republic of the	Mauritania	Sudan
Congo, Republic of	Mauritius	Swaziland
Côte d'Ivoire	Mayotte	Tanzania, United Republic of
Djibouti	Morocco	Togo
Egypt	Mozambique	Tunisia
Eritrea	Namibia	Uganda
Ethiopia	Niger	Zambia
Gabon	Nigeria	Zimbabwe

A.5. Countries in the Near East that either produce, consume, import or export fishmeal and/or fish oil

Bahrain	Kuwait	Syrian Arab Republic
Iran, Islamic Republic of	Lebanon	United Arab Emirates
Iraq	Oman	Yemen
Israel	Qatar	
Jordan	Saudi Arabia	

Source: FAO Fish Stat

Use of wild fish and other aquatic organisms as feed in aquaculture – a review of practices and implications in the Americas[1]

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[1] The geographic scope of this review encompasses Latin America and North America, with special emphasis on Peru, Chile, Brazil, Mexico, Ecuador, Panama and the Bolivarian Republic of Venezuela in Latin America and the Caribbean, and the United States of America and Canada in North America.

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SUMMARY

Capture fisheries production within the region has a long tradition, and in 2004, total landings were estimated at 26.25 million tonnes, which represented 27.2 percent of total global capture fisheries production for that year. The region is home to three of the four most important countries in the world in terms of total capture fisheries landings. After China, these include Peru at 9.6 million tonnes, Chile at 5.3 million tonnes and the United States of America at 5.0 million tonnes. Commercial aquaculture production is of recent origin within the region, commencing in the United States of America with the culture of oysters and channel catfish in the 1950s and 1960s, respectively. Moreover, whereas capture fisheries production within the region has decreased by 6 percent since 1995, aquaculture production has grown over two-fold since 1995 to 2.1 million tonnes in 2004 (valued at US$6.55 billion) at an average compound rate of 8.9 percent per year.

In 2003, over 9.9 million tonnes or 47.2 percent of the total fishery catch (21.0 million tonnes) within the region was destined for reduction and non-food uses (global average = 36.6 percent), ranging from 9.0 percent for Brazil, 17.2 percent for Canada, 18.9 percent for Mexico, 21.9 percent for the United States of America and 25.0 percent for Ecuador to 76.4 percent for Chile and 87.8 percent for Peru. Small pelagic fish species form the bulk of reduction fisheries landings, with anchovies, herrings, pilchards, sprats, sardines and menhaden totalling 13.19 million tonnes or 50.2 percent of the total reported fisheries landings (26.25 million tonnes in 2004), followed by miscellaneous pelagic fish (2.68 million tonnes, including mackerels and capelin) and other species including squid, cuttlefish and octopus (0.78 million tonnes).

Total fishmeal and fish oil production within the region from 1995 to 2004 fluctuated from 2.0 to 3.7 million tonnes (mean of 3.3 million tonnes) and from 0.37 to 0.90 million tonnes (mean of 0.68 million tonnes), respectively. According to the latest fishing industry estimates, the region produced 3.37 million tonnes of fishmeal and 0.55 million tonnes of fish oil in 2005, or 57.3 percent and 57.1 percent of the total reported global fishmeal and fish oil production for that year, respectively. Globally, the region contributed 68.5 percent of total world fishmeal exports and 55.1 percent of total world fish oil exports in 2005, primarily to Asia and Europe.

In 2004, the domestic aquaculture sector within the region used 469 500 tonnes of fishmeal (13.3 percent of total fishmeal production within the region) and 237 910 tonnes of fish oil (35.1 percent of total fish oil production within the region), the largest consumers of fishmeal and fish oil being salmonids and marine shrimp. Collectively, these species accounted for 89.4 percent and 96.1 percent of the total fishmeal and fish oil used by the regional aquaculture sector in 2004. With further anticipated expansion, there is a clear need to reduce the dependence of the aquaculture sector within the region on fishmeal and fish oil and to replace them with alternative locally available feed ingredients whose production can keep pace with the growth and specific requirements of the sector.

The use of whole, low-value fish (usually referred to as "trash fish") as feed by the aquaculture sector within the region is small and is currently restricted to the on-growing and fattening of tuna in Mexico using locally caught sardines. Total trash fish consumption was estimated to be about 70 000 tonnes in 2006. However, the volume of sardines and other small pelagics used as baitfish for commercial and recreational fisheries within the region (primarily by the United States of America and Canada) is believed to be greater than that used by the aquaculture sector, and is conservatively estimated to be about 100 000 tonnes per annum.

The introduction of appropriate legislative and environmental controls by governments of the major fishing nations, including the introduction and implementation of operational management procedures such as fishing quotas and closed seasons, has given renewed impetus for the fishing industry to process more of the traditional feed-fish species catch for direct human consumption. It is anticipated that this trend will increase in the long term as feed-fish supplies remain tight and fishmeal and fish oil prices continue to rise. It is further

anticipated that this portion of the catch will be processed for direct human consumption, primarily in the form of easy-to-use and ready-to-eat affordable processed fish products such as canned marinates and stabilized surimi-based fish products. To achieve this goal, certain strategic approaches and recommendations for regional cooperation are made.

1. INTRODUCTION[3]

1.1 Background

Global aquaculture production has grown at 11 percent a year over the last decade and is projected to continue increasing. Along with this growth, there has been a trend within most developing and many developed countries toward the increased use of artificially compounded feeds (aquafeeds) for farmed finfish and crustaceans. This trend has been particularly apparent in developing countries with the progressive intensification of farming systems. Compounded feeds are increasingly being used for the production of both lower-value staple food-fish species (mainly freshwater finfish such as carp, tilapia and catfish) and higher-value species for luxury or niche markets (mainly marine and diadromous species such as shrimp, salmon, trout, yellowtail, seabass, seabream and grouper). In fact, the production of aquafeeds has been widely recognized as one of the fastest expanding agricultural industries in the world, with growth rates in excess of 30 percent per year.

At present, the culture of higher-value species is largely dependent upon the use of fishery resources as feed inputs, including fishmeal, fish oil, and lower-value (in marketing terms) trash fish species as direct feed for use within farm-made feeds. It has recently been argued that too much fish is currently used to feed cultured fish and crustaceans, and it is maintained that the fish should be used instead for human consumption in developing countries to improve food security and reduce poverty (Naylor *et al*., 2000).

By contrast, it is often argued that the bulk of the fish reduced for incorporation into animal feeds cannot be used for direct human consumption (Miles and Chapman, 2006). Although many of the "food grade" fish (in particular jack mackerel, horse mackerel, hake, whiting, pilchards, sardines and capelin) are suitable for human consumption, the argument is based on the sheer volume of catches relative to the size of local markets and that the reduction of this fish may have beneficial effects on poverty through creation of employment or indirect effects via taxation of fishmeal exports.

In view of the divergent perspectives presented above and the ongoing debate on the use of fish as feed, the need for a comprehensive global study and analysis was identified.

2. REGIONAL AQUACULTURE OVERVIEW

2.1 Status and trends

Aquaculture production within the region is of recent origin, commencing in the United States of America with the culture of oysters and channel catfish in the 1950s and 1960s, respectively. The United States of America dominated aquaculture production within the region until 2001, when Chile overtook the United States of America due to the spectacular rise and growth of commercial salmon farming in that country (primarily due to the direct transfer of salmon farming technology and investment from Norway; Masser and Bridger, 2006). Total salmon production in Chile increased over 9 000-fold from only 49 tonnes in 1978 to 442 610 tonnes in 2004 (FAO, 2006a). Total aquaculture production within the region in 2004 was 2 093 003 tonnes (Fig 1) and valued at US$6.55 billion, representing 3.5 percent and 9.3 percent of total global aquaculture production by weight and value, respectively (FAO, 2006a).

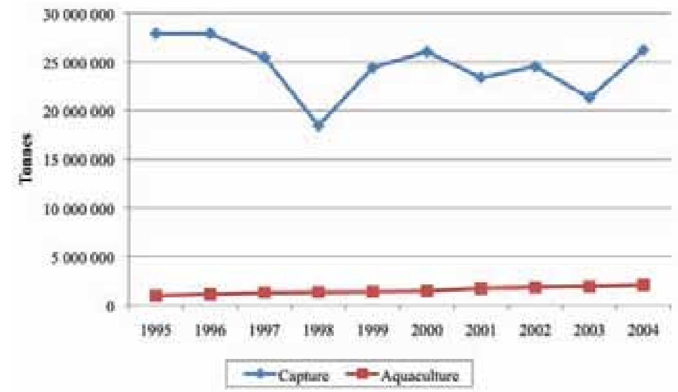
Thirty five countries (out of a possible 40 within the region) reported aquaculture production in 2004. The largest country producers were Chile at 694 693 tonnes

[3] This review is based on a collation, analysis and synthesis of the published literature. Data were also obtained through dialogue with different reduction fisheries and aquaculture stakeholders within the region. The review covers the period (for reduction fisheries and aquaculture) from 1995 until 2004 (and includes 2005, where data are available).

(33.2 percent of total regional production) and the United States of America at 606 549 tonnes (29.0 percent), followed by Brazil at 269 699 tonnes (12.9 percent) and Canada at 145 018 tonnes (6.9 percent) (Table 1).

In marked contrast to aquaculture, capture fisheries production within the region in 2004 was over 12 times higher at 26.26 million tonnes (Figure 1; representing 27.2 percent of total global capture fisheries landings), with Peru, Chile and the United States of America reporting the second, third and fourth highest capture fisheries landings after China in 2004 (FAO, 2006a). Since 1995, aquaculture production within the region has been growing at an average compound rate of 8.9 percent per year, and between 1995 and 2004 grew two-fold from 968 128 tonnes to 2.09 million tonnes. In marked contrast, capture fisheries production within the region over the same period decreased by over 6 percent from 27.94 million tonnes in 1995 to 26.26 million tonnes in 2004 (FAO, 2006a).

FIGURE 1
Relationship between the growth of capture fisheries and aquaculture within the Americas



Source: FAO (2006a)

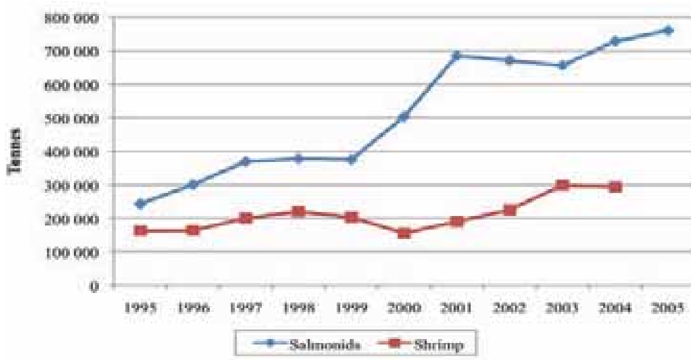
The main finfish and crustacean species farmed in the region are diadromous salmonids and penaeid shrimps (Figure 2) and to a lesser extent, freshwater finfishes (Figure 3). For example, in 2004 the major cultured finfish and crustaceans were as follows: Atlantic salmon, 446 830 tonnes (coldwater diadromous fish species, main producers: Chile, Canada); channel catfish, 288 623 tonnes (warmwater freshwater fish species, main producer: United States of America); Pacific white shrimp, 270 592 tonnes (warmwater brackishwater/marine crustacean species, main producers: Brazil, Mexico, Ecuador, Colombia); rainbow trout, 168 604 tonnes (coldwater diadromous fish species, main producers: Chile, United States of America); tilapia sp., 110 868 tonnes (warmwater freshwater fish species, main producers: Brazil, Colombia); coho salmon, 91 360 tonnes (coldwater diadromous fish species, main producer: Chile), common carp, 59 134 tonnes (warmwater freshwater fish species, main producer: Brazil); Nile tilapia, 42 263 tonnes (warmwater freshwater fish species, main producers: Costa Rica, Colombia); colossoma/cachama, 36 252 tonnes (warmwater freshwater fish species, main producer: Brazil) and the red swamp crawfish, 31 926 tonnes (freshwater crustacean, main producer: United States of America (FAO, 2006a).

At present, the bulk of the higher-value aquaculture species produced in the Latin America and Caribbean region is destined for export to some of the major developed countries (the European Union (EU), Japan and the United States of America) (Aguila, 2006; Rojas, Simonsen and Wadsworth, 2006). The top exported aquaculture species are Atlantic salmon (export valued at US$1 847 million in 2004), Pacific white shrimp (production valued at US$1 216 million) and rainbow trout (production valued at US$679 million) (FAO, 2006a). Salmon and trout are mainly produced in cages or tank-based culture systems, while Pacific white shrimp are produced in coastal ponds with high water exchange. By contrast, the bulk of freshwater fish production in the United States of America and Brazil is currently restricted to the culture of more affordable food-fish species for domestic consumption. These fish are produced mainly in earthen ponds, and more recently in open cage-based farming systems in the case of tilapia and cachama (FAO, 2006a).

2.2 Future aquaculture outlook

While the prospects for the aquaculture industry in the region are bright (Masser and Bridger, 2006; Rojas, Simonsen and Wadsworth, 2006; Flores-Nava, 2007), the sector has not been without its problems and constraints, which will have to be addressed if it is to grow in a sustainable manner, including (but not limited to):

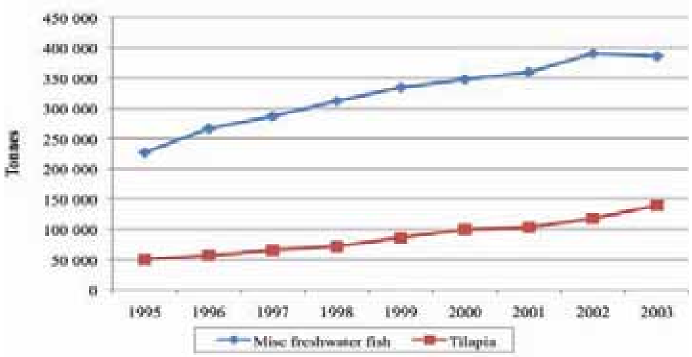
FIGURE 2
Aquaculture production of salmonids and marine shrimp within the Americas



Source: FAO (2006a), except salmonid data for 2005 from AquaVision (2006)

- *The need for improved environmental sustainability* – The intensive culture of finfish within open floating-cage farming systems can exert adverse effects on the surrounding aquatic environment and ecosystem, including pollution impacts from uneaten feed and excreta (Mente *et al*., 2006; Muñoz, 2006; Rojas, Simonsen and Wadsworth, 2006), the transfer of diseases and parasites of cage-reared fish to natural fish populations (Volpe *et al*., 2006), dependency of cage-reared salmonid and other carnivorous fish species upon fishery resources as feed inputs (Kristofersson and Anderson, 2006; Tacon, Hasan and Subasinghe, 2006), increased risk of fish escapes from cages and potential negative genetic impacts on wild fish populations (Naylor *et al*., 2005; FAO, 2006b), increased potential negative impacts upon predatory mammals and birds (Masser and Bridger, 2006; Rojas, Simonsen and Wadsworth, 2006) and increased community concerns regarding the use of shared public inland and coastal waterbodies for rearing fish and the environmental sustainability of open cage-based farming systems (FAO, 2006b, Tacon, Hasan and Subasinghe, 2006); and

FIGURE 3
Aquaculture production of miscellaneous freshwater fish species (mainly channel catfish) and tilapia within the Americas



Source: FAO (2006a)

- *The need for improved food security and poverty alleviation impacts* – Preliminary estimates (2002–2004) of the prevalence of undernourishment in the region, expressed as a percentage of the total population, currently range from under 2.5 percent in the case of Canada, Cuba, the United States of America and Uruguay to over 20 percent within several aquaculture exporting countries, including Guatemala, 22 percent; Panama, 23 percent; and Nicaragua, 27 percent (FAO, 2006c). Moreover, the apparent consumption of fish and fishery products varied widely within the region, ranging from under 10 kg/caput/year supply (2001–2003 average: Honduras, 1.1; Bolivia, 1.9; Guatemala, 2.0; Nicaragua, 4.3; Ecuador, 4.7; El Salvador, 5.0; Colombia, 5.3; Costa Rica, 5.7; Brazil, 6.4) to over 20 kg/caput/year supply (Chile, 17.9; Suriname, 18.8; Peru and Bolivarian

TABLE 1
Summary of total aquaculture production and main species groups in the region in 2004

Region/country/species	Production (tonnes)	Value (US$ million)
Latin America and the Caribbean	**1 341 436**	**5 250.0**
Top 10 countries by production		
Chile	694 693	2 810.0
Brazil	269 699	956.6
Mexico	89 037	291.3
Ecuador	63 579	292.8
Colombia	60 072	277.4
Cuba	27 562	29.4
Costa Rica	24 708	80.2
Honduras	22 520	114.9
Venezuela (Bolivarian Republic of)	22 210	65.8
Peru	22 199	130.6
Top species groups		
Diadromous fish*	586 289	2 470.0
Freshwater fish	311 052	917.6
Crustaceans	290 134	1.3
Marine fish	929	10.7
Top cultivated species		
Salmonids	586 277	2 470.0
Shrimp	289 496	1 330.0
Tilapia	146 078	422.6
Miscellaneous freshwater fish**	90 834	319.7
Carps, barbels and other cyprinids	74 140	175.3
North America	**751 567**	**1 305.9**
Top country by production		
United States of America	606 549	907.0
Canada	145 018	398.9
Top species groups		
Freshwater fish	306 848	561.3
Diadromous fish	146 964	460.4
Crustaceans	36 740	64.5
Marine fish	1 373	6.4
Top cultivated species		
Miscellaneous freshwater fish	291 418	475.4
Salmonids	141 748	429.1
Freshwater crustaceans	31 964	43.1

*Includes salmonids, milkfish, eels and sturgeons.
**Includes channel catfish at 285 970 tonnes (United States of America).
Source: FAO (2006a), SUBPESCA (2006a)

Republic of Venezuela, 19.2; Jamaica, 21.8; the United States of America, 22.6; Canada, 23.8) (global average: 16.4 kg/caput/year) (FAO, 2006d). Therefore, increased aquaculture production and availability of low-grade food fish may have potential roles toward improving food security in the region.

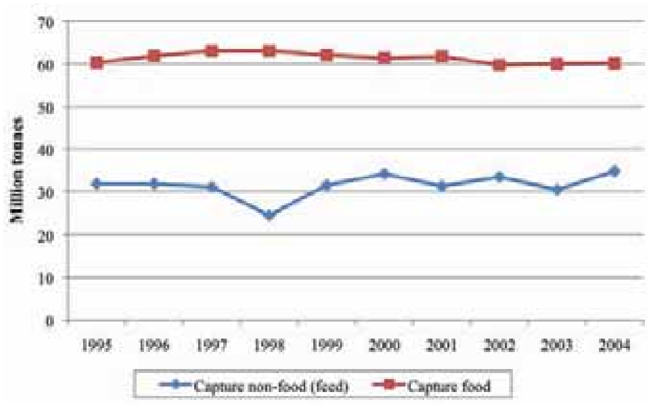
3. USE OF CAPTURE FISHERY PRODUCTS IN ANIMAL FEEDS

3.1 Fisheries landings destined for reduction and other non-food use

Although total global fish and shellfish landings from capture fisheries were 95 million tonnes in 2004, over 34.8 million tonnes or 36.6 percent was destined for non-food uses and reduction into fishmeal and fish oil and/or for direct animal feeding. The bulk of these landings was in the form of lower-value small-pelagic oily fish species, including anchovies, herring, capelin, sardines, pilchards, mackerel, sand eels, menhaden and under-sized commercial food-fish species (Figure 4).

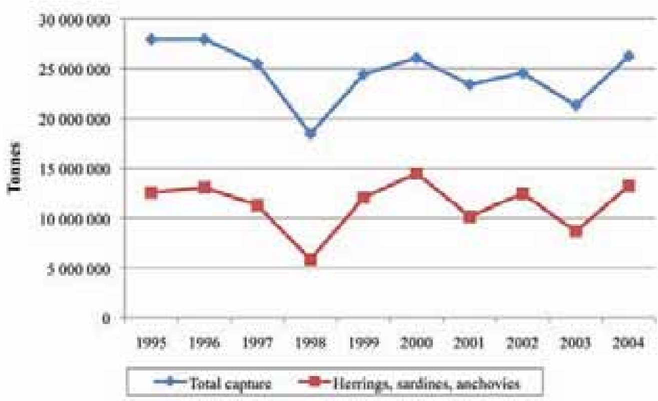
Within the Americas, the percentage of landings destined for non-food uses is significantly higher than the global percentage, with over 9.9 million tonnes or 47.2

FIGURE 4
Global finfish and shellfish production from capture fisheries, and disposition of the catch



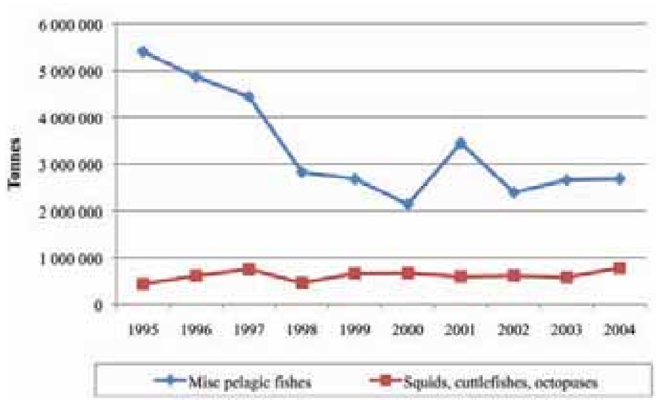
Source: FAO (2006a)

FIGURE 5
Total capture fisheries landings of herrings, sardines and anchovies within the Americas



Source: FAO (2006a)

FIGURE 6
Total capture fisheries landings of miscellaneous pelagic fishes (include mackerels and capelin) and squids, cuttlefishes and octopuses within the Americas



Source: FAO (2006a)

percent of total finfish and shellfish landings from capture fisheries (21.0 million tonnes in 2003) destined for reduction and other non-food uses. The percent of total landings in the Americas destined for reduction and other non-food uses ranged from <1 percent in Argentina, Colombia, Cuba, El Salvador, Guatemala, Honduras, Nicaragua and Bolivarian Republic of Venezuela, to 6.8 percent in Costa Rica, 9.0 percent in Brazil, 17.2 percent in Canada, 18.9 percent in Mexico, 21.9 percent in the United States of America and 25.0 percent in Ecuador, to as high as 76.4 percent in Chile and 87.8 percent in Peru (FAO Food Balance Sheets for 2003: S. Vannuccini, Data and Statistics Unit, FAO Fisheries and Aquaculture Department, Rome, personal communication, 2007).

3.2 Origin, species composition and use

Small pelagic fish species form the bulk of capture fisheries landings destined for reduction in the Americas, with anchovies, herrings, pilchards, sprats, sardines and menhaden totalling 13.19 million tonnes or 50.2 percent of the total reported capture fisheries landings of 26.25 million tonnes in 2004 (Figure 5), followed by miscellaneous pelagic fishes (2.68 million tonnes, includes mackerels and capelin) (Figure 6), and squids, cuttlefishes and octopuses (0.78 million tonnes) (Figure 6).

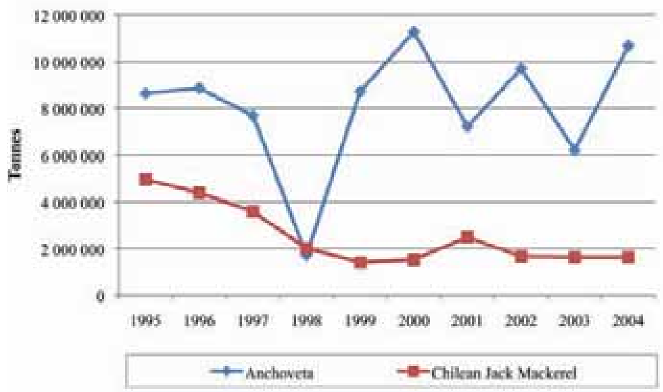
On a species basis, the top pelagic fish destined for reduction and other non-food uses in 2004 in the Americas included (in order of landed live-weight equivalents):

- Peruvian anchovy – total reported landing of 10 679 338 tonnes in 2004, to which Peru contributed 82.5 percent (Flores, 2006), Chile 17.4 percent (SUBPESCA, 2006b) and Ecuador 0.1 percent (Figure 7);

- Chilean jack mackerel – total reported landings of 1 638 530 tonnes in 2004, to which Chile contributed 88.6 percent and Peru 11.4 percent (Figure 7);
- Chub mackerel – total reported landings of 730 427 tonnes in 2004, to which Chile contributed 79.0 percent, Peru 8.5 percent, Ecuador 7.1 percent and Mexico 3.6 percent (Figure 8);
- California pilchard – total reported landings of 683 560 tonnes in 2004, to which Mexico contributed 86.9 percent and the United States of America 13.1 percent (Figure 9);
- Jumbo flying squid – total reported landings of 555 764 tonnes in 2004, to which Peru contributed 48.6 percent; Chile 31.5 percent and Mexico 19.8 percent (Figure 9);
- Gulf menhaden – total reported landings of 464 148 tonnes in 2004 (369 896 tonnes in 2005; NMFS, 2007), to which the United States of America contributed 100 percent (Figure 10);
- Araucanian herring – total reported landings of 356 090 tonnes in 2004, to which Chile contributed 100 percent (Figure 11);
- Atlantic herring – total reported landings of 268 690 tonnes in 2004, to which Canada contributed 68.1 percent and the United States of America 30.3 percent (Figure 12);
- Atlantic menhaden – total reported landings of 215 163 tonnes in 2004 (194 242 tonnes in 2005, NMFS; 2007), to which United States of America contributed 100 percent (Figure 10);

FIGURE 7

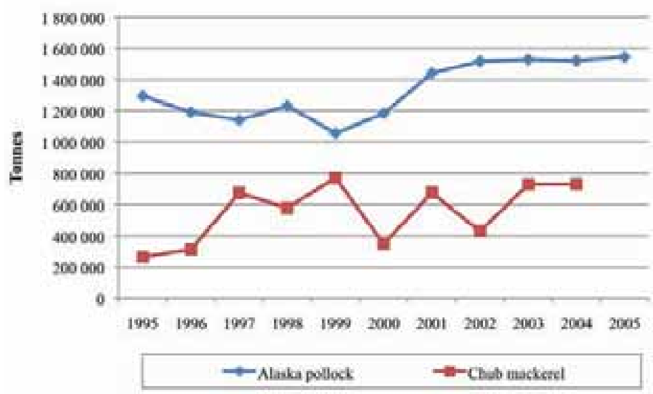
Total capture fisheries landings of anchoveta and Chilean jack mackerel within the Americas



Source: FAO (2006a)

FIGURE 8

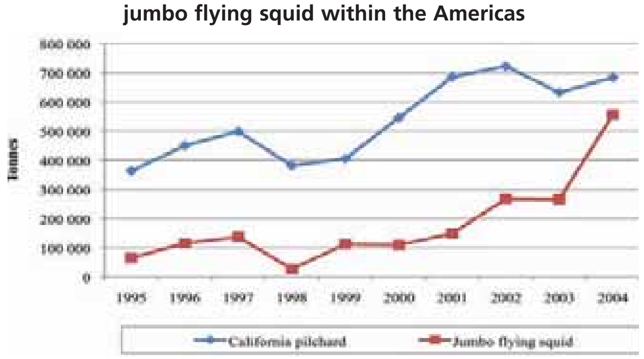
Total capture fisheries landings of Alaska pollock and chub mackerel within the Americas



Source: FAO (2006a), except 2005 data from NMFS (2007)

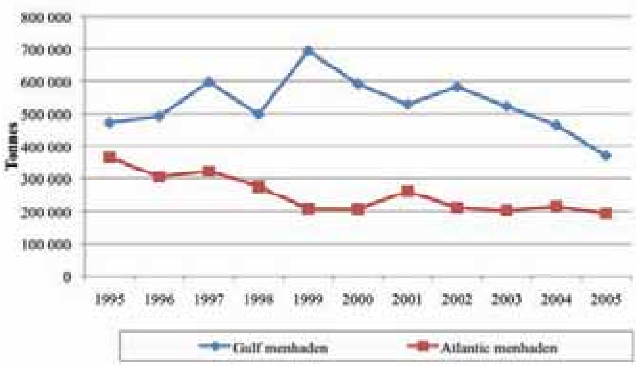
FIGURE 9

Total capture fisheries landings of California pilchard and jumbo flying squid within the Americas



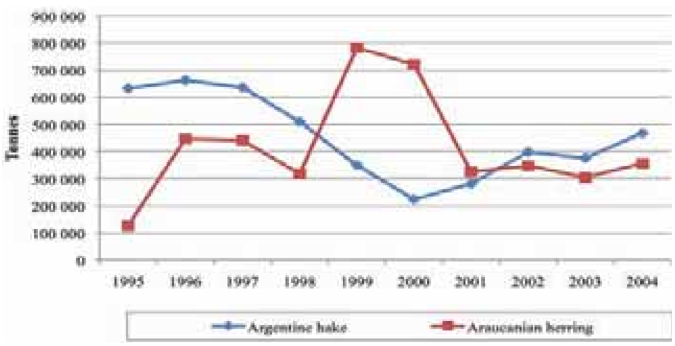
Source: FAO (2006a)

FIGURE 10
Total capture fisheries landings of Gulf menhaden and Atlantic menhaden within the Americas



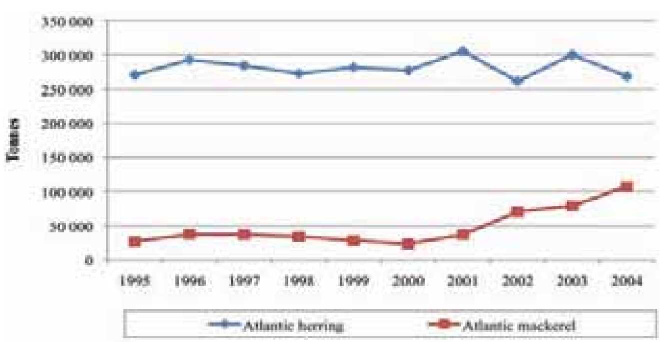
Source: FAO (2006a), except 2005 data from NMFS (2007)

FIGURE 11
Total capture fisheries landings of Araucanian herring and Argentine hake within the Americas



Source: FAO (2006a)

FIGURE 12
Total capture fisheries landings of Atlantic herring and Atlantic mackerel within the Americas



Source: FAO (2006a)

- Round sardinella – total reported landings of 142 982 tonnes in 2004, to which the Bolivarian Republic of Venezuela contributed 99.2 percent (Figure 13);
- Atlantic mackerel – total reported landings of 107 682 tonnes in 2004, to which the United States of America contributed 50 percent and Canada 50 percent (Figure 12);
- Pacific anchoveta – total reported landings of 73 203 tonnes in 2004, to which Panama contributed 64.2 percent and Colombia 28.9 percent (Figure 14);
- Pacific herring – total reported landings of 57 981 tonnes in 2004, to which United States of America contributed 58.9 percent and Canada 41.1 percent (Figure 15);
- Pacific thread herring – total reported landings of 54 105 tonnes in 2004, to which Panama contributed 84.1 percent and Ecuador 15.9 percent (Figure 15);
- Brazilian sardinella – total reported landings of 53 421 tonnes in 2004, to which Brazil contributed 100 percent (Figure 16);
- Capelin – total reported landings of 52 351 tonnes in 2004, to which Canada contributed 69.1 percent and Greenland 30.9 percent (Figure 16);
- Atka mackerel – total reported landings of 49 508 tonnes in 2004 (58 733 tonnes in 2005; NMFS, 2007), to which the United States of America contributed 100 percent (Figure 16);
- Argentine anchovy – total reported landings of 39 367 tonnes in 2004, to which Argentina contributed 94.7 percent (Figure 14).

Other fish species destined for reduction (either from by-products or whole):

- Alaska pollock – total reported landings 1 522 860 tonnes in 2004 (1 547 010 tonnes in 2005; NMFS, 2007), to which the United States of America contributed 99.8 percent (Figure 8);
- Argentine hake – total reported landings 467 748 tonnes in 2004, to which Argentina contributed 89.1 percent, Uruguay 8.9 percent and the Falkland

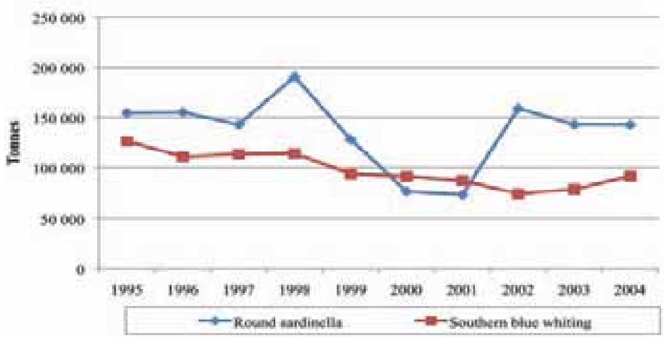
Islands (Malvinas) 1.7 percent (Figure 11); and

- Southern blue whiting – total reported landings 92 183 tonnes in 2004, to which Argentina contributed 54.5 percent, Chile 42.4 percent (Chile reported blue whiting landings of 25 358 tonnes in 2005; SUBPESCA, 2006c) and the Falkland Islands (Malvinas) 3.0 percent (Figure 13).

At present, no official statistical information exists at the regional level concerning the percent of the total catch destined for reduction, other non-food uses and/or for direct human consumption for each of the above species.

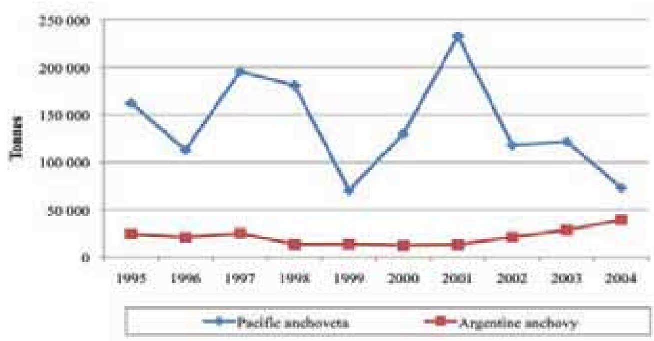
Information is currently only available at the country level (calculated from the FAO Food Balance Sheets) for 2003, with total fisheries production (capture fisheries and aquaculture combined) differentiated in terms of food uses (for direct human consumption) and non-food uses, including reduction into fishmeal and fish oil, and other miscellaneous uses (the latter includes use as a direct aquaculture feed, as bait and as ornamental fish: S. Vannuccini, Data and Statistics Unit, FAO Fisheries and Aquaculture Department, Rome, personal communication, 2007). Apart from the above, limited information is available for the major fisheries nations in the region, including Peru (Flores, 2006; SNP, 2006), Chile (Jara, 2006; SUBPESCA, 2006d) and the United States of America (NMFS, 2007). This will be discussed in greater detail in Sections 3.3 and 3.4.

FIGURE 13
Total capture fisheries landings of round sardinella and southern blue whiting within the Americas



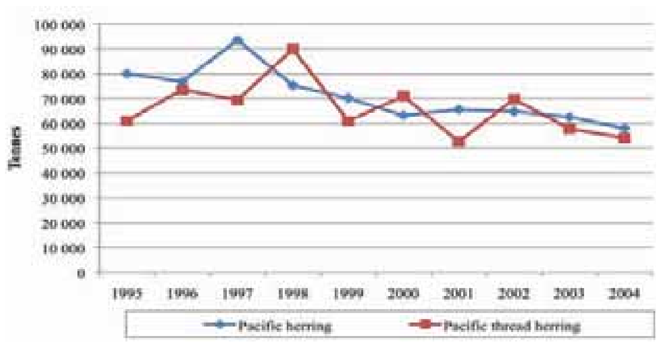
Source: FAO (2006a)

FIGURE 14
Total capture fisheries landings of Pacific anchoveta and Argentine anchovy within the Americas



Source: FAO (2006a)

FIGURE 15
Total capture fisheries landings of Pacific herring and Pacific thread herring within the Americas



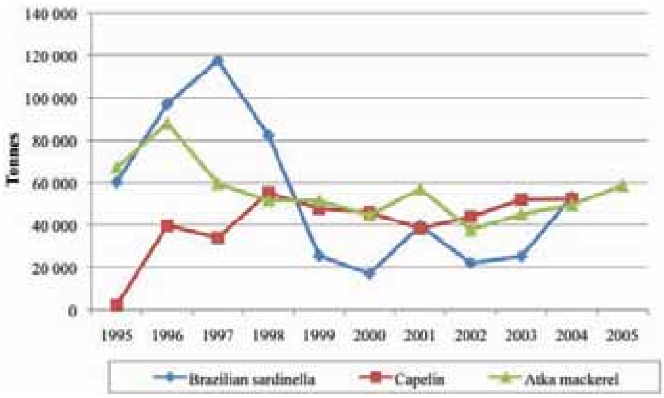
Source: FAO (2006a)

3.3 Fishmeal and fish oil production and trade

3.3.1 Fishmeal and fish oil production

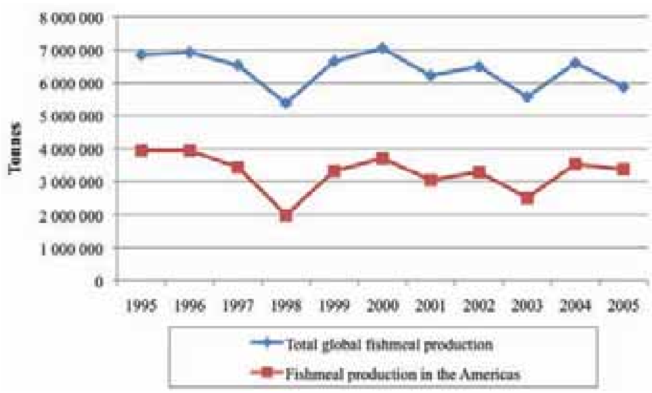
Total fishmeal and fish oil production within the Americas has fluctuated from a low of 2.0 million tonnes in 1998 to a high of 3.7 million tonnes in 2000 in the case of fishmeal (mean = 3.27 million tonnes) (Table 2, Figure 17) and from a low of 0.37 million tonnes in 1998 to a high of 0.90 million tonnes in 2000 in the case of fish oil

FIGURE 16
Total capture fisheries landings of Brazilian sardinella, capelin and atka mackerel within the Americas



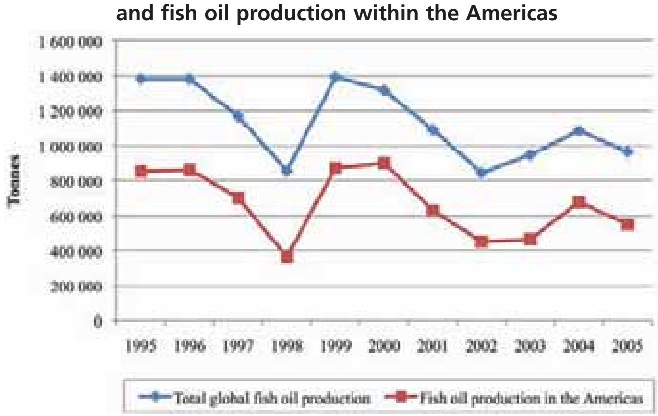
Source: FAO (2006a), except 2005 data from NMFS (2007)

FIGURE 17
Relationship between total global fishmeal production and fishmeal production within the Americas



Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 18
Relationship between total global fish oil production and fish oil production within the Americas



Source: FAO (2006a), except 2005 data from Mittaine (2006)

(mean =0.68 million tonnes) (Table 3, Figure 18). The only significant production trend over this period was the dramatic effect of the El Niño event on the Peruvian anchovy catch (and consequently fishmeal and fish oil production in Peru), with global fishmeal and fish oil production decreasing by 41.8 percent and 47.9 percent, respectively, from one year to the next after the 1997–1998 El Niño. Latest International Fishmeal and Fish Oil Organisation (IFFO) estimates for total fishmeal and fish oil production in 2005 within the Americas have been reported as 3.37 million tonnes and 0.55 million tonnes, or 57.3 percent and 57.1 percent of total global fishmeal and fish oil production for 2005, respectively (Mittaine, 2006).

Fishmeal and fish oil production in Peru and Chile exceeds that of all other countries, Peru and Chile alone accounting for 83.5 percent of total fishmeal production (Figures 19 and 20) and 78.3 percent of total fish oil production (Figures 21 and 22) within the Americas in 2005; the United States of America ranked third in the region in terms of fishmeal (8 percent) and fish oil (13.6 percent) production (Mittaine, 2006). Of particular note is that 70 percent of the total fishmeal production and 35 percent of the total fish oil production within the region were not reported to FAO on a species-specific level in 2004 (Tables 2 and 3).

3.3.2 *Fishmeal and fish oil trade*

Figures 23 and 24 show the reported total production, exports and imports of fishmeal and fish oil from the Americas from 1995 to 2005, respectively. The region is a net exporter of fishmeal and to a lesser extent fish oil, with exports closely following production trends. Globally in 2005, the region accounted for 68.5 percent of total world fishmeal exports and 55.1 percent of total world fish oil exports, 4.6 percent of total world fishmeal imports (over 95 percent of available fishmeal stocks being imported by the Asian and European regions) and 16.6 percent of total world fish oil imports (64.4 percent of available fish oil stocks being imported by the European region) (Mittaine, 2006).

China was by far the largest importer of fishmeal in 2005 (1.6 million tonnes in 2005 or 36.9 percent of total global fishmeal imports), with 91.4 percent of these imports sourced from the Americas, including Peru (67.2 percent), Chile (17.4 percent), the United States of America (4.4 percent), Argentina (1.6 percent) and Panama (0.8 percent). In contrast, Norway was the largest importer of fish oil in 2005 (214.8 thousand tonnes or 27.8 percent of total fish oil imports) (Mittaine, 2006).

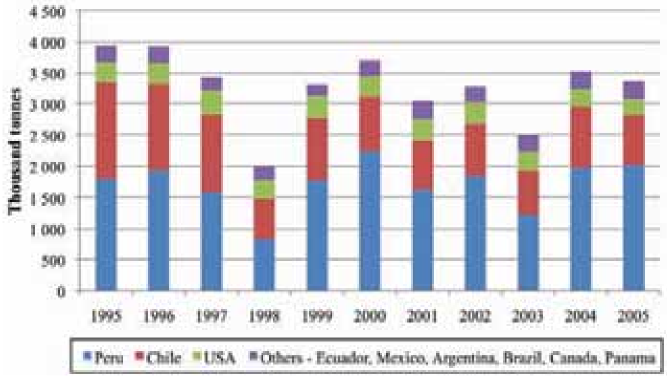
At the country level, Peru stands out as being the world's largest producer and exporter of fishmeal and fish oil (Figure 25) (FAO, 2006a; Mittaine, 2006).

By contrast, Chile (the world's second largest fishmeal and fish oil producer), while still being a net exporter of fishmeal (Figure 26), has now emerged as a major importer of fish oil (in addition to that already produced in the country, Figure 27). It is second only to Norway in terms of total fish oil imports, which are imported mainly from Peru to meet the demands of its rapidly growing salmonid aquaculture industry (FAO, 2006a; Mittaine, 2006; Tacon, Hasan and Subasinghe, 2006).

Other major fishmeal and fish oil producers, exporters and importers within the region are shown in Figures 28 to 39, including:

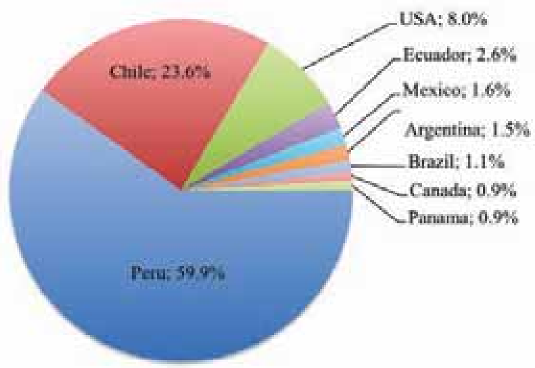
- United States of America (Figures 28 and 29): major exporter and increasing domestic consumer;
- Brazil (Figures 30 and 31): increasing domestic consumer;
- Ecuador (Figures 32 and 33): net exporter and increasing domestic consumer;

FIGURE 19
Fishmeal production by major country within the Americas



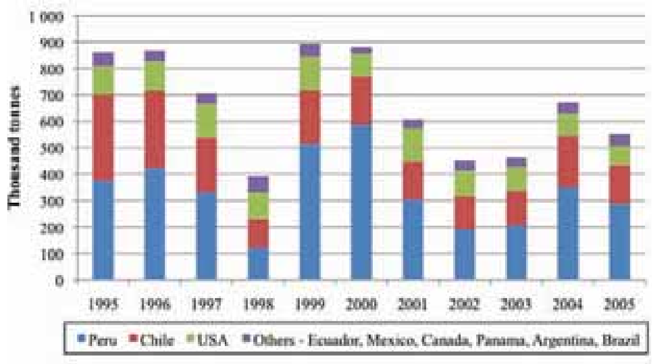
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 20
Fishmeal production by country in the Americas, 2005



Source: Mittaine (2006)

FIGURE 21
Fish oil production by major country within the Americas



Source: FAO (2006a), except 2005 data from Mittaine (2006)

TABLE 2
Reported total fishmeal production in the Americas (values given in thousand tonnes, dry, as-fed basis)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total fishmeal production – global	**6 852**	**6 924**	**6 541**	**5 378**	**6 655**	**7 046**	**6 219**	**6 498**	**5 576**	**6 604**
Total fishmeal production – Americas	3 943	3 930	3 433	1 997	3 318	3 706	3 041	3 284	2 509	**3 528**
Fishmeal from pelagic fish										
Oily-fishmeal, nei	1 731	2 113	1 749	1 153	2 039	2 564	2 029	2 206	1 591	2 369
Anchoveta meal	804	471	572	153	444	422	232	365	211	442
Jack mackerel meal	956	834	594	260	204	216	302	243	227	233
Menhaden meal	204	190	217	178	212	197	184	190	175	167
Mackerel meal	25.3	34.3	49.1	13.9	25.8	21.1	76.6	69.0	123	115
Pilchard meal	50.3	103	98.8	73.4	214	153	72.4	71.3	60.4	73.7
Tuna meal	29.3	25.7	25.4	27.7	27.1	20.7	17.2	17.8	15.3	14.0
Herring meal	20.0	6.2	5.7	5.3	4.9	7.3	8.8	8.0	4.3	4.9
Clupeoid fishmeal	–	–	–	0.15	0.52	3.75	2.86	4.19	–	–
Fishmeal from demersal fish										
White-fishmeal, nei	70.0	104	45.9	102	91.1	48.8	66.9	58.9	57.7	76.5
Blue whiting meal	0.19	0.64	0.88	0.92	0.72	1.14	0.93	0.63	1.16	0.36
Other marine meals										
Fish solubles *	40.6	37.2	65.3	15.3	43.7	45.7	44.6	46.6	36.4	24.1
Fishmeal, nei **	0.15	0.05	0.09	0.16	0.10	0.10	0.10	0.10	0.10	0.10
Crustacean meals										
Crustacean meal, nei	3.38	2.86	3.64	4.85	5.20	3.69	2.19	1.15	1.09	3.41
Crab meal ***	4.66	5.32	5.53	5.30	4.01	2.56	2.33	1.67	2.68	1.65

*Dried or condensed fish solubles are derived from the drying or evaporation of the aqueous liquid fraction (stickwater) resulting from the wet rendering (cooking) of fish into fishmeal, with or without removal of the oil.
**Fishmeal is defined as the clean, dried, ground tissue of undecomposed whole fish or fish cuttings (processing waste), either or both, with or without the extraction of part of the oil.
***Crab meal is the undecomposed, ground, dried waste of the crab and usually contains the shell, viscera and part or all of the flesh.
Source: FAO (2006a)

TABLE 3
Reported total fish oil production in the Americas (values given in thousand tonnes, dry, as-fed basis)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total fish oil production – global*	**1 382**	**1 382**	**1 169**	**856**	**1 393**	**1 317**	**1 092**	**846**	**948**	**1 086**
Total fish oil production - Americas	854	864	702	366	873	901	629	453	466	678
Anchoveta oil	383	426	342	134	520	606	327	199	214	357
Fish body oils, nei	356	321	232	128	223	205	173	157	161	235
Menhaden oil	108	112	126	101	129	86.5	127	95.5	88.7	81.3
Herring oil	7.1	4.87	3.07	2.89	1.9	2.57	1.61	1.96	2.03	2.56
Other fish liver oils, nei	0.21	<0.01	<0.01	0.02	<0.01	0.38	0	0.02	0.15	2.01
Cod liver oil **	0.03	0.01	0	0.02	<0.01	0.01	0.54	0.02	0.02	0.01

*Fish oil is the oil from rendering whole fish or cannery waste.
** Demersal fish liver oil.
Source: FAO (2006a)

- Mexico (Figures 34 and 35): net exporter and increasing domestic consumer;
- Canada (Figures 36 and 37): net importer of fishmeal and fish oil; and
- Panama (Figures 38 and 39): net exporter and small domestic consumer.

It is important to note that Canada is currently the only country within the region that is a net importer of fishmeal and fish oil, primarily to meet the feed needs of its domestic salmonid aquaculture sector (Table 1).

3.3.3 Fishmeal and fish oil use and demand

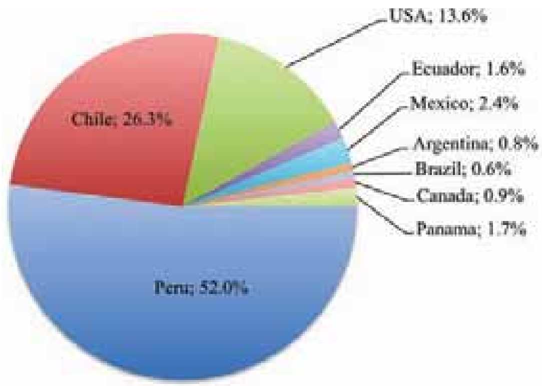
It is estimated that in 2004 the global finfish and crustacean aquaculture sector consumed 3 452 000 tonnes of fishmeal (Figure 40), which equates to 52.3 percent of the total global fishmeal production of 6 604 229 tonnes in 2004, and 893 400 tonnes of fish oil (Figure 41) or 82.2 percent of the total global fish oil production of 1 085 674 tonnes in 2004 (FAO, 2006a).

The data presented in Table 4 show that the estimated global fishmeal and fish oil use within compound aquafeeds has increased almost two-fold from 1995 to 2004, rising from 1 728 to 3 452 thousand tonnes in the case of fishmeal and from 494 to 893 thousand tonnes in the case of fish oil.

Within the Americas, fishmeal and fish oil use within compound aquafeeds in 2004 was estimated to be as follows:

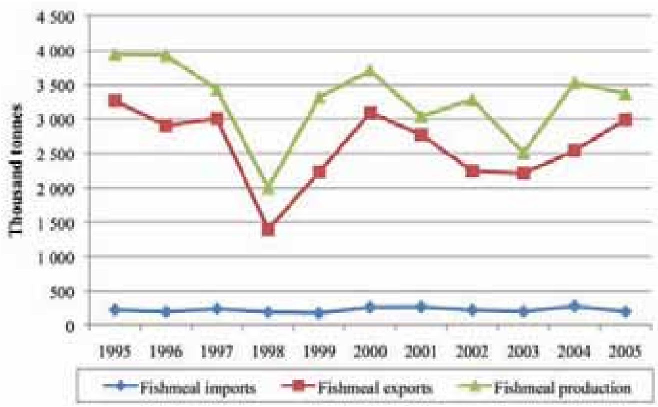
- **Salmon:** total production, 554 511 tonnes; feed use, 720 000 tonnes; average fishmeal content, 35 percent; fish oil content, 25 percent; estimated fishmeal use, 252 000 tonnes; fish oil use, 180 000 tonnes; total, 432 000 tonnes;
- **Shrimp:** total production, 294 227 tonnes; feed use, 455 000 tonnes; average fishmeal content, 22 percent; fish oil content, 2 percent; estimated fishmeal use, 100 100 tonnes; fish oil use, 9 100 tonnes; total, 109 200 tonnes;
- **Trout:** total production, 173 514 tonnes; feed use, 225 000 tonnes; average fishmeal content, 30 percent; fish oil content, 17.5 percent; estimated fishmeal use, 67 500 tonnes; fish oil use, 39 500 tonnes; total, 107 000 tonnes;
- **Catfish:** total production, 291 572 tonnes; feed use, 467 000 tonnes; average fishmeal content, 5 percent; fish oil content, 1 percent; estimated fishmeal use, 23 400 tonnes; fish oil use, 4 700 tonnes; total 28 100 tonnes;
- **Tilapia:** total production, 155 150 tonnes; feed use, 210 000 tonnes; average fishmeal content, 5 percent; fish oil content, 1 percent; estimated fishmeal use, 10 500 tonnes; fish oil use, 2 100 tonnes; total 12 600 tonnes;

FIGURE 22
Fish oil production by country in the Americas, 2005



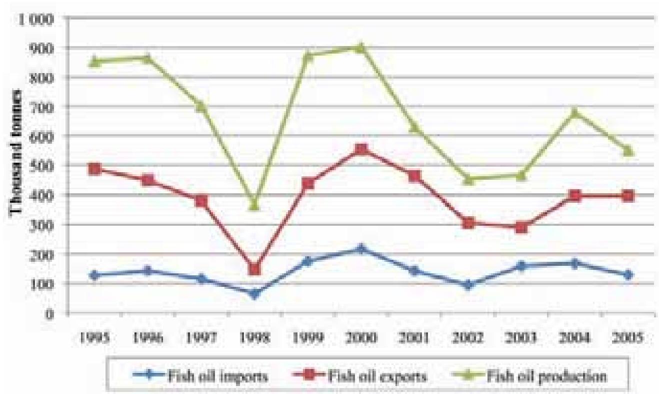
Source: Mittaine (2006)

FIGURE 23
Americas: fishmeal balance sheet



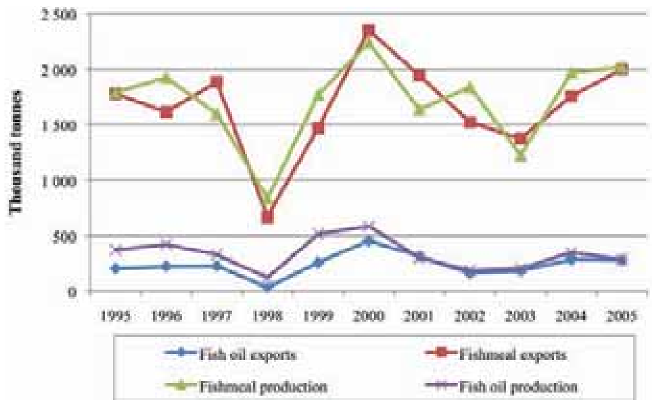
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 24
Americas: fish oil balance sheet



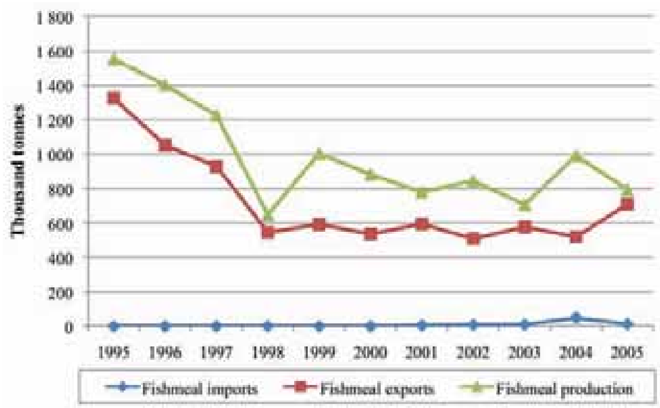
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 25
Peru: fishmeal and fish oil balance sheet



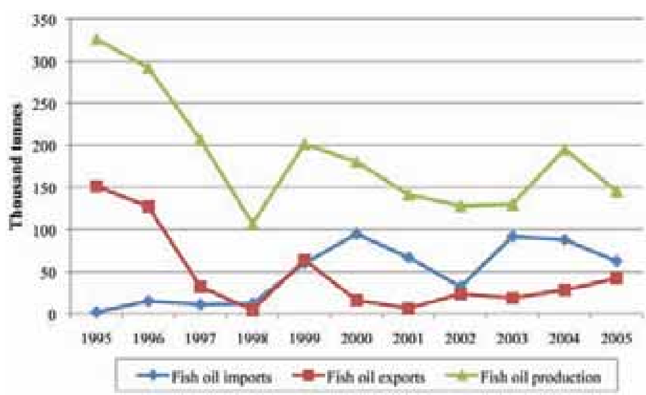
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 26
Chile: fishmeal balance sheet



Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 27
Chile: fish oil balance sheet



Source: FAO (2006a), except 2005 data from Mittaine (2006)

- **Freshwater crustaceans:** total production, 32 597 tonnes; feed use, 32 000 tonnes; average fishmeal content, 20 percent; fish oil content, 2 percent; estimated fishmeal use, 6 400 tonnes; fish oil use, 600 tonnes; total 7 000 tonnes;
- **Miscellaneous freshwater fish:** total production, 90 680 tonnes; feed use, 91 000 tonnes; average fishmeal content, 5 percent; fish oil content, 1 percent; estimated fishmeal use, 4 500 tonnes; fish oil use, 910 tonnes; total 5 410 tonnes;
- **Cyprinids:** total production, 80 498 tonnes; feed use, 76 000 tonnes; average fishmeal content, 5 percent; fish oil content, 1 percent; estimated fishmeal use, 3 800 tonnes; fish oil use, 760 tonnes; total 4 560 tonnes; and
- **Marine fish:** total production, 2 302 tonnes; feed use, 3 200 tonnes; average fishmeal content, 40 percent; fish oil content, 7.5 percent; estimated fishmeal use, 1 300 tonnes; fish oil use, 240 tonnes; total, 1 540 tonnes.

By far the largest consumers of fishmeal and fish oil within the region are salmonids and marine shrimp, together which accounted for 89.4 percent and 96.1 percent, respectively, of the total fishmeal and fish oil consumed by the aquaculture sector within the Americas in 2004. Summation of the above data indicates that the aquaculture sector in the Americas consumed 469 500 tonnes of fishmeal (13.3 percent of total fishmeal production within the region) and 237 910 tonnes of fish oil (35.1 percent of total fish oil production within the region) for the production of 1 675 051 tonnes of cultured compound feed-fed aquaculture species in 2004. This quantity of fishmeal and fish oil is equivalent to the consumption of 2.8 to 3.5 million tonnes of pelagics (using a dry meal plus oil to wet fish weight equivalents conversion factor of 1 to 4 to 1 to 5; Tacon, Hasan and Subasinghe, 2006; see also Figure 42 for fish: fishmeal conversion ratio) for the production of 1.7 million tonnes of aquaculture produce.

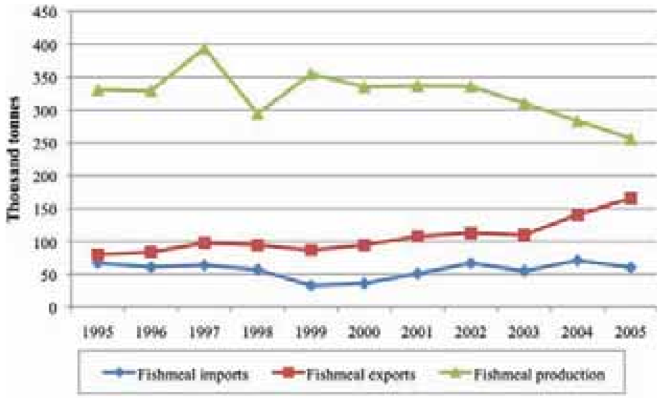
According to Aguila (2006), the salmonid aquaculture sector in Chile consumed 900 000 tonnes of compound aquafeeds in 2005, including 300 000 tonnes of domestically produced fishmeal and all of the nationally produced fish oil (over 117 300 tonnes in 2005).

Limited supplies for fishmeal and fish oil, together with continuing strong demand from the larger and fast-growing aquaculture sectors in Asia and Europe, has resulted in a strong rise in the price of fishmeal over the past 12 months (Figure 43).

Projections concerning the future availability, price and use of fishmeal and fish oil vary widely depending upon viewpoint and assumptions used (Shepherd, 2005; Tacon, 2005; Jackson, 2006; Tacon, Hasan and Subasinghe, 2006). For example, according to Tacon, Hasan and Subasinghe (2006), fishmeal and fish oil use in aquaculture is expected to decrease in the long run (Table 5); assumptions were rising prices due to limited supplies and increasing demand (Figure 43), increasing competition for pelagics for direct human consumption and the desire on the part of consumers for sustainability and a concern for the state of the oceans.

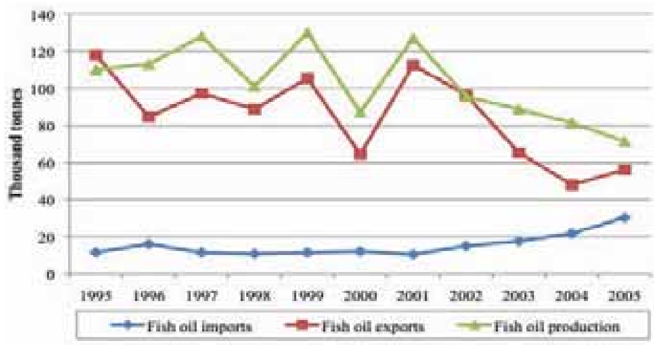
However, according to industry estimates, and in particular that of the International Fishmeal and Fish Oil Organisation (IFFO), fishmeal and fish oil use is expected to steadily increase, such that by 2012 aquaculture would use 60 percent of the global supplies of fishmeal and 88 percent of the global supplies of fish oil (Figures 44 and 45) (Jackson, 2006).

FIGURE 28
United States of America: fishmeal balance sheet



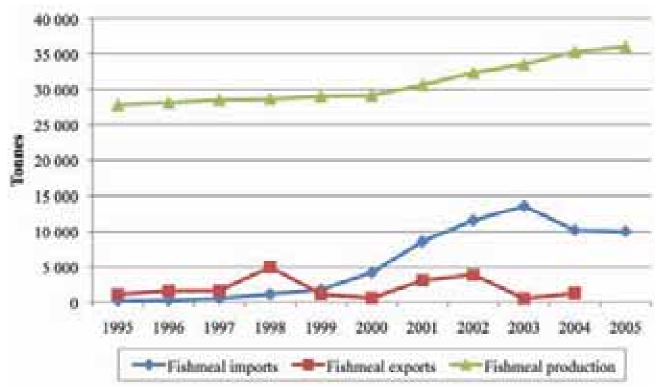
Source: FAO (2006a), except 2005 data from NMFS (2007)

FIGURE 29
United States of America: fish oil balance sheet



Source: FAO (2006a), except 2005 data from NMFS (2007)

FIGURE 30
Brazil: fishmeal balance sheet

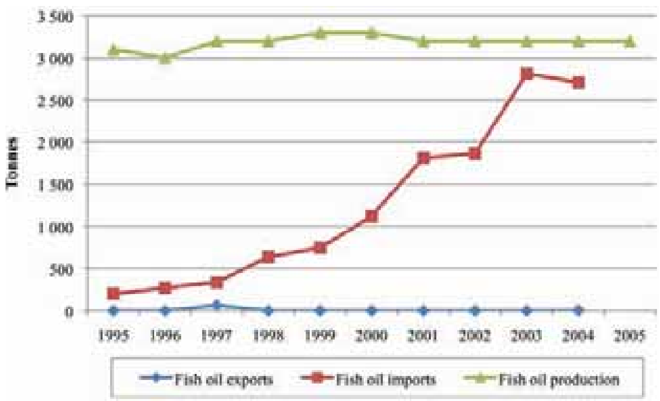


Source: FAO (2006a), except 2005 data from Mittaine (2006)

3.3.4 Other uses

Apart from the use of fishmeal and fish oil within feeds for farmed aquatic and terrestrial animals (Tacon, Hasan and Subasinghe, 2006), fish oils are also used for human consumption, either in their refined natural state (in capsules and health foods) or hardened in the form of margarine and shortenings. For example, according

FIGURE 31
Brazil: fish oil balance sheet



Source: FAO (2006a), except 2005 data from Mittaine (2006)

to Shepherd (2005) 14 percent of the total global production of fish oils in 2002 was used for edible purposes. However, no precise official statistical information exists concerning the use of fish oils for human consumption within the Americas.

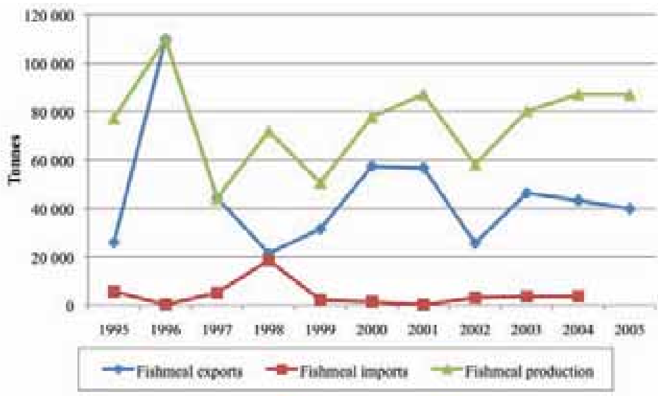
Fish oils may also be used for specific technical applications, such as in the manufacture of quick-drying oils and varnishes, as fatty acid precursors for the preparation of metallic soaps used in lubricating greases or as water-proofing agents (FAO, 1986; Bimbo and Crowther, 1992).

3.4 Trash fish and other miscellaneous non-food uses of fishery products

In addition to the targeted reduction of fish and shellfish species into fishmeal and fish oil, other non-food uses of fishery products include: 1) the use of fish as a direct aquaculture feed or within farm-made aquafeeds, 2) the use of fish and shellfish species as fishing bait for commercial fishing or for sport fisheries, 3) the use and capture of wild-caught brood fish and shellfish and larvae, and 4) the direct production and sale of wild-caught and/or cultured freshwater and marine ornamental fish and shellfish species for hobbyists.

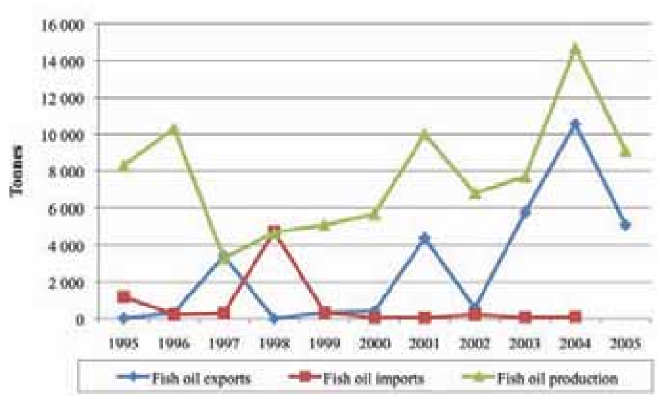
Low-value trash fish species may be used as aquaculture feed, either directly in fresh or frozen form as a complete natural grow-out/fattening diet in the case of tuna or fresh/frozen squid for shrimp maturation, or indirectly, in processed form within farm-made aquafeeds (Allan, 2004; Edwards, Tuan and Allan, 2004; Ottolenghi *et al.*, 2004; Funge-Smith, Lindebo and Staples, 2005; Tacon, Hasan and Subasinghe, 2006). As mentioned previously, there are no official estimates concerning the amount of trash fish used in aquaculture (either alone or incorporated into farm-made aquafeeds) within the Americas (Flores-Nava, 2007), other than a total estimated

FIGURE 32
Ecuador: fishmeal balance sheet



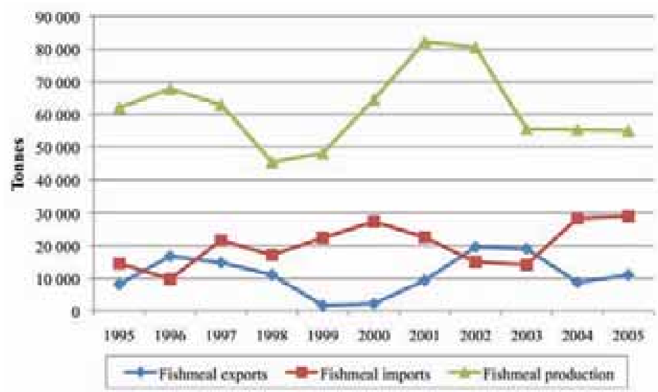
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 33
Ecuador: fish oil balance sheet



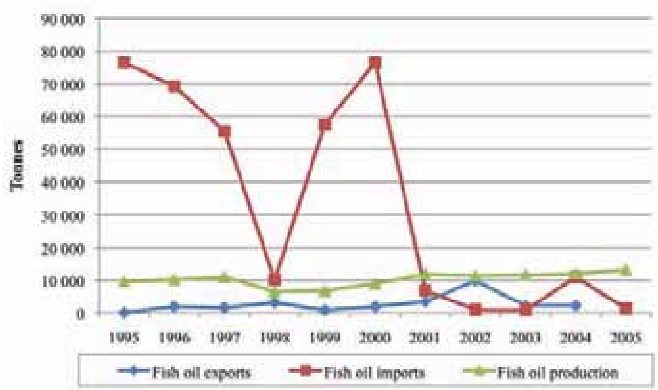
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 34
Mexico: fishmeal balance sheet



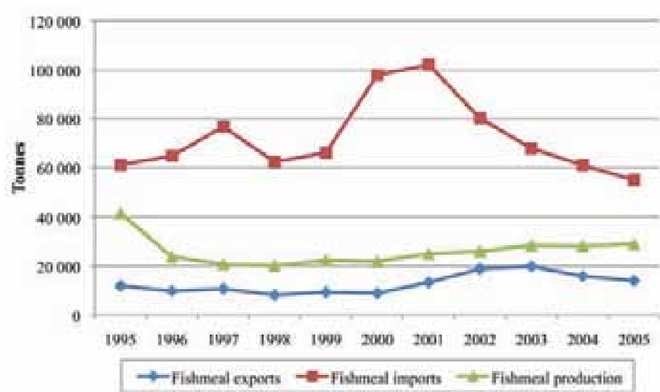
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 35
Mexico: fish oil balance sheet



Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 36
Canada: fishmeal balance sheet



Source: FAO (2006a), except 2005 data from Mittaine (2006)

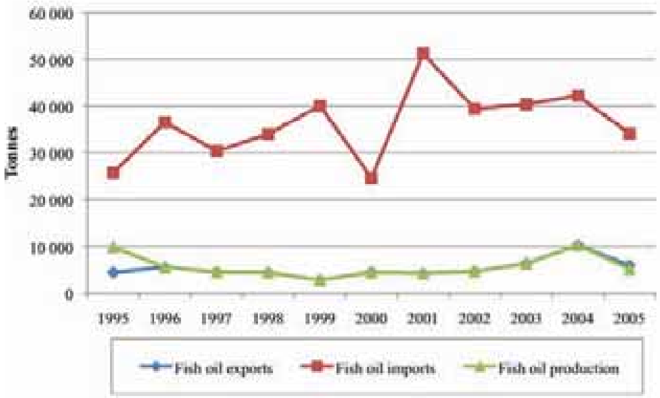
country figure for reduction and for other uses (Table 6). However, in Mexico, it is estimated that the Pacific bluefin tuna fattening industry (estimated production at 5 000 tonnes in 2006) is a major consumer of locally caught fresh/frozen sardines (Dalton, 2004; M.T. Viana, Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California, personal communication, 2007).

Fish and shellfish species are used directly as live/fresh bait for commercial and/or recreational fishing operations, including lobster and crab fishing in the United States of America and Canada (anon., 2000; O'Malley, 2004; Elliot, 2006), longlining for tuna, swordfish, mahi-mahi and shark, and in recreational sport fisheries (ACIAR, 2001). According to Elliot (2006), Atlantic herring are the major source of lobster bait in the United States of America, whereas Atlantic mackerel are the most common bait in Canada. The same author estimates that 50 000 to 60 000 tonnes of fish bait are used annually in the United States of America's lobster fishery to yield approximately 35 000 tonnes of adult lobster; the ratio of bait inputs to lobster landings being 1.5:1 (Elliot, 2006). However, NMFS (2007) estimates that the total landings of fresh and frozen fish for bait and animal feed were 203 000 tonnes in 2005, and 9 000 tonnes canned for bait or animal (pet) feed.

Other baitfish species reportedly used in the United States of America are anchovies (99 percent of all landings of 11 349 tonnes used as fish bait; NMFS, 2007), menhaden (small amounts used as bait for the Gulf Coast blue crab fishery; anon., 2000), mackerel (O'Malley, 2004) and sardines (Dalton, 2004).

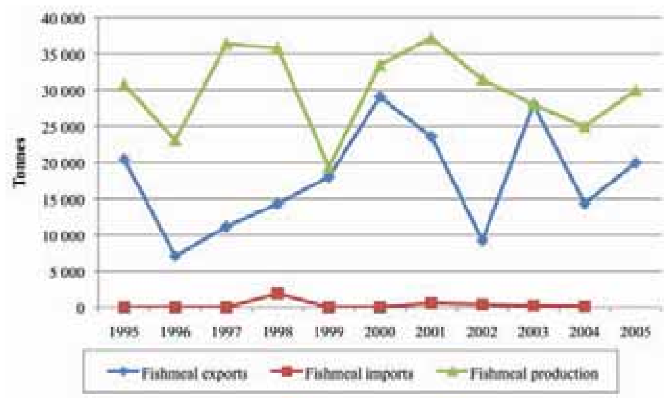
From the data presented in Table 6, South America (particularly because of Peru and Chile) stands out in that non-food uses of fishery products exceed that of food uses.

FIGURE 37
Canada: fish oil balance sheet



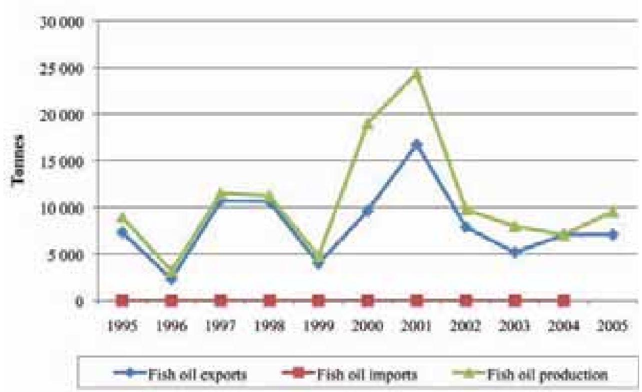
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 38
Panama: fishmeal balance sheet



Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 39
Panama: fish oil balance sheet



Source: FAO (2006a), except 2005 data from Mittaine (2006)

The high "other non-food uses" production figures reported for the United States of America (247 827 tonnes), Chile (174 539 tonnes) and Canada (86 754 tonnes) are believed to be due to the high use of fish bait within these countries.

For example, according to NMFS (2007), only 728 000 tonnes or 17.0 percent of the total United States of America domestic landings of fish and shellfish were destined for non-food uses in 2005, including reduction to meal and oil (516 000 tonnes or 70.9 percent), fresh and frozen for bait and animal feed (203 000 tonnes or 27.9 percent) and canned for bait or animal feed (9 000 tonnes or 1.2 percent). Moreover, although 99 percent of landed anchovies within the United States of America were used for bait (the United States of America importing all edible anchovies), menhaden was used primarily for the production of meal, oil and solubles, with only small amounts used for bait.

Similarly, in Peru it has been estimated that only 27 065 tonnes of anchoveta or 0.32 percent of the total anchoveta catch of 8 555 955 tonnes in 2005 was used for human consumption, with the remainder (8 530 551 tonnes or 99.68 percent) destined for reduction into fishmeal and fish oil (Flores, 2006). Moreover, in Chile it has been estimated that the exports of pelagics for direct human consumption has increased over 8-fold from 19 775 tonnes in 2000 to 171 972 tonnes in 2005, including 139 335 tonnes of Chilean jack mackerel, 25 902 tonnes of Patagonian grenadier and 6 735 tonnes of chub mackerel (Jara, 2006).

3.4.1 Other miscellaneous fishery products

In addition to the use of trash fish, other fishery products that can be considered here include:

TABLE 4

Estimated global use of fishmeal and fish oil (dry, as-fed basis) in compound aquafeeds, during 1995–2004 (thousand tonnes)*

Species-Group	1995	1998	1999	2000a**	2000b	2001	2002a	2002b	2002c	2003	2004****
*Shrimp****											
Fishmeal	420	486	407	372	428	510	480	487	522	670	843
Fish oil	42	34.7	33	30	36	42.5	41.7	39	42	58.3	76.7
Freshwater crustaceans											
Fishmeal	–	–	–	–	93	119	122	60	–	139	184
Fish oil	–	–	–	–	7.7	10.4	12.2	12	–	13.9	18.4
Marine finfish											
Fishmeal	266	419.9	492	635	533	505	640	417	702	590	632
Fish oil	80	112.5	170	249	121	120	140	106	125	110.6	118.6
Salmon											
Fishmeal	317	485.7	437	491	525	595	554	455	554	573	622
Fish oil	176	264.9	273	307	262	282	253	364	443	409	444.2
Trout											
Fishmeal	202	219.4	170	189	159	179	169	180	221	216	227
Fish oil	115	123.4	85	95	93	104	96	168	147	126	132.6
Eel											
Fishmeal	136	113.5	182	173	186	180	179	174	190	171	175
Fish oil	68	21.4	36	17	14.9	15	15.2	1	10	11.4	12.5
Milkfish											
Fishmeal	32	26.6	37	36	37	37	38	42	57	36	30
Fish oil	11	8	9	6	3.7	4.2	4.7	6	10	5.2	5.0
Feeding carp											
Fishmeal	332	362.1	64	350	368	366	414	337	334	438	453
Fish oil	42	60.3	13	0	0	73.1	82.7	0	0	43.8	45.3
Tilapia											
Fishmeal	69	72	61	55	61	70	68	73	95	79	82
Fish oil	5	7.2	9	8	10	11.6	13.5	10	14	15.8	16.4
Catfish											
Fishmeal	22	50.5	18	15	23	24	21	12	14	24	70
Fish oil	9	6.3	6	5	5.8	6	7.2	6	7	8	14.0
Carnivorous freshwater fish											
Fishmeal	–	–	78	–	–	–	–	40	124	–	128
Fish oil	–	–	15	–	–	–	–	16	19	–	8.5
Total§											
Fishmeal	1 728	2 256	2 091	2 316	2 413	2 585	2 685	2 217	2 873	2 936	3 452
Fish oil	494	649	662	716	554	668.8	666.2	732	829	802	893.4

* Data not calculated for 1996 and 1997.

**There were two estimations of global use of fishmeal and fish oil for 2000 (differentiated as 2000a and 2000b) and three estimations for 2002 (differentiated as 2002a, 2002b and 2000c).

***Shrimp** includes all marine shrimps, prawns, etc. according to the FAO International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) Code 45; **Freshwater crustaceans** includes freshwater prawn, river crab and crayfish according to ISSCAAP Code 41; **Marine finfish** includes all marine fishes according to ISSCAAP Code 3, with the exception of mullets; **Salmon** includes all the salmon species listed in ISSCAAP Code 23, including Atlantic salmon, coho salmon, chinook salmon, chum salmon, cherry salmon and sockeye salmon; **Trout** includes all the trout species listed in ISSCAAP Code 23, including rainbow trout, sea trout and brook trout; **Eel** includes all river eel species listed in ISSCAAP Code 22; **Feeding carp** species includes all carps, barbels and other cyprinids listed in ISSCAAP Code 11, with the exception of the filter feeders silver carp, bighead carp, catla and rohu; **Tilapia** includes all tilapia species listed in ISSCAAP Code 12, with the exception of other cichlids; **Catfish** includes all omnivorous catfish species listed in ISSCAAP Code 13; **Carnivorous freshwater fish** species include Chinese bream, mandarin fish, yellow croaker, and long-nose catfish but excludes eel.

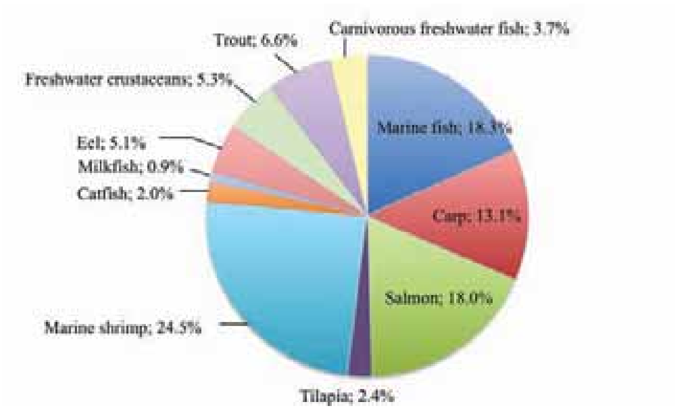
****Adapted from Tacon (2006), and includes 6.2 and 1.2 thousand tonnes of fishmeal and fish oil for freshwater colossoma fish species.

§Total values under each column are not necessarily the sum of their respective figures and may include fishmeal and fish oil uses by other species/species-groups not shown in the table.

Source: Data for 1995–2003 have been adapted from Tacon, Hasan and Subasinghe (2006), while that for 2004 is from Tacon (2006)

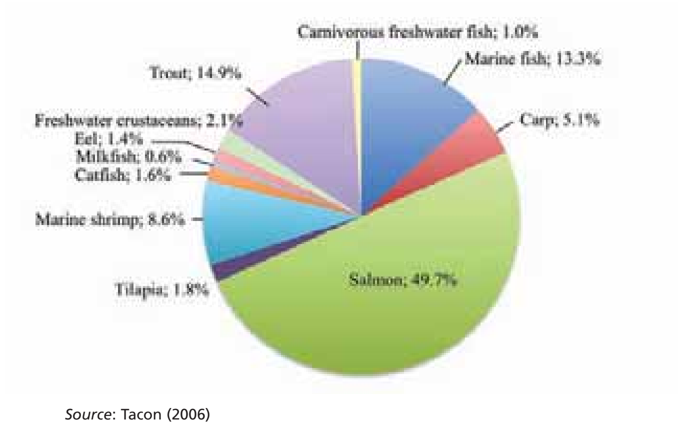
- **Antarctic krill:** Only the United States of America reported landings of 8 550 tonnes of Antarctic krill in 2004 (total global landings reported as 118 165 tonnes in 2004; FAO, 2006a). Krill is the one of the basic building blocks of the marine aquatic food chain and in reduced meal form is a good source of high-quality marine animal protein, essential lipids and phospholipids, pigments, vitamins and minerals. The current total allowable catch (TAC) of krill is 4 million tonnes (Rutman, Diaz and Hinrichsen, 2003). In aquaculture, krill products are used primarily as dietary feeding attractants/palatants and as a source of carotenoid pigments, and it is estimated that the current global consumption of krill products in commercial aquaculture and aquarium feeds is between 10 000 and 15 000 tonnes (Tacon, Hasan and Subasinghe, 2006).
- **Squid meal and squid oil:** Although total landings of the jumbo flying squid were reported at 555 764 tonnes in 2004 (Peru, 48.6 percent; Chile, 31.5 percent; Mexico, 19.8 percent; Figure 9), no information is available concerning the portion of catch destined for reduction or human consumption. Despite this, squid meal is known to be produced commercially in Peru and Chile, and is commonly used as a feed ingredient in commercial shrimp feeds produced within the region. Squid meal is an excellent source

FIGURE 40
Estimated global use of fishmeal by major cultured species group in compound aquafeeds, 2004



Source: Tacon (2006)

FIGURE 41
Estimated global use of fish oil by major cultured species group in compound aquafeeds, 2004



Source: Tacon (2006)

TABLE 5

Estimates and future projections of the use of fishmeal and fish oil in aquafeeds in thousand tonnes and as a percentage

	Global production		Fishmeal used (thousand tonnes)		Fish oil used (thousand tonnes)		% of fishmeal production		% of fish oil production	
	Fishmeal	Fish oil	FAO*	IFFO	FAO	IFFO	FAO	IFFO	FAO	IFFO
2002	6 201	959	2 696	2 769	758	810	43	45	79	84
2005	5 877	965	2 666	3 041	551	813	45	52	57	84
2010	6 000	950	2 478	3 286	534	826	41	55	56	87
2012	6 000	950	2 577	3 607	664	836	43	60	70	88

*FAO, Food and Agriculture Organization of the United Nations; IFFO, International Fishmeal and Fish Oil Organisation.
Source: Jackson (2006)

of high-quality marine protein and essential lipids, cholesterol, phospholipids, phosphorus and trace elements (Devresse, 1995; Chamberlain and Hunter, 2001; Cordova-Murueta and Garca-Carreno, 2002). The global market for squid meal in commercial aquafeeds is estimated to be between 25 000 and 75 000 tonnes and for squid oil, between 10 000 and 25 000 tonnes (Tacon, Hasan and Subasinghe, 2006).

FIGURE 42
Fish/fishmeal conversion ratio in Peru during 1988–2004 (3 month average)

Source: Shepherd (2005)

- **Shrimp meal and crab meal:** Shrimp meal and crab meal are used primarily as dietary feeding attractants and/or as a natural source of carotenoid pigments (Chamberlain and Hunter, 2001; Villarreal *et al.*, 2004). As with krill and squid, these products also serve as rich sources of dietary protein, carotenoid pigments, cholesterol, phospholipids and minerals (Tacon and Akiyama, 1997; Hertrampf and Piedad-Pascual, 2000). The market size for shrimp meal within aquafeeds is currently estimated at between 75 000 and 225 000 tonnes (mean of 90 000 tonnes) and for crab meal, at between 35 000 and 55 000 tonnes (Tacon, Hasan and Subasinghe, 2006).

FIGURE 43
Trends of fishmeal prices in Peru and Chile compared with soybean meal (FOB: freight on board)

Source: SUBPESCA (2007)

- **Aquaculture-produced meals and oils:** These include meals and oils produced through the reduction of by-products arising from aquaculture processing facilities, including salmon meal, salmon oil and shrimp head meal (Fox *et al*., 1994; Pongmaneerat *et al*., 2001; Kotzamanis *et al*., 2001; Turchini, Gunasekera and De Silva, 2003; Hardy, 2004; Wright, 2004). For example, it is estimated that in Chile the processing of 500 000 tonnes of farmed salmon could yield about 150 000 tonnes of non-edible products (ca. 30 percent salmon rounded weight, depending upon species and processing efficiency), which in turn could produce about 30 000 tonnes of salmon fishmeal (20 percent yield) and 20 000 tonnes of salmon oil (15 percent yield (J.P. Hinrichsen, Hinrichsen Trading S.A., Santiago, Chile, personal communication, 2005). However, it is important to mention that despite the high nutritional value of these products (Wright, 2004, the re-feeding of these products to the same species (intra-species recycling) is currently prohibited by law (for disease/biosecurity reasons) within the main salmon-producing countries, including Norway and Chile (Gill, 2000; SCAHAW, 2003; Ø. Jakobsen, Marine Harvest Ingredients, Norway, personal communication, 2004).

TABLE 6
Reported food and non-food uses for total fishery production in 2003* (tonnes, live weight)

	Production	Food uses	Non-food uses	Reduction	Other uses
World	132 523 900	102 777 264	29 746 636		
America	22 908 742	12 989 761	9 918 982	9 352 129	566 853
North and Central	9 089 622	7 471 696	1 617 926	1 238 846	379 080
North America	6 951 773	5 769 188	1 182 585	837 854	344 731
Caribbean	199 109	174 931	24 178	500	23 678
Central America	1 938 740	1 527 577	411 163	400 492	10 671
South America	13 819 120	5 518 064	8 301 056	8 113 283	187 773
Argentina	916 246	916 245	1	0	1
Belize	15 353	5 353	10 000	0	10 000
Bolivia	6 974	6 973	1	0	1
Brazil	1 086 504	1 014 000	72 504	72 500	4
Canada	1 229 925	1 043 951	185 974	99 220	86 754
Chile	4 185 188	1 418 261	2 766 927	2 592 388	174 539
Colombia	218 689	218 689	0	0	0
Costa Rica	49 873	47 862	2 011	2 000	11
Cuba	68 363	68 361	2	0	2
Ecuador	465 084	365 082	100 002	100 000	2
Greenland	238 205	226 055	12 150	2 000	10 150
Guatemala	30 480	30 469	11	0	11
Honduras	30 835	30 832	3	0	3
Mexico	1 523 675	1 253 075	270 600	270 000	600
Nicaragua	22 331	22 330	1	0	1
Panama	229 652	101 117	128 535	128 492	43
Peru	6 103 478	756 468	5 347 010	5 347 007	3
USA	5 483 285	4 498 824	984 461	736 634	247 827
Venezuela (Bolivarian Republic of)	540 161	540 159	2	0	2

*Information presented is calculated from the FAO Food Balance Sheets for 2003, with total fisheries production (capture fisheries and aquaculture combined) differentiated in terms of food uses (for direct human consumption) and non-food uses, including reduction into fishmeal and fish oil, and other miscellaneous uses (the latter includes use as a direct aquaculture feed, breed/bait and ornamental fish (S. Vannuccini, Data and Statistics Unit, FAO Fisheries and Aquaculture Department, Rome, personal communication, 2007).

4. SUSTAINABILITY OF REDUCTION FISHERIES AND FEED USE

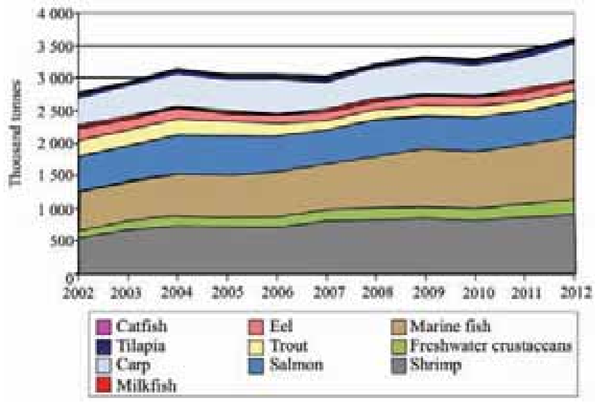
4.1 Review of the impacts of reduction fisheries and feed on ecosystems

4.1.1 Status of exploitation of major reduction fisheries in the Americas

Table 7 summarizes the status of exploitation of the major pelagic and demersal fish stocks within the major fishing regions in the Americas according to the FAO review of marine capture fisheries (FAO, 2005). According to the FAO review, over 52 percent of the world fish stocks are considered to be fully exploited, and as such are populations that are already at or very close to their maximum sustainable production limit, with no room for further expansion and with some risk of decline if not properly managed. Of the remaining stocks, approximately 17 percent are over-exploited, 7 percent are depleted and 1 percent are recovering, and thus offer no room for further expansion.

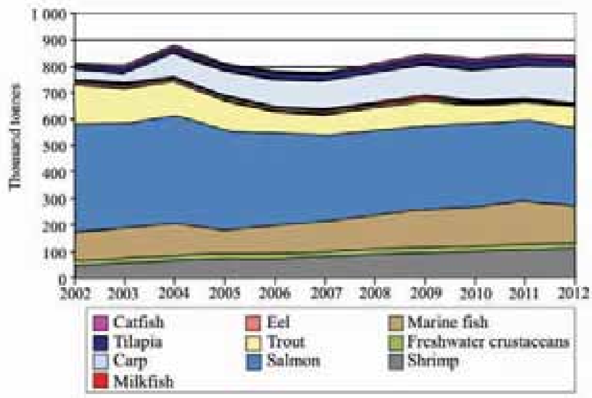
In the case of the major pelagic reduction fisheries in the Americas, a combination of heavy fishing pressure and severe adverse environmental conditions associated with changes in the El Niño Southern Oscillation have led to a general decline in the three most abundant pelagic species in the southeast Pacific, viz. the Peruvian anchoveta, the South American pilchard and the Chilean jack mackerel. For example, the stocks of Peruvian anchoveta have shown signs of recovery and at present are considered most likely fully or overexploited, with catches in the order of 7 to 11 million tonnes after a sharp decline to only 1.7 million tonnes in 1998 (FAO, 2005) (Figure 7). Similarly, the South American pilchard has declined sharply as part of a decadal regime period, and in 2004 yielded only 6 898 tonnes after reaching up to 6.5 million tonnes in 1985 (major producing countries: Peru, Chile and Ecuador) (FAO, 2005, 2006a). Similarly, the Chilean jack mackerel is assessed as being fully to overexploited and yielded 1.7 million tonnes in 2002 after declining continuously from a peak in landings of 5 million tonnes in 1994 (Figure 7).

FIGURE 44
Projections of the use of fishmeal for the major fed species in aquaculture until 2012



Source: Jackson (2006)

FIGURE 45
Projections of the use of fish oil for the major fed species in aquaculture until 2012



Source: Jackson (2006)

Other reduction fisheries in the Americas that have shown a general decline in catches over the last decade include the Atlantic and Gulf menhaden (Figure 10: fully exploited), the Pacific anchoveta (Figure 14: moderately to fully exploited), the Pacific herring (Figure 15: moderately to overexploited), and the Brazilian sardinella (Figure 16: overexploited).

4.2 Current criteria and indicators for measuring fisheries sustainability

4.2.1 Marine Stewardship Council mission, obligations, principles and criteria

According to the official web site of the Marine Stewardship Council (MSC) (http://eng.msc.org), the MSC works to enhance responsible management of seafood resources to ensure the sustainability of global fish stocks and the health of the marine ecosystem. In particular, the mission of the MSC is to safeguard the world's seafood supply by promoting the best environmental choice.

In February 1996, the World Wide Fund for Nature (WWF) and Unilever formed a partnership with the goal of creating economic incentives for sustainable fishing through the establishment of an independent, non-profit Marine Stewardship Council.

TABLE 7
Status of exploitation of major pelagic fish stocks in the Americas

Species	Main fishing nations	Status*
Northwest Atlantic (FAO Statistical Area 21):		
Atlantic herring	Canada, United States of America	U–F–R
Atlantic menhaden	United States of America	F
Atlantic mackerel	Canada, United States of America	F
Capelin	Canada	F
Western Central Atlantic (FAO Statistical Area 31):		
Atlantic menhaden	United States of America	F
Atlantic thread mackerel	United States of America, Cuba	Unknown
Gulf menhaden	United States of America	F
Round sardinell	Venezuela (Bolivarian Republic of)	M/F
Southwest Atlantic (FAO Statistical Area 41):		
Argentine hake	Argentina, Uruguay	O–D
Patagoian grenadier	Argentina, Falkland Islands ((Malvinas)	M
Southern blue whiting	Argentina, Chile	F–O
Southern hake	Argentina	F
Argentine anchovy	Argentina	U–M
Brazilian sardinella	Brazil	O
Argentine shortfin squid	Argentina	F
Northeast Pacific (FAO Statistical Area 67):		
Alaska pollock	United States of America	F
Pacific herring	United States of America, Canada	M–O
Eastern Central Pacific (FAO Statistical Area 77):		
California pilchard	Mexico, United States of America	M–F
California anchovy	United States of America, Mexico	M–F
Pacific anchoveta	Panama	M–F
Pacific thread herring	Panama	M–F
Chub mackerel	Mexico, United States of America	M
Pacific jack mackerel	United States of America	U
Jumbo flying squid	Mexico	M–F
Southeast Pacific (FAO Statistical Area 87):		
Anchoveta	Peru, Chile	R–O
Araucanian herring	Chile	F–O
Pacific thread herring	Ecuador	F
South American pilchard	Chile, Peru, Ecuador	F–O
Chilean jack mackerel	Chile, Peru	F–O
Chub mackerel	Chile, Peru	M–F
Jumbo flying squid	Peru, Chile, Mexico	M

*Status: U – underexploited, M – moderately exploited, F – fully exploited, O – overexploited, D – depleted, R – recovering.
Source: FAO (2005)

The MSC would house and oversee a programme whereby fisheries conforming to a set of predetermined criteria for sustainable fishing would be eligible for certification by independent, MSC-accredited certifying firms. Products from fisheries certified to MSC standards could carry an on-pack logo, providing consumers with the choice of selecting seafood products that come from sustainably managed sources.

In the very early stages of the MSC initiative, Unilever and WWF recognized that a technically sound and widely accepted set of criteria on which to base certification decisions would be of critical importance to the success of the MSC certification programme. To this end, in September of 1996, they initiated a process of broad consultation aimed at ensuring that the development of the MSC and its proposed certification programme would be as fully informed as possible by the full range of individuals and organizations with expertise and interest in fisheries sustainability. The primary goal of the consultative process was to arrive at a widely accepted set of Principles and Criteria for Sustainable Fishing that could be used as the basis for the certification programme. However, the process was also designed to accomplish a number of additional goals.

The consultative process was conducted in three phases. The purpose of the first phase was to develop a preliminary set of Draft Principles and Criteria for Sustainable Fishing that would provide a starting point for engaging in broader consultation. This was accomplished by the convening of a small group of internationally renowned experts in marine fisheries for three days in Bagshot, United Kingdom in September 1996. This group drew heavily on the wealth of existing internationally recognized documents dealing with fisheries sustainability, as well as on their own combined expertise and experience, in achieving consensus on a set of Draft Principles and Criteria for Sustainable Fishing.

The second phase of consultation consisted of a series of eight two-day workshops around the world through which MSC sponsors sought to introduce local and regional stakeholders to the MSC initiative, to gain an understanding of their different perspectives and to gather feedback. Workshop participants represented individual fishers; commercial fishing industries; seafood buyers, processors and retailers; government regulatory authorities; government and academic scientists; economists; independent certifiers; conservation groups; indigenous peoples and other interested parties.

The third phase of this process involved the revision of the Bagshot Draft Principles and Criteria at an intensive three-day workshop held in Virginia, United States of America. Participants were drawn from among the original drafters of the Bagshot draft and from several of the regional workshops. Working from a summary of the recommendations from all of the regional workshops, supplemented by some preliminary "lessons-learned" from the early stages of several test cases, this group of experts was able to reach agreement on revisions to the Draft Principles and Criteria.

Overall, the goals of the 1996–1997 consultative process were met. It resulted in a revised set of Draft Principles and Criteria for Sustainable Fishing and provided the MSC with important insight into the issues and concerns that must be considered in the ongoing planning for and implementation of the MSC certification programme in order for it to be credible and supportable. The MSC, now established as independent from its founding sponsors, has a working set of Principles and Criteria for sustainable fishing (http://eng.msc.org) that were developed with input from potential stakeholders around the world and by consensus of a representative group of noted experts.

4.2.2 Fishmeal Information Network (FIN) initiative and activities

FIN is an initiative of the international Grain and Feed Trade Association (GAFTA), which represents more than 800 suppliers of fishmeal, other animal feed ingredients, grain, pulses and rice in more than 80 countries. GAFTA aims to promote international trade and to protect the interests of its members and has been the driving force since 1971, when it was established as a result of a merger between the London Corn Trade Association and Cattle Food Trade Association.

FIN is funded by the Sea Fish Industry Authority, a statutory body funded by levies from the fishing industry. FIN's activities are guided by a steering committee on which suppliers, GAFTA's executive and Seafish are represented; and coordinated and managed by a team of three people from the agrifood strategic communications consultancy, The Chamberlain Partnership.

According to the official website (www.gafta.com/fin/), FIN is a resource for factual information about fishmeal and fishmeal issues in the United Kingdom. FIN was established at the height of the bovine spongiform encephalopathy (BSE) crisis in 1997. The widely held view that meat and bone meal was implicated in BSE led to scrutiny of fishmeal, which revealed no evidence of health risk to animals or human beings. Throughout the debate on this and subsequent feed-related issues, FIN's strategic objective has been to defend and enhance the role of fishmeal as a safe and valuable feed ingredient for all types of farm livestock in the United Kingdom.

FIN's key activities are:

- to provide a source of information and a point of contact for the industry as a whole;
- to supply comprehensive factual information relating to fishmeal, addressing concerns and highlighting the positive benefits of its use as a feed ingredient;
- to monitor and effectively communicate industry attitudes to fishmeal and the effect specification changes could have on its use;
- to safeguard the livestock producers' option to use fishmeal under the relevant safety and quality assurance schemes or within the production criteria specified by individual purchasers;
- to ensure regulatory decisions on feed taken at the United Kingdom and the EU level do not discriminate unfairly or without justification against fishmeal; and
- to provide practical advice to livestock producers about fishmeal and its use as a feed ingredient.

FIN compiles various in-depth reports and dossiers, including an annual review of the feed-grade fish stocks used to produce fishmeal and fish oil for the United Kingdom market. The review focuses on recent independent assessments of these stocks published by independent bodies such as the United Nation's Food and Agriculture Organization (FAO) and the International Council for the Exploration of the Sea (ICES).

Although FIN produces an extremely useful web site and sustainability dossier dataset on the reported status and sustainability of marine capture fisheries directly or indirectly linked to the United Kingdom/EU fishing industry and seafood market (www.gafta.com/fin/index.php?pge_id=2), it is essentially a compilation of existing published peer-reviewed and non-peer reviewed reports, reviews and commentaries produced for the benefit of the United Kingdom's commercial fishmeal and seafood fishing industry.

4.2.3 Overview of fisheries resources

The 2004 FAO State of World Fisheries and Aquaculture report (FAO, 2005) looks at the Southeast Pacific and shows that three species account for around 80 percent of total catches: the Peruvian anchoveta (two stocks), the Chilean jack mackerel and the South American pilchard (sardine). The whole of the Southeast Pacific is under the influence of two phases of the El Niño Southern Oscillation (El Niño and La Niña). These are the main sources of inter-annual variability, having noticeable regional and extra-regional impacts on climate and on the state of fishery resources and related fishery productivity, particularly when the warm phase of El Niño occurs. As a consequence, large catch fluctuations are common in the area.

A combination of high fishing pressure and adverse environmental conditions, including the severe El Niño event (warm water currents) in 1997–1998, led to a sharp decline in catches of the two principal species (anchoveta and Chilean jack mackerel) during the late 1990s. While the stocks of anchoveta have recovered, with catches in Chile and Peru on the order of 10 million tonnes since 2000, catches of Chilean jack mackerel totalled 1.7 million tonnes in 2000, representing less than 50 percent of the fishery's historic peak production reached in 1994.

The National Oceanic and Atmospheric Administration (NOAA) of the United States of America predicted normal to slightly cooler conditions in 2005 and in February 2006 announced the official return of La Niña (the periodic cooling of ocean waters in the east-central equatorial Pacific), which remained into late spring. This is favourable for stock growth.

Catches in Peru

Peruvian anchoveta (anchovy) is a short-lived species. In the severe El Niño year of 1998, catches were 3.5 million tonnes and according to FAO (2005), post-El Niño recovery of anchoveta stocks has been surprisingly fast. In Peru, total catch levels were 7.8 million tonnes in 1999, up to 9.7 million in 2000 (the largest single species catch), and 8 million tonnes in 2001 and 2002. There was a drop in 2003 to 5.3 million tonnes, and catches increased to 8.6 million tonnes in 2004. In 2005, catches were 8.7 million tonnes.

FAO (2005) states that the two stocks of anchoveta are now reported as recovered from the El Niño 1997–1998 depletion, and while there are still some concerns about potential overfishing, particularly due to the gross excess of fishing capacity, it is hoped the two stocks will evolve to and be maintained at a safer fully exploited level. However, given the existing excess fishing capacity (estimated to be 40 per cent higher than advisable) and the known high natural variability and vulnerability of anchoveta to heavy fishing, particular measures need to be adopted to prevent overfishing.

The Peruvian Government has adopted a precautionary approach to fisheries management to safeguard the viability and prevent depletion of stocks by means of national quotas for individual species and a closed season programme. Peruvian fishmeal production in 1999 was 1.9 million tonnes, more than twice the 1998 level of 815 000 tonnes and representing a return to normal levels. Production increased to 2.3 million tonnes in 2000 and was 1.8 million tonnes in 2001, 1.9 million tonnes in 2002, 1.2 million tonnes in 2003, 1.9 million tonnes in 2004 and 2 million tonnes in 2005.

Catches in Chile

The catch of jack mackerel in Chile has been controlled by annual quotas since 1999/2000. In 2005, catches were 1.29 million tonnes, of which approximately 325 000 tonnes went for canning and freezing for human consumption. This compares with catches of 1.36 million tonnes in 2004, 1.38 million tonnes in 2003, 1.44 million tonnes in 2002 and 1.65 million tonnes in 2001. Catches have increased since the landings of 1.24 million tonnes in 1999 in line with the fixed quota.

The FAO Review of the State of World Marine Fishery Resources (FAO, 2005) states that tight management measures based on the application of a non-transferable individual quota system have been established for Chilean jack mackerel. However, even if catches tended to stabilize, there are concerns about the state of the stock and the sustainability of the fishery, particularly as recent fishing effort might be overexploiting the stock.

To preserve stocks, the Under Secretary of Fisheries, with the approval of the National Fisheries Council in Chile, has responded with a number of monitored control measures based on acoustic assessments of fish stocks and research cruises. The Chilean Government regularly introduces temporary fishing bans throughout the year, mainly to protect spawning activity and recruitment periods. To fairly divide fishing between these temporary bans, legislation has now been introduced that will impose quotas for each licensed fishing company according to its average catch over the last two years and its storage capacity.

Anchoveta catches in Chile were 1.5 million tonnes in 2005, 1.7 million tonnes in 2004, 0.75 million tonnes in 2003, 1.5 million tonnes in 2002 and 0.85 million tonnes in 2001. Catches of sardine (*Clupea*) were 277 000 tonnes in 2005, 329 000 tonnes in 2004, 274 000 tonnes in 2003 and 310 000 tonnes in 2002, which is nearly the same amount as landed in 2001 (325 000 tonnes). This is in contrast with catches of 782 000 tonnes in 1999 and 723 000 tonnes in 2000. Since 2002, this resource has been subject to a national quota.

Total catches of pelagic fish used in the fishmeal industry in Chile have decreased from 4.5 million tonnes in 1999 to 3.7 million tonnes in 2000, 3.2 million tonnes in 2001, 3.7 million tonnes in 2002, 2.9 million tonnes in 2003, 3.9 million tonnes in 2004 and 3.5 million tonnes in 2005. This is mainly due to a reduction in TACs imposed by the Chilean Government. Total fishmeal production was 1 million tonnes in 1999, 842 000 tonnes in 2000, 699 000 tonnes in 2001, 839 000 tonnes in 2002, 664 000 tonnes in 2003, 933 000 tonnes in 2004 and 789 000 tonnes in 2005.

4.2.4 Observations on existing principles and criteria for sustainable fisheries

To date, the criteria used by fisheries biologists, fisheries economists and fishery policy-makers to determine the sustainability of specific reduction fisheries have been mainly based on variations in reported landings, stock biomass (usually on a traditional single species basis), fishing capacity and effort, and on the existence and implementation of adequate fisheries management regimes to ensure that the landings of the target species are kept within agreed safe biological limits (Yndestad and Stene, 2002; SEAFEEDS, 2003; Bjørndal *et al*., 2004).

However, present sustainability criteria give little or no consideration to wider ecosystem implications such as trophic interactions; habitat destruction; and potential social, economic and environmental benefits and risks (Parsons, 2005). Clearly, it follows from the above discussion that if wider ecosystem and socio-economic factors are to be incorporated into revised and broader ecologically based sustainability assessments of reduction fisheries, then new revised definitions, principles and criteria will have to be developed (SEAFEEDS, 2003; Huntington, 2004; Huntington *et al.*, 2004; Lankester, 2005).

It is relevant to mention here that FAO has developed and published guidelines on an Ecosystem Approach to Fisheries (EAF) management (FAO, 2003) in support of the FAO *Code of Conduct for Responsible Fisheries* (CCRF) (FAO, 1995). These guidelines state that the purpose of an ecosystem approach to fisheries "is to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems". The guidelines define an EAF as follows: "An ecosystem approach to fisheries strives to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries".

FAO has also produced technical guidelines on indicators for sustainable development of marine capture fisheries (FAO, 1999) that outline the process to be followed at the national and regional levels to establish a Sustainable Development Reference

System (SDRS). The guidelines were produced in support of the CCRF and cover all dimensions of sustainability (ecological, economic, social and institutional), as well as the key aspects of the socio-economic environment in which fisheries operate.

In view of the above discussion and the international nature and non-static distribution of existing fish and shellfish stocks, it is recommended that principles and criteria for sustainable fisheries be based on those developed by the FAO (FAO, 1995, 1999, 2003) and that ecosystem impacts (including socio-economic and food security impacts) also address the issue of the intended use and destination of the fish or shellfish in question (FAO, 1998).

For example, Article 2.f of the FAO CCRF states one of the major objectives of the Code as being to "promote the contribution of fisheries to food security and food quality, giving priority to the nutritional needs of local communities". In particular, "States should encourage the use of fish for human consumption and promote consumption of fish whenever appropriate", and discourage the use of foodfish fit for human consumption for animal feeding (FAO, 1995, 1998; Tacon, Hasan and Subasinghe, 2006).

4.3 Sustainable use of available fishery resources

As mentioned previously, available capture fishery landings within the region have decreased by 6 percent since 1995 (Figure 1) and therefore capture fisheries landings have not kept pace with the population growth rate in the region, the total human population in the region growing at an average rate of 1.34 percent per year from 780.5 million people in 1995 to 879.7 million people in 2004 (FAO, 2006e). In marked contrast, aquaculture production within the region has been growing at 8.9 percent per year over the same period. Moreover, the region is unique in that over 47 percent of the total fishery catch is destined for reduction and non-food uses (FAO, 2006a).

Coupled with the prevalence of malnutrition and undernourishment within the Americas (see Section 2.2), legitimate concerns have been raised regarding the long-term sustainability and consequent availability of fishery resources within the region, and in particular concerning the reduction and use of potentially food-grade small-pelagic fish species for animal feeding (including for aquaculture production) rather than for direct human consumption (Goldburg and Naylor, 2005; Tacon, Hasan and Subasinghe, 2006).

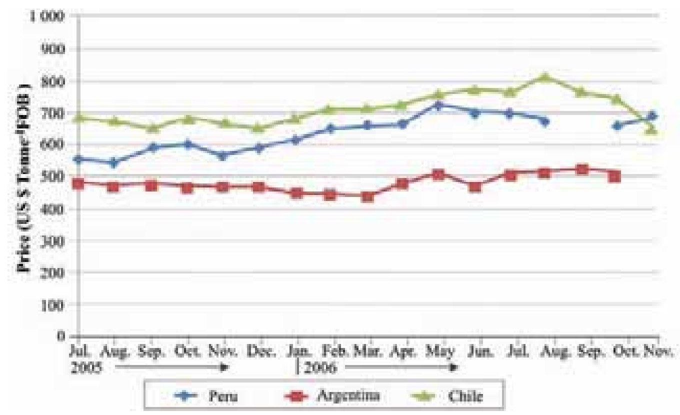
For example, in Chile an increasing proportion of the marine fish catch of traditional "forage" fish species is being processed for direct human consumption, exports for direct human consumption increasing by 816 percent, 497 percent and 2 880 percent from 1 209 tonnes in 2000 to 139 335 tonnes in 2005 in the case of the Chilean jack mackerel (*Trachurus symmetricus*), from 4 340 tonnes in 2000 to 25 902 tonnes in 2005 in the case of the Patagonian grenadier (*Macruronus magellanicus*), and from 226 tonnes in 2000 to 6 735 tonnes in 2005 in the case of the chub mackerel (*Scomber japonicus*), respectively (Jara, 2006).

Apart from food security issues, there are also growing ecosystem function concerns regarding the potential accumulation of environmental contaminants (which include persistent organic pollutants (POPs) and heavy metals) within wild fish stocks and the possible short-and long-term impacts of these contaminants on the reproduction and health of fish stocks and piscivorous wildlife, including birds and mammals (Ross, 2002; anon., 2003; Falandysz, 2003; Weber and Goerke, 2003; Hinck *et al.*, 2006; Letcher *et al.*, 2006; Shi *et al.*, 2006). It follows from the above that there is also a risk of contamination of aquaculture products from the use of contaminated fishmeals, fish oils and trash fish as feed inputs (SCAN, 2000; Herrmann, Collingro and Papke, 2004; Bell *et al.*, 2005; Foran *et al.*, 2005; Tacon, 2005; Dorea, 2006; Bethune *et al.*, 2006).

In general, the lowest contaminant levels have been observed in pelagic fish species, fishmeals, fish oils and farmed salmon originating from South America (i.e. Chile and

Peru), while the highest contaminant levels in the same groups (as above) originate from Europe (SCAN, 2000; Joas, Potrykuse and Chambers, 2001; Easton, Luszniak and Von der Geest, 2002; EC, 2002; Hites *et al*., 2004a, 2004b; Foran *et al*., 2005). Moreover, as a general rule since the majority of these contaminants are fat soluble and tend to bio-accumulate within fatty animal tissues, contaminant levels tend to be highest within longer-lived and more fatty pelagic fish species (anon., 2003; Korsager, 2004; Oterhals, 2004).

FIGURE 46
Comparative prices of fish oil used in salmon feeds in Chile, Peru and Argentina

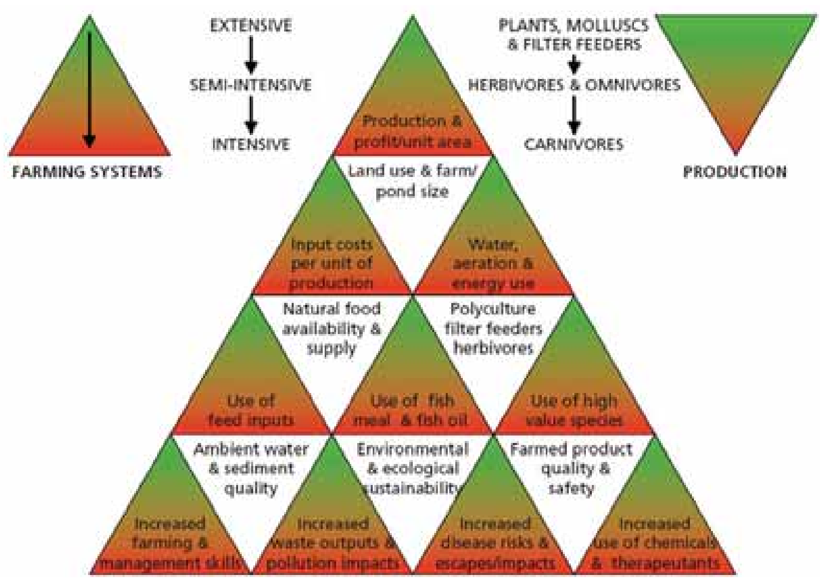


Source: anon (2007)

As a consequence of the natural accumulation of POPs within fish fatty tissues and fish oil (SCAN, 2000; Bell *et al.,* 2005) and the fact that aquaculture is already using over 82.2 percent of total global fish oil supplies (see Section 3.3), it is believed that dietary fish oil inclusion levels within aquafeeds will decrease in the long run as global supplies remain limited (Figure 24) and fish oil prices continue to rise (Figure 46), and by so doing ensure the continued growth of the fish oil-dependent marine/brackishwater aquaculture sector (Tacon, Hasan and Subasinghe, 2006).

A similar situation is expected with fishmeal, where rising prices (Figure 43) (Pescaaldia, 2007) and decreasing supplies (for various reasons, including the possible increased use of traditional forage fish species for direct human consumption) will force the aquaculture industry (for purely economic reasons) toward the increased use of more sustainable non-food grade feed resources as dietary fishmeal replacers, including the increased use of terrestrial agricultural animal and plant by-product meals.

FIGURE 47
Major differences between conventional extensive, semi-intensive and intensive farming systems in terms of production, resource use and potential/perceived environmental risks



Source: Adapted from Tacon, Phillips and Barg (1995)

5. ENVIRONMENTAL IMPACTS OF FISH-FED AQUACULTURE

Aquaculture feeds and feeding regimes play a major role in determining the environmental impact of semi-intensive and intensive finfish and crustacean farming operations (Tacon and Forster, 2003; Mente *et al*., 2006). This is particularly true for those intensive farming operations employing open aquaculture production systems, which include net cages/pen enclosures placed in rivers, estuaries or open waterbodies; and land-based flow-through tank, raceway or pond production systems (Black, 2001; Goldburg, Elliot and Naylor, 2001; Brooks, Mahnken and Nash, 2002; Lin and Yi, 2003; Piedrahita, 2003; Muñoz, 2006). This is perhaps not surprising, because the bulk of the dissolved and/or suspended inorganic and/or organic matter contained within the effluents of intensively managed open aquaculture production systems is derived from feed inputs, either directly in the form of the end-products of feed digestion and metabolism or from uneaten/wasted feed (Cho and Bureau, 2001), or indirectly through eutrophication and increased natural productivity (Tacon, Phillips and Barg, 1995).

It follows from the above that the rate of supply and assimilation of fish-fed aquaculture operations (includes the use of fishmeal, fish oil and/or trash fish-based feeds) will play a major role in dictating the nutrient and/or waste outputs from the aquaculture production facility. Moreover, it also follows that these outputs and their environmental impacts will, in turn, vary depending upon the farming system employed (open or closed farming systems), on-farm feed/nutrient and water management, and the assimilative capacity of the surrounding aquatic and terrestrial environment.

In general, the higher the intensity and scale of production, the greater the nutrient inputs required and consequent risk of potential negative environmental impacts through water use and effluent discharge (Figure 47).

For the purposes of this paper, the environmental impacts of fish-fed aquaculture operations can be viewed as follows:

5.1 Fishmeal and fish oil

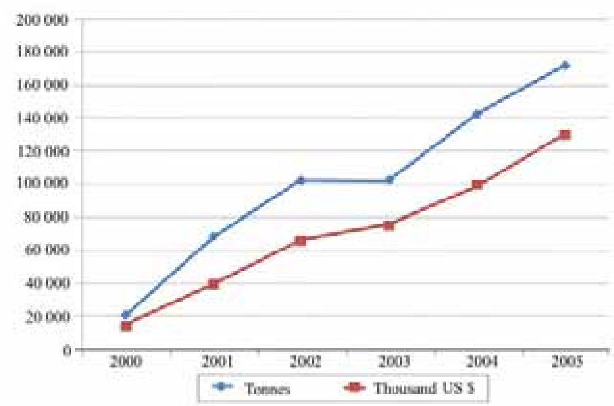
Direct environmental impacts include:

- increased environmental pollution resulting from the rapid growth and expansion of semi-intensive shrimp farming and intensive salmonid farming operations dependent upon the use of compound feeds containing fishmeal and fish oil as major dietary nutrient sources (Tacon, 2002, 2005);
- increased dependence of the aquaculture sector within the Americas upon marine capture fisheries for sourcing finfish and crustaceans for reduction into fishmeal and fish oil (Goldburg, Elliot and Naylor, 2001; Kristofersson and Anderson, 2006; Skewgar *et al*., 2007); and
- use of environmentally contaminated fishmeals and fish oils in aquafeeds, and consequent potential risk of transferring contaminants to the cultured species, the environment and the end consumer (Hites *et al*., 2004a, 2004b; Foran *et al*., 2005).

Indirect environmental impacts include:

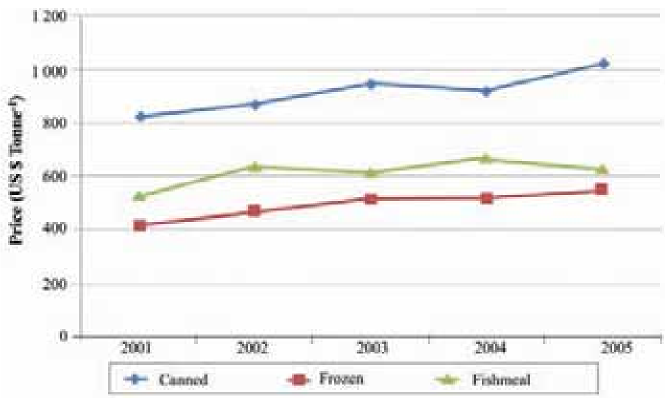
- removal of large quantities of forage fish species from the

FIGURE 48
Chilean exports of pelagic fish species for direct human consumption (tonnes and thousand US$)



Source: Jara (2006)

FIGURE 49
Chilean prices for major product lines



Source: SUBPESCA (2005)

marine ecosystem and potential ecosystem and biodiversity impacts upon other dependent piscivorous animal species, including other fish species, birds and mammals (Huntington *et al*., 2004; Worm *et al*., 2006; Skewgar *et al*., 2007).

5.2 Trash fish and baitfish

Direct environmental impacts include:

- increased environmental pollution resulting from the use of highly perishable and water-polluting trash fish-based feed items (Tacon *et al*., 1991; Ottolenghi *et al*., 2004);
- increased biosecurity and disease risks of feeding unpasteurized trash-fish products back to cultured fish and/or wild fish through bait use (Gill, 2000; SCAHAW, 2003; Hardy, 2004; anon., 2005);
- increased fishing pressure on wild juvenile target species for fattening and on pelagics for feeding/bait use (Dalton, 2004; Ida, 2006); and
- increased use of trash fish may also include the captured juveniles of higher-value commercial food-fish species and consequent risk of overfishing on available fish stocks (FAO, 2004).

Indirect social impacts include:

- increasing trash fish prices due to high demand for trash fish for use as aquaculture feed, which may place these fish out of the economic reach of the poor and needy for direct human consumption as an affordable food source (Edwards, Tuan and Allan, 2004).

5.3 Krill

Despite the fact that there are over 85 known species of krill (Nicol and Endo, 1997) and that total reported krill landings reached over 1 118 165 tonnes in 2004, only one krill species is currently reported, viz. Antarctic krill (*Euphausia superba*) (FAO, 2006a). In view of the important ecological role played by krill in marine food webs, it is imperative that all krill species be reported and quantified by fishers for transparency, traceability and the long-term sustainability of the krill fisheries sector (Nicol, 2006; Murphy *et al*., 2007). Removal of large quantities of krill from the marine ecosystem may have adverse long-term ecosystem impacts on dependent species, and in particular for many protected marine mammals and birds (Reid and Croxall, 2001; Hill *et al*., 2006).

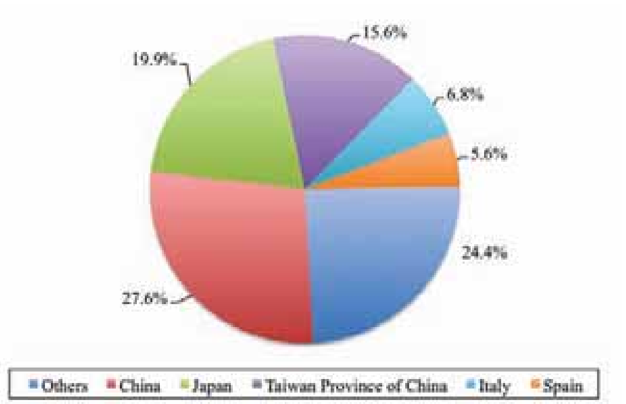
6. POTENTIAL ALTERNATIVE USES OF FEED-FISH SPECIES

6.1 Increased use of traditional feed-fish species for direct human consumption

6.1.1 Frozen and preserved products

As mentioned previously, an increasing portion of the catch of Chilean jack mackerel and other pelagics (e.g. Patagonian grenadier and chub mackerel) is being processed for direct human consumption (Figure 48). Despite the fact that the average price for frozen jack mackerel and fishmeal is very similar (Figure 49), the reported fishmeal and fish oil yield from jack mackerel is about 23 and 5–7 percent, respectively, in contrast to 70–75 percent for frozen fish (Wray, 2001). Clearly, under these circumstances selling the fish for direct human consumption may be more profitable than reduction. The major export markets for Chilean jack mackerel are China, Japan and Taiwan POC (fishmeal) (Figure 50), Nigeria, Cuba and Peru (frozen products) (Figure 51), and Sri Lanka, Japan and Taiwan POC (preserved products) (Figure 52).

FIGURE 50
Principal export markets for Chilean jack mackerel fishmeal, 2004



Source: SUBPESCA (2005)

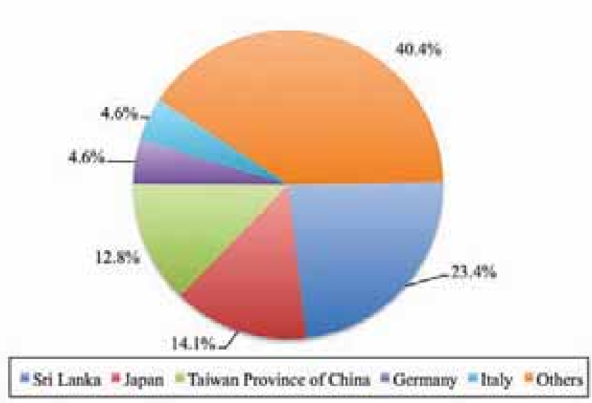
The trend toward increased direct human consumption of traditional feed-fish species (including the use of refined fish oil for direct consumption) is expected to continue in the long term as fish prices continue to rise (Figures 46 and 49) (Normile, 2002); national governments such as Chile (SERNAC, 2007) and Peru (Chquin, 2006) actively encourage the direct consumption of potential food-grade pelagic fish species; and fish harvesting, processing and stabilization methods improve (Bechtel, 2003; Gelman *et al.*, 2003).

FIGURE 51
Principal export markets for frozen Chilean jack mackerel, 2004

Source: SUBPESCA (2005)

Similarly, in the case of Peru, the growth of the portion of the anchoveta harvest destined for direct human consumption has increased markedly since 2000 (Figure 53). Although the portion destined for human consumption is still small (27 065 tonnes or 0.32 percent of the total anchoveta catch in 2005), it is significantly higher in comparison to the 0.01 percent used over the period 1991–1995, the 0.06 percent used over the period 1996–2000 and the 0.19 percent used over the period 2001–2004 (Flores, 2006).

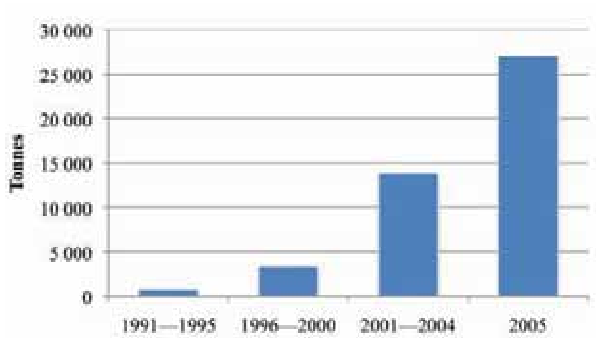
FIGURE 52
Principal export markets for preserved Chilean jack mackerel, 2004



Source: SUBPESCA (2005)

It is frequently stated that there is no cultural tradition for consumption of anchoveta in Peru (RPP, 2006; anon., 2007), and that it is for this reason that the bulk of the anchoveta catch is reduced to fishmeal for export and foreign cash earnings. However, this is not the case, as the earliest known civilization in the Americas, the "Caral civilization" (a thriving metropolis as Egypt's great pyramids were being built, located in the Supe Valley near the coast of central Peru, which flourished

FIGURE 53
Increase in the use of Peruvian anchoveta catch for direct human consumption in Peru



Source: Flores (2006)

for about five centuries starting about 2600 B.C.) relied largely on fish and shellfish, including anchoveta and sardines, as their main source of protein (Fountain, 2001). Sadly, the Caral civilization ended around 1600 B.C., and with it, the "cultural tradition" of consuming fish and shellfish (anon., 2002).

Although apparent fish consumption in Peru is 19.2 kg per caput (2001–2003 average) and is above the global average of 16.4 kg per year (FAO, 2006d), it should be noted that Peru has the second largest capture fisheries landings in the world (9.6 million tonnes in 2004) (FAO, 2006a) and currently utilizes 87.8 percent of this harvest for reduction and other non-food uses, primarily for export as a relatively cheap source of feed-grade animal protein and lipid. In a country where about half of the population is living below the national poverty line (over half of rural Peruvians, who make up 15 percent of the population, are considered extremely poor, that is, living on less than US$1 a day) (see World Bank Peru Country Brief on http://web.worldbank.org), anchoveta represents an invaluable source of much needed high-quality marine animal protein and a rich source of vitamins A and D, iodine and omega-3 polyunsaturated fatty acids.

However, the introduction of closed fishing seasons, fishing quotas and stricter environmental controls within the major fishing nations and fisheries in South America (Jackson, 2006) has resulted in renewed efforts to process more of the traditional feed-fish catch for direct human consumption in a bid to improve profitability (Wray, 2001). In the past (during the twentieth century), the problem usually associated with the direct utilization of anchoveta and other small oily pelagic fish species has been related to their rapid deterioration in quality on prolonged storage and the difficulties of processing large volumes of fish over a relatively short period of time (Hansen, 1996; Park and Lanier, 2000; Gelman *et al*., 2003). However, recent advances in fishing methods and fish processing technology (Bechtel, 2003) are now such that a wide variety of different food products has been successfully developed from anchoveta and other small pelagic fish species.

Apart from improvements in fish freezing and chilling methods (Hansen, 1996; Careche, Garcia and Borderias, 2002), one of the important advances in fish processing has been the development of stabilized surimi products (Bertullo *et al*., 2004; Tabilo-Munizaga and Barbosa-Canovas, 2004; Bentis, Zotos and Petridis, 2005; Park, 2005; Kaba, 2006); surimi is stabilized myofibrils from muscle, or more simply put, mechanically deboned fish flesh that has been washed with water and then stabilized (after dewatering) by blending with cryoprotectants (low molecular weight carbohydrates such as sucrose or sorbitol) to ensure a good shelf-life and protein functionality (gelling, texture) during prolonged storage or freezing (Park and Lanier, 2000, Kaba, 2006).

Other food products that have been successfully prepared from anchoveta and other small oily pelagic fish species include frankfurters, fish balls, fish chips, fish nuggets, fish fillets, fish sausages, noodles and ravioli products produced from surimi/minced fish (Gelman *et al*., 2003); canned anchovy marinates (Cabrer, Casales and Yeannes, 2002; Sen and Temelli, 2003; Diei-Ouadi, 2005; Sanchez-Monsalvez *et al*., 2005); fermented and powdered anchovy seasoning products (Jo, Oh and Choi, 1999); edible quality refined fish oils (Crowther, Booth and Blackwell, 2002); anchovy protein hydrolysates and oils (Wang *et al*., 1996); dried anchovies (Anthonysamy, 2005); menhaden roe (Smith and Ahrenholz, 2000); smoked/cured fish products (Hansen, 1996); and dry-salted products, fish biscuits and extruded fish balls (dried) made from food-grade fishmeal and cereals (Instituto Tecnologico Pesquero del Peru (ITP): Investigacion y Desarrollo de Productos Pesqueros – Fichas Tecnicas (www.itp.org.pe)).

6.2 Increased use of fishery wastes and bycatch for direct human consumption

In addition to the use of traditional landed fish catches, the fishing industry also generates wastes, and a considerable portion of the bycatch is discarded that could be processed for direct human consumption. For example, according to Kelleher (2005) it is estimated that about 8 percent of the world's marine fisheries catch is discarded, with yearly average discards estimated to be 7.3 million tonnes.

Harrington, Myers and Rosenberg (2005) estimated that 1.06 million tonnes of fish were discarded and 3.7 million tonnes of fish were landed in the marine fisheries of the United States of America in 2002. Similarly, within the State of Alaska (which accounts for over 51 percent of the nation's fish catch), average fisheries production is about 2.5 million tonnes (Low, 2003), of which over half consists of processing wastes (Crapo and Bechtel, 2003). According to recent estimates for 2005, the total fisheries harvest in Alaska was 2 447 995 tonnes, of which 1 309 212 tonnes or 53.5 percent were fishery by-products, including heads (384 468 tonnes: 62.5 percent Alaskan pollock, 19.1 percent salmon, 10.5 percent Pacific cod, 5.8 percent flatfish, 2.9 percent Atka mackerel), viscera (423 818 tonnes: 70.1 percent Alaskan pollock, 8.7 percent salmon, 10.1 percent Pacific cod, 3.7 percent flatfish, 2.9 percent yellowfin sole), frames (385 260 tonnes: 80.8 percent Alaskan pollock, 10.5 percent Pacific cod, 5.8 percent flatfish) and skin (107 327 tonnes: 79.1 percent Alaskan pollock, 12.6 percent Pacific cod, 8.3 percent flatfish) (P.J. Bechtel, Agricultural Research Service, United States Department of Agriculture, University of Alaska, Fairbanks, USA, personal communication, 2007). At present, the bulk of these by-products is destined for reduction into fishmeal and fish oil and in 2005, Alaska produced some 84 579 tonnes of fishmeal and 21 916 tonnes of fish oil (P.J. Bechtel, Agricultural Research Service, United States Department of Agriculture, University of Alaska, Fairbanks, USA, personal communication, 2007).

Although scant information exists concerning the size of the fishery waste stream and bycatch in the Americas or concerning possible ecosystem impacts resulting from their use and/or removal, it is believed that these products hold particular promise for surimi and fish oil production.

7. FEED-FISH ISSUES OF REGIONAL IMPORTANCE

7.1 Issues of regional importance

The following are the major feed-fish issues of regional importance:

- The region is home to three of the top four capture fisheries countries in the world (after China, with 17.3 million tonnes in 2004), namely Peru (9.6 million tonnes), Chile (5.3 million tonnes) and the United States of America (5.0 million tonnes).
- A very high proportion of the fish catch within the region (e.g. Chile, 76.4 percent; Peru, 87.8 percent) is destined for reduction and non-food uses (average of 47.2 percent).
- According to the FAO, the abundance of the three most important pelagic species contributing to the region's reduction fisheries (anchoveta, pilchard and jack mackerel) has generally declined in the southeast Pacific.
- To date, no reduction fisheries within the region have been certified by the Marinc Stewardship Council (MSC).
- There is a lack of internationally agreed criteria for monitoring ecosystem impacts of reduction fisheries within the region, including fishery sustainability criteria.

- Per capita fish supply within the region is generally low compared with other regions of the world and in particular, in Honduras (1.1 kg), Bolivia (1.9 kg), Guatemala (2.0 kg), Nicaragua (4.3 kg), Ecuador (4.7 kg), El Salvador (5.0 kg), Colombia (5.3 kg), Costa Rica (5.7 kg) and Brazil (6.4 kg per year) (2001–2003 global average of 16.4 kg per year).
- Although total capture fisheries production within the region in 2004 was over 12 times higher than aquaculture production, capture fisheries production has declined by 6 percent since 1995 compared with aquaculture production within the region, which has grown at an average rate of 8.9 percent per year since 1995.
- According to fishing industry sources, the region produced 57.3 percent of the total estimated global fishmeal and about 57.1 percent of the total global fish oil in 2005.
- According to the FAO, about 70 percent of the total fishmeal production and 35 percent of the total fish oil production within the region were not reported at the species level in 2004.
- In 2005, the region contributed 68.5 percent of total world fishmeal exports and 55.1 percent of total world fish oil exports, primarily to Asia and Europe, respectively.
- The domestic aquaculture sector within the region used 469 500 tonnes of fishmeal (13.3 percent of total fishmeal production within the region) and 237 910 tonnes of fish oil (35.1 percent of total fish oil production within the region) in 2004.
- The largest consumers of fishmeal and fish oil within the region are salmonids and marine shrimp, these species accounting for 89.4 percent of the total fishmeal and 96.1 percent of the total fish oil consumed by the aquaculture sector within the region in 2004.
- Projections concerning future market availability and price of fishmeal and fish oil within the region are that supplies will remain tight and prices high.
- There is a need to reduce the dependence of the aquaculture sector upon fishmeal and fish oil through the use of alternative locally available feed ingredients whose production can keep pace with the growth and specific requirements of the aquaculture sector within the region.
- The use of low-value whole feed-fish species (trash fish) by the aquaculture sector within the region is relatively small and is currently restricted to the on-growing and fattening of tuna in Mexico with locally caught sardines (*Sardinops sagax*); total consumption in 2006 was estimated at about 70 000 tonnes.
- The use of feed-fish as baitfish for commercial and recreational fisheries within the region (primarily by the United States of America and Canada) is believed to be greater than that used by the aquaculture sector within the region and is conservatively estimated to be about 100 000 tonnes.
- An increasing portion of the marine fish catch is likely to be processed for direct human consumption within the region, primarily in the form of easy-to-use and affordable processed fish products, including canned marinates and stabilized surimi-based fish products.

7.2 Organizations and institutions in the region engaged in related issues

A list of the regional and national organizations and institutions engaged in fisheries and aquaculture-related activities within the region has been compiled by FAO (for further information, go to www.fao.org/fi/library/links/htm).

7.3 Overview of strategies to address regional issues

Three main strategic approaches are recommended:

- **Strategic approach 1** is to decrease the overall proportion of the marine fish catch destined for reduction and non-food uses through the increased use of traditional forage fish species for direct human consumption:
  - o country/species focus: Peru – anchoveta, Chile – jack mackerel, United States of America – menhaden
  - o processing focus: canned marinated products and boneless minced meat products
  - o product focus: easy-to-store and ready-to-eat fish products
  - o target group focus: children, rural and urban communities
  - o nutrition focus: under-nutrition, brain food, vitamins A and D, iodine, omega-3 fatty acids
  - o methodology: product development and education/media promotion, school meals
- **Strategic approach 2** is to reduce the dependency of the resident aquaculture sector within the region upon the use of fishmeal and fish oil through the development and increased use of cost-effective locally available agricultural feed resources:
  - o species/country focus: salmon – Chile and Canada; shrimp – Ecuador and Colombia
  - o farming focus: salmon – net-cages; shrimp – ponds with zero-exchange
  - o ingredient focus: rendered products, plant proteins, single cell protein (SCP), plant oils and marine polychaetes
  - o methodology: laboratory and pilot-scale diet testing to market size and economic evaluation
- **Strategic approach 3** is to reduce the dependency of the commercial and sports/recreational fisheries sector within the region upon the use of marine fish bait species through the development and use of farmed fish bait species and artificially prepared fish baits using fish processing wastes:
  - o species/country focus: lobster – the United States of America and Canada; Tuna – Mexico and the United States of America
  - o bait focus: farmed freshwater fish and milkfish; fish sausages/attractant combinations
  - o methodology: laboratory/field testing of fish baits and economic evaluation with target species

8. SUMMARY OF MAJOR FINDINGS AND RECOMMENDATIONS

8.1 Summary of major findings

The following are the study's major findings:

- Capture fisheries production within the region was 26.25 million tonnes in 2004, representing 27.2 percent of total global capture fisheries landings. The region is home to three of the top four countries in the world in terms of capture fisheries landings, after China (17.3 million tonnes in 2004), namely Peru (9.6 million tonnes), Chile (5.3 million tonnes) and the United States of America (5.0 million tonnes).
- Commercial aquaculture production within the region is of recent origin, totalling 2.1 million tonnes (or one-twelfth of capture fisheries production and 3.5 percent of total global aquaculture production by weight in 2004), in 2004 the major country producers being Chile (695 000 tonnes or 33.2 percent of total regional production), the United States of America (606 000 tonnes or 29.0 percent of total regional production), Brazil (270 000 tonnes or 12.9 percent of total

regional production) and Canada (145 000 tonnes or 6.9 percent of total regional production).

- In marked contrast to capture fisheries production that has declined by 6 percent since 1995, aquaculture production within the region has grown over two-fold from 968 000 tonnes in 1995 to 2 093 000 tonnes in 2004, at an average compound rate of 8.9 percent per year.
- At present, over 9.9 million tonnes or 47.2 percent of the total fishery catch within the region is destined for reduction and non-food uses (global average 36.6 percent), with values ranging from as little as less than 1 percent (Argentina, Colombia, Cuba, El Salvador, Guatemala, Honduras, Nicaragua, Bolivarian Republic of Venezuela), 6.8 percent (Costa Rica), 9.0 percent (Brazil), 17.2 percent (Canada), 18.9 percent (Mexico), 21.9 percent (the United States of America), 25.0 percent (Ecuador), to as high as 76.4 percent (Chile) and 87.8 percent (Peru).
- Small pelagic fish species form the bulk of capture fisheries landings destined for reduction, with anchovies, herrings, pilchards, sprats, sardines and menhaden totalling 13.19 million tonnes or 50.2 percent of the total reported capture fisheries landings (26.25 million tonnes in 2004), followed by miscellaneous pelagic fishes (2.68 million tonnes, including mackerels and capelin), and squids, cuttlefishes and octopuses (0.78 million tonnes).
- From 1995 to 2004, total fishmeal and fish oil production within the region fluctuated between 2.0 and 3.7 million tonnes (mean of 3.3 million tonnes) and from 0.37 to 0.90 million tonnes (mean of 0.68 million tonnes), respectively. The only significant production trend over this period was the dramatic effect of the El Niño Southern Oscillation event on landings of Peruvian anchovy (and consequently fishmeal and fish oil production in Peru), with global fishmeal and fish oil production decreasing by 41.8 percent and 47.9 percent, respectively, from one year to the next after the 1997–1998 El Niño.
- According to the latest fishing industry estimates, the region produced 3.37 million tonnes of fishmeal and 0.55 million tonnes of fish oil in 2005, or 57.3 percent and 57.1 percent of the total reported global fishmeal and fish oil production for that year, respectively.
- Globally, the region contributed 68.5 percent of total world fishmeal exports and 55.1 percent of total world fish oil exports in 2005, primarily to Asia and Europe, respectively.
- In 2004, the domestic aquaculture sector within the region used 469 500 tonnes of fishmeal (13.3 percent of total fishmeal production within the region) and 237 910 tonnes of fish oil (35.1 percent of total fish oil production within the region), the largest consumers being salmonids and marine shrimp, which accounted for 89.4 percent and 96.1 percent of the total fishmeal and fish oil consumed by the aquaculture sector within the region.
- The use of low-value whole feed-fish species (trash fish) by the aquaculture sector within the region is small and is currently restricted to the on-growing and fattening of tuna in Mexico using locally caught sardines (*Sardinops sagax*); total consumption in 2006 was estimated at about 70 000 tonnes.
- The quantity of fresh or frozen feedfish that is used as baitfish for commercial and recreational fisheries within the region (primarily the United States of America and Canada) is believed to be greater than that used by the aquaculture sector within the region and is conservatively estimated to be about 100 000 tonnes per annum.
- It is anticipated that an ever-increasing portion of the marine fish catch will be processed for direct human consumption within the region, primarily in the form of easy-to-use and ready-to-eat affordable processed fish products such as canned marinates and stabilized surimi-based fish products.

8.2 Recommendations

In line with the FAO *Code of Conduct for Responsible Fisheries* (CCRF) (FAO, 1995), which states that "States should encourage the use of fish for human consumption", it is recommended that:

- the aquaculture sector reduce its dependence upon fishmeal and fish oil through the use of alternative locally available feed ingredients, the production of which can keep pace with the growth and specific requirements of the aquaculture sector;
- governments within the region promote the use of the existing feed-grade waste streams within the fisheries sector, including discarded fisheries bycatch and fishery processing wastes, as feed in aquaculture;
- governments within the region encorage/promote the use of traditional forage fish species for direct human consumption; and
- both commercial fisheries and sports/recreational fisheries be encouraged to replace food-grade marine fish-bait species by farmed fish-bait species and/or artificial fish baits developed from feed-grade fish processing waste.

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Use of wild fish and other aquatic organisms as feed in aquaculture – a review of practices and implications in Europe[1]

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[1] The geographic scope of this report is Europe, with a particular focus on Denmark, Iceland, Norway, Spain, Russian Federation, United Kingdom, Faeroe Islands, Sweden, France, Germany, Greenland,Ireland, Italy, Netherlands, Poland, Portugal and Ukraine.

SUMMARY

The intensive production of mainly carnivorous species in Europe uses fish feeds with a high content of fishmeal and fish oil, currently consuming around 615 000 tonnes of fishmeal and 317 000 tonnes of fish oils per year, thus requiring around 1.9 million tonnes of feedfish. While the capture and processing of feedfish provides only a small contribution to European fisheries-related employment (0.5 percent) and value added (2.8 percent), they help support an important aquaculture industry that has been dependent upon regional fishmeal and fish oil production to sustain its growth. With a conservatively estimated rise of European aquaculture production of 2 percent per year, fishmeal and fish oil use are likely to rise to 629 000 tonnes and 343 000 tonnes, respectively, by 2015, despite the greater use of vegetable-based substitutes and the greater efficiencies in feeding and nutrition.

The main sources of these feedfish are the small pelagic stocks of northern Europe, the Peruvian anchovy and jack mackerel of South America, and the fishmeal produced from trimmings and the bycatch of food fisheries. Due to the small size and low age of these feedfish, the stocks are difficult to manage on a multi-annual basis like many stocks in Europe. While their high fecundity allows stocks to recover from depletion fairly rapidly, there is concern over the impact of fishing pressure on predator-prey relationships in already stressed ecosystems.

Although quality and price are the main determinants for fishmeal purchasers in the aquafeeds industry, the sustainability of feed-fish sources is beginning to become more important. As yet there is no fully independent comprehensive analytical framework that integrates target stock assessment with the wider ecosystem linkages. To a degree this exists with the development of ecosystem models and approaches such as the Marine Stewardship Council (MSC) criteria for “responsible fishing”. Once such a framework has been created and is accepted as a suitable benchmark by the aquafeed industry and its detractors, then it will be easier for purchasers to purchase only from sustainable feed-fish stocks. This process will inevitably have consequences, such as greater pressure on those stocks deemed as sustainable, as well as possible effects on market economics.

The various feed fisheries targeted for fishmeal in Europe have little alternative uses. However some fisheries such as blue whiting, capelin, anchovy, herring and sprat, can be used for direct human consumption. The portion that goes for human consumption is not determined by technical limitations but depends largely on economic and cultural factors, which are more difficult for the industry to address directly. Despite the relatively low cost of products originating from small pelagic fisheries, they are not considered to contribute significantly to ensuring the food security of any part of Europe, due to the ready availability of other nutritional options.

This report concludes with a number of issues that are considered to be of particular regional significance. These, together with the recommendations, are summarized briefly below:

- Improved management of European feed fisheries is needed through a combination of greater political will and the gradual adoption of the ecosystem approach as implementation mechanisms evolve.
- Technical and other assistance to feed fisheries outside European waters, in particular to South American and Antarctic resources, should be provided through greater cooperation and the strengthening of relevant regional fisheries management organizations.
- Barriers to the sourcing and use of sustainable fishmeal and fish oils should be addressed by (i) adopting well-structured feed-fish fisheries sustainability criteria to guide buyers; (ii) improving traceability of materials, especially if blended during manufacture or distribution; (iii) encouraging sustainable purchasing

strategies through the use of formal environmental management systems; and (iv) premium branding of aquafeeds and aquaculture products produced using sustainable raw materials.

- Markets for European feedfish and their by-products in Eastern Europe and the Far East should be investigated. These markets currently absorb between 60 000–100 000 tonnes of Icelandic capelin per year (60–85 percent of the total), which might be increased.
- Food products for direct human consumption should be developed from species that are currently reduced to fishmeal and fish oil. These products should be economically competitive, appeal to European and export markets and be resistant to the cyclical nature of fishmeal and fish oil commodity pricing.
- Further development of plant-based substitutes for fishmeal and fish oil inclusion in aquafeeds is needed. These substitutes must be able to provide cost-effective alternatives to fish-based products, be acceptable to consumers and not raise sustainability issues in their own right. Much of the required research has already been completed to effect significant levels of substitution, but various commercial and consumer issues also need to be addressed.

1.INTRODUCTION[2]

1.1 Background

The fishmeal and fish oil industry started in northern Europe at the beginning of the twentieth century. Initially based mainly on surplus catches of herring from seasonal coastal fisheries, this was essentially an oil production activity, with fish oil finding industrial uses in the lubrication of machinery, leather tanning, and in the production of soap, glycerol and other non-food products. The residue was originally used as fertilizer, but since the turn of the twentieth century it has been dried and ground into fishmeal for animal feed. The fishmeal and fish oil sector has now developed into a major supplier of raw material for animal and fish feeds.

The demand for aquafeeds continues to increase, yet the overall global supply of fishmeal and fish oil is relatively fixed (SEAFeeds, 2003). This implies that there will be increased pressure on the fisheries that supply these commodities unless alternatives become both available and acceptable. While there is no real reason why feed fisheries should not continue to supply the aquaculture industry in the future, adequate sustainability assurances need to be in place.

2. OVERVIEW OF AQUACULTURE SYSTEMS AND PRACTICES IN EUROPE

This section looks at the nature of aquaculture in Europe, examines the past trends in production and then attempts to forecast where the industry will be in the next decade.

2.1 Current status and trends

Aquaculture is the farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated (FAO, 2009)[3]. Although freshwater aquaculture has been practiced in Europe for many centuries, full-cycle aquaculture in brackishwaters and marine waters is a more recent phenomenon. Large-scale mariculture first started in the 1970s with the Atlantic salmon (*Salmo salar*), whose large eggs and simple juvenile nutrition permitted the straightforward production of fingerlings for on-growing. Over the same period, research was being conducted into the breeding and feeding of other marine species with smaller, pelagic eggs. This has now led to the widespread production of seabass and seabream in the Mediterranean Sea and increasing volumes of more temperate species such as Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), Atlantic halibut (*Hippoglossus hippoglossus*) and turbot (*Psetta maxima*), which are being produced as technological constraints are gradually overcome and their farming becomes economically viable.

An examination of salmonid (salmon and trout) production in Europe (Figure 1) shows that the production of Atlantic salmon still dominates European mariculture in terms of volume, although growth is slowing as a result of softening prices and competition from Chile. European salmon production is largely based around the deepwater bays (lochs and fjords) of western Scotland, Ireland, Faeroe Islands and Norway. Salmon farming is almost exclusively conducted in sea cages with good tidal flushing, with a trend for larger cage systems with deeper moorings increasingly offshore.

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[2] This review, which covers the period from 1995 to 2005, is essentially a desk study based on secondary sources of information and data derived from published literature and unpublished reports. Where possible, primary source data/information has also been collected through consultations with those associated with reduction fisheries and aquaculture practices in the region.

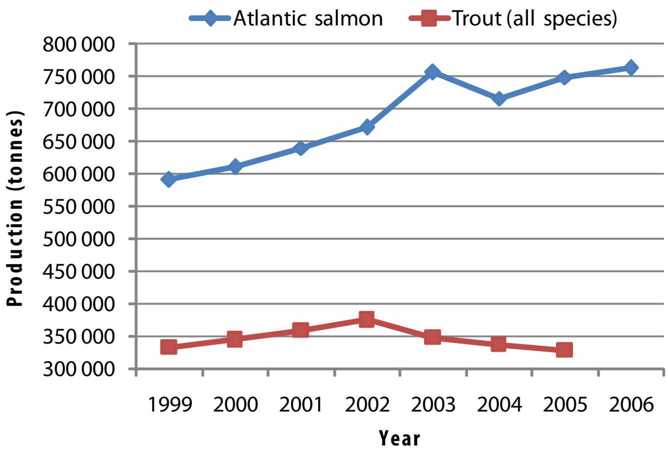
[3] FAO Glossary of aquaculture (accessed on 31 July 2009) (http://www.fao.org/fi/glossary/aquaculture/default.asp)

Seabass and seabream aquaculture has developed more recently and the production of both species groups has tripled over the last decade, reaching around 80 000 tonnes and 97 000 tonnes, respectively, in 2005 (Figures 2 and 4, Table 1). Based mainly in Greece, Turkey and Italy, seabass farming expanded rapidly in the late 1990s but has steadied since 2000. Seabream farming, principally of the gilthead seabream (*Sparus aurata*), also showed a brief plateau in the early 2000s but continues to increase, largely due to the rapid growth of Turkish production. Both species groups are mainly farmed in sea cages in sheltered areas, although land-based units are also used in France and Spain. Italy traditionally used the "vallicoltura"[4] system but has also moved towards intensive production in land-based operations and marine cage farms. Without tidal flushing, cage-farm units in the Mediterranean Sea tend to be smaller than salmon cage farms in the Atlantic.

The production of other marine fish such as turbot, halibut and cod is increasing steadily as technical constraints are overcome (Figures 2 and 4, Table 1). Turbot and Dover sole (*Solea solea*) are mostly produced in land-based farms on the Atlantic coasts of Spain and France, while cod, halibut and

FIGURE 1

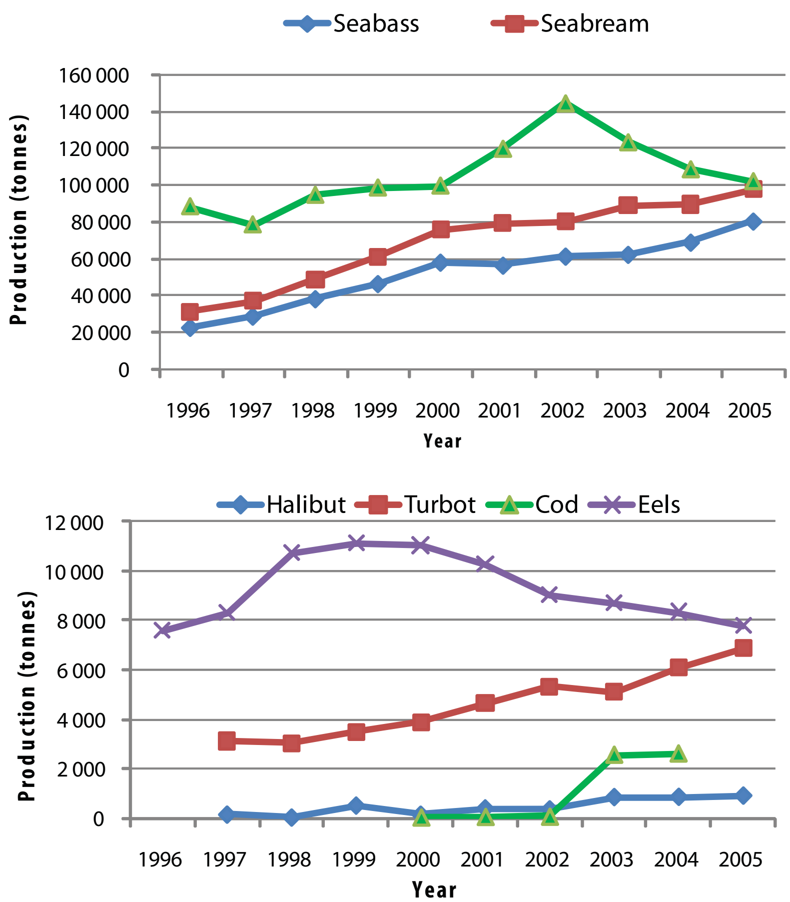
Atlantic salmon and trout production in Europe, 1999–2005



Source: www.feap.info/feap/aquaculturedata/default_en.asp

FIGURE 2

Marine finfish production in Europe, 1996–2005



Source: www.feap.info/feap/aquaculturedata/default_en.asp

[4] Traditional extensive lagoon-based fish culture

TABLE 1

Marine finfish production in Europe, 1996–2005 (tonnes)

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Seabass	22 334	28 433	37 939	46 157	57 811	56 162	61 093	62 060	68 679	80 161
Seabream	31 132	36 843	48 450	60 831	75 232	79 003	79 767	88 340	88 922	97 060
Salmon	403 284	452 702	502 361	591 068	610 947	640 777	671 655	756 744	717 831	712 271
Sea-grown trout	87 941	78 025	94 250	98 219	99 282	119 431	144 270	122 987	108 198	101 680
Halibut	–	138	20	503	135	389	350	845	855	905
Turbot	–	3 118	3 035	3 466	3 873	4 640	5 320	5 107	6 086	6 865
Cod	–	–	–	–	16	41	50	2 550	2 600	n/a
Eels	7 594	8 293	10 738	11 109	11 033	10 284	9 033	8 715	8 340	7 800
Total	**552 285**	**607 552**	**696 793**	**811 353**	**858 329**	**910 727**	**971 538**	**1 047 348**	**1 001 511**	**1 006 742**

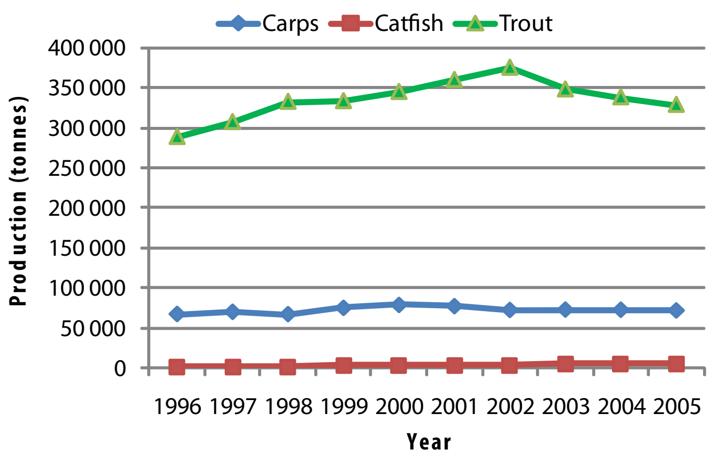
n/a: Data not available
Source: www.feap.info/feap/aquaculturedata/default_en.asp

haddock are farmed in cages in the colder waters of Norway, Iceland and the United Kingdom. Halibut juveniles are reared in land-based tanks until they are 30–40 g before they are stocked into sea cages. Unlike salmon, they prefer sheltered areas with little current movement.

In Europe, eel farms can be found in countries such as Sweden, the United Kingdom, the Netherlands, France, Spain, Denmark, Italy and Greece. Due to the complexity of their life cycle, no one has yet managed to successfully breed European eels (*Anguilla anguilla*). Instead, eel farms rely on using young eels returning from the Sargasso Sea to grow. Eel culture or farming involves catching juvenile (glass) eels when they enter freshwater and growing them to a marketable size. While 95 percent of eels are grown in freshwater, Italy, the United Kingdom, France and Germany culture eels in brackishwater (4.5 percent of production) and full seawater (0.5 percent). The three main techniques for culturing eels include the use of ponds, accelerated temperature facilities and recirculation systems.

The fattening of bluefin tuna (*Thunnus thynnus*) has expanded rapidly in the Mediterranean Sea over the last five years. The Mediterranean Sea farmed tuna production in 2004 was approximately 23 000 tonnes (FAO, 2005b), of which around 95 percent was exported to Japan, although the International Commission on Conservation of Atlantic Tuna (ICCAT) reports that there is currently cage capacity of around 41 000 tonnes (for a six-month growing period). This is mostly in Spain (29 percent), Turkey (23 percent), Croatia (16 percent), Malta (15 percent) and Italy (11 percent), with lower levels of production in Greece and Portugal.

FIGURE 3
Freshwater finfish production in Europe, 1996–2005



In freshwaters, two species groups predominate, trout and cyprinids (Figures 3 and 4, Table 2). Trout farming is carried out commercially in 23 European states, with annual production exceeding 60 000 tonnes in Norway and 35 000 tonnes in Denmark, Italy, France and Spain, while Finland, Germany, Poland and the United Kingdom each produce

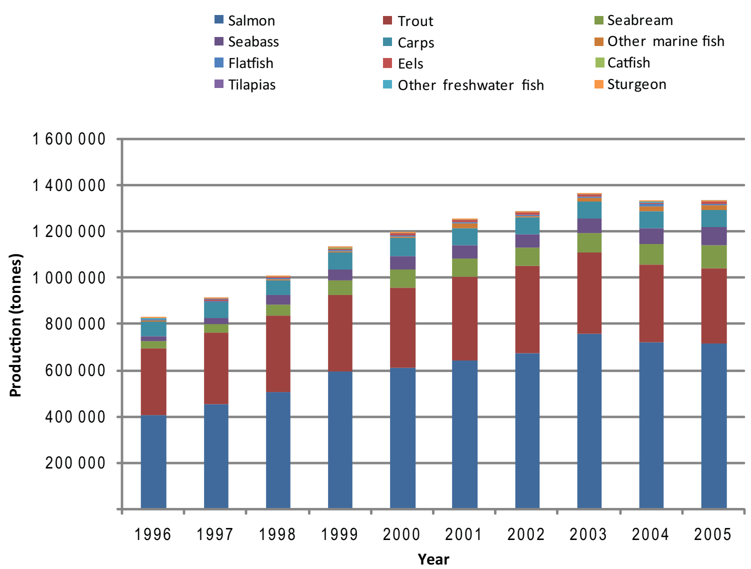
TABLE 2
Freshwater finfish production in Europe 1996–2005 (tonnes)

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Trout	288 483	307 316	332 616	333 473	344 969	360 035	375 346	348 137	338 258	328 816
Carps	67 494	70 343	67 300	75 329	79 300	77 664	72 743	73 265	73 039	72 090
Bighead carp	n/a	n/a	*450*	–	–	–	–	–	–	–
Silver carp	n/a	n/a	*2 062*	*3 648*	*3 379*	*3 195*	*2 580*	*2 777*	*3 747*	*3 950*
Common carp	n/a	n/a	*62 550*	*70 144*	*73 121*	*71 669*	*67 616*	*68 282*	*67 936*	*66 740*
Grass carp	n/a	n/a	*2 238*	*1 587*	*2 800*	*2 800*	*2 547*	*2 206*	*1 356*	*1 400*
Catfish	2 067	2 208	2 565	3 359	4 490	4 071	3 756	5 458	5 510	5 470
Tilapias	250	300	300	200	150	150	150	450	450	550
Other freshwater fish	453	568	546	619	595	420	496	528	481	495
Sturgeon	642	572	463	544	265	196	200	230	275	332
Total	**359 389**	**381 307**	**403 790**	**413 524**	**429 769**	**442 536**	**452 691**	**428 068**	**418 013**	**407 753**

n/a: Data not available.
Source: www.feap.info/feap/aquaculturedata/default_en.asp

between 10 000 and 25 000 tonnes. The main species is rainbow trout (*Oncorhynchus mykiss*), although there is limited production of brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*), and growing interest for arctic char (*Salvelinus alpinus*). European trout production has been in decline over the last three years, from a high of 375 000 tonnes in 2002 to 329 000 tonnes in 2005. During the same period, the value to trout farmers slipped from €2.26/kg to €2.03/kg for portion-size trout, while large trout rose in value from €2.40/kg to €2.50/kg. The overall first sale value fell from €805.2 million to around €700 million. With a few exceptions, trout production in Europe is poorly organized and is operated by a large number of small, independent farmers. This has led to a production-led rather than a market-led industry, with fragmented sales and decreasing returns to farmers.

FIGURE 4
Finfish aquaculture production in Europe, 1996–2005



Source: www.feap.info/feap/aquaculture/default_en.asp

Five cyprinid species share the European scene, being the common carp (*Cyprinus carpio*), the silver carp (*Hypophthalmichthys molitrix*), the bighead carp (*Aristichthys nobilis*), the grass carp (*Ctenopharyngodon idellus*) and the tench (*Tinca tinca*). Carp farming is mainly in extensive or semi-intensive pond-based systems, the latter being predominantly typical in Central and Eastern Europe. There is a big difference in the production characteristics of Western Europe and Central/Eastern Europe, the latter contributing 76 percent of European cyprinid production in 2005. The total European production dropped from 158 000 tonnes in 1988 to 72 000 tonnes in 2005, the biggest reductions being seen in the early 1990s and in the major production countries. Part of the reason for these circumstances was the social and economic change occurring in Central and Eastern Europe. However, there are only limited market opportunities available, particularly given the rising availability of other inexpensive food products.

2.2 Future outlook

Despite ongoing supply problems and rising prices, the consumption of fish and seafood is forecast to increase in all the major European markets. This is attributed to a number of factors, including the well-documented move towards healthy eating and lifestyles, the recent scares over meat safety, and the increased added-value opportunities for fish and fish products due to demographic and societal changes. Before looking at the outlook for aquaculture production, it is important to understand how demand for seafood might change due to changes in the European population, per capita demand for seafood, and the supply from capture fisheries.

2.2.1 Population growth in Europe

The population of the European Union (EU) is likely to fall significantly by 2050, even allowing for inward migration. Deaths will begin to outnumber births across the EU in the next five years, and a collapse in childbirth rates and increased emigration has already caused populations to start shrinking in several of the former communist countries of Eastern and Central Europe that joined the EU in 2004. Eurostat models suggest that by 2013 the population of Italy will start to fall, joined a year later by Germany and Slovenia and, in 2018, by Portugal. The population of Britain will continue to grow, peaking in 2040, followed by 10 years of gentle decline. Overall, the total population of the EU is expected to rise by more than 13 million between now and 2025, although after 2010 that increase will be entirely the result of immigration. By 2025, net migration will not be able to counteract the falling birth rates of the continent, and by 2050 the population of the EU will be 450 million, a decrease of more than 20 million people from the peak. The share of the population over the age of 65 will increase considerably in the EU – the old age dependency ratio (persons aged 65 years and over compared with persons 15–64 years-old) is expected to approximately double by 2050 from the initial 25 percent in 2004. There are rare exceptions: the populations of Ireland, Cyprus, Luxembourg, Malta and Sweden will continue to grow even after 2050.

2.2.2 Per capita food consumption

The per capita consumption of seafood in Western Europe has increased steadily over the last few decades and is set to rise further by 2030 (Ye, 1999), reaching around 36 kg/person/year (Table 3). Consumption in the Nordic countries, which is higher than elsewhere in Europe, is also likely to increase, but not as much as in Western Europe. In the ex-centrally planned economies (CPEs) of Eastern Europe,

TABLE 3
European per capita seafood consumption (historical and predicted)

Area/Year	Historical per capita fish consumption (kg/person/year)							Forecast		Increase 1995–2030	
	1965	1970	1975	1980	1985	1990	1995	2015	2030	%	kg
Western Europe	18.2	18.4	17.4	17.4	19.9	22.2	22.1	26.7	30.1	+36.2	+8
Nordic countries	27.9	30.8	31.7	32.4	32.5	34.0	35.6	38.8	41.7	+17.1	+6.1
Eastern Europe	16.1	20.2	24.3	22.3	25.1	20.6	10.7	25.4	30.8	+187.9	+20.1
Europe average	17.4	19.6	21.1	20.1	22.7	21.7	16.8	26.3	30.8	+83.3	+14.0

Source: Ye (1999)

consumption dropped dramatically over the 1990s but is expected to increase quickly to nearly 31 kg/person/year.

Per capita fish supply figures from the Food and Agriculture Organization (FAO) of the United Nations (Delgado *et al.*, 2002) for the period 1999–2001 indicate that the 15 EU countries have a per capita supply of 24.2 kg/year; the new EU states, 10.7 kg/year; other countries of Western Europe (The Faroe Islands, Iceland, Norway and Switzerland), 29.9 kg/year; and the countries of Eastern Europe, 3.1 kg/year. The areas of the former Union of the Soviet Socialist Republics (USSR) have a per capita supply of 16.9 kg/year.

TABLE 4
Predicted production from capture fisheries and aquaculture (million tonnes)

Year	2000	2004	2010	2015	2020	2030
Information source	FAO statistics*	FAOstatistics**	SOFIA 2004***	FAO study****	SOFIA 2004***	SOFIA 2004***
Capture fisheries	95	96	93	*105*	*93*	*93*
Marine capture	*86*	*87*	*87*		*87*	*87*
Inland capture	*9*	*9*	*6*		*6*	*6*
Aquaculture	36	45	53	74	70	83
Total production	**131**	**141**	**146**	**179**	**163**	**176**
Food fish production	96 (73%)		120 (82%)		138 (85%)	150 (85%)
Non-food use	35 (27%)		26 (18%)		26 (15%)	26 (15%)

Source: *FAO (2002); **FAO (2006a); ***FAO (2005c); ****Failler (2005)

2.2.3 Supply from capture fisheries and aquaculture

According to FAO, total global fish production (capture fisheries plus aquaculture) might increase from 131 million tonnes in 1999/2001 to 146 million tonnes in 2010 and then to 179 million tonnes by the year 2015 (Table 4). This means that growth in global fish production is projected to decline from the annual rate of 2.7 percent of the last decade to 2.1 percent per year between 1999/2001 and 2010 and to 1.6 percent per year between 2010 and 2015. Global capture production is projected to stagnate, while global aquaculture production is projected to increase substantially, albeit at a slower rate than in the past. Out of the expected increase of 48 million tonnes in total global fish production from 1999/2001 to 2015, 73 percent would come from aquaculture, which is projected to account for 39 percent of global fish production in 2015 (up from 27.5 percent in 1999/2001).

TABLE 5
Regional share of total food-fish production %, 1973–1997 (actual) and 2020 (projected)

Region	Actual annual production (%)			Projected (%)
	1973	1985	1997	2020
Europe (subtotal)	30	23	11	9
EU-15	13	9	6	5
Eastern Europe and former USSR	17	14	5	4
China	10	13	36	41
Other Asia	17	19	21	21
Latin America	5	6	7	7
West Asia and northern Africa	1	2	2	2
Sub-Saharan Africa	4	4	4	5
United States of America	4	6	5	4
Japan	17	14	6	4
Other	12	13	8	7
Total	**100**	**100**	**100**	**100**

Source: Delgado et al. (2002)

Within these global figures, the proportion of fisheries production from Europe is of particular interest. The International Food Policy Research Institute (IFPRI) has projected that the total European share of food-fish production will drop from 30 percent in 1973 to 9 percent in 2020 (Delgado *et al.*, 2002). Of this, the relative importance of capture fisheries production in the EU-15 Member States is projected to drop from 79 percent in 1997 to 71 percent in 2020 (Table 5).

2.2.4 Outlook for European aquaculture

Aquaculture is now a maturing industry in Europe, especially for the established species such as salmon and trout. Past sectoral growth has been driven by the development of breeding and grow-out technologies for new species and their adoption by the commercial sector. A brief look at Figure 4 shows the steady climb in production up until 2003 and the apparent plateau in production to date. This flattening in production reflects (i) a decline of around 45 000 tonnes of United Kingdom and Faroese salmon production and (ii) a similar decline in trout production since 2002. Other species, especially seabass and seabream, continue to expand as more eastern Mediterranean countries adopt the technology, and prices recover from a slump in 2002–2003.

Delgado *et al.* (2002) forecast that the pre-2004 accession EU Member States would see a growth rate approximating that of global output but this appears optimistic. Brugère and Ridler (2004) forecast that growth from 2000 to 2020 would be less than 1 percent for most of Western Europe, with the exception of Norway, which is committed to its aquaculture sector as a means of maintaining isolated communities (Table 6). While these figures must be used with some caution, they do emphasize that aquaculture expansion in Europe will not continue at historical rates.

TABLE 6
Historical and forecasted aquaculture output in Europe

Country	Historical output (tonnes)		Actual annual growth rates (%)		Forecast 2000–2020	
	2000	2004	1980–1990	1990–2000	Output 2020 (tonnes)	Annual growth (%) 2000–2020
Spain	315 321	363 181	0.4	3.8	361 017	0.7
France	261 216	243 907	2.0	0.8	307 497	0.8
Italy	213 054	117 786	7.1	3.5	279 363	1.0
United Kingdom	159 267	207 203	30.0	11.5	168 241	0.3
Europe-15	1 314 017	–	4.0	3.5	1 539 664	0.8
Norway	493 111	637 993	31.1	13.2	1 620 000	6.3
Europe	2 067 068	2 205 649	6.9	3.2	3 557 000*	4.8*

*author's estimate
Source: Brugère and Ridler (2004)

Based on a regression analysis of trends of growth in European aquaculture, this study has projected European aquaculture production in 2015 (Table 7 and Figure 5). Two scenarios are given, one (S1) based on trends over 1996–2005 and the second (S2) on trends over 2001–2005.

Both scenarios broadly agree on the species that show a constant trend since 1996 but differ where there has been a sharp up or down trend in production over the last five years. In particular, salmon and trout have both shown a slowdown over the last five years, and this is reflected in scenario 2 (S2). Based on this latter scenario, which is considered to be the most realistic, European aquaculture is likely to reach production of 1.57 million tonnes by 2015, an overall increase of 2 percent per year. This seems reasonably realistic, although it may be an underestimate if Norwegian production increases at a greater rate than the rest of Europe. Other studies are more optimistic than this study – an estimate based on Brugère and Ridler (2004) indicates an increase of 4.8 percent, mainly driven by an increase in Norwegian production.

TABLE 7
Past, current and predicted European aquaculture production (tonnes)

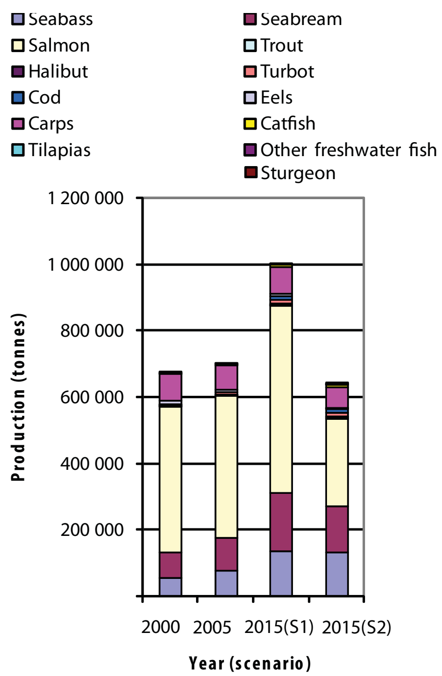
Species	2000	2005	2015			
			S1		S2	
	Tonnes	Tonnes	Tonnes	Increase**	Tonnes	Increase**
Seabass	57 811	80 161	136 968	171%	132 332	165%
Seabream	75 232	97 060	175 589	181%	140 941	145%
Salmon	610 947	712 271	1 149 081	161%	926 852	130%
Trout	444 251	430 496	567 256	132%	264 112	61%
Halibut	135	905	1 970	218%	2 513	278%
Turbot	3 873	6 865	11 349	165%	11 863	173%
Cod	16	2 600*	11 031	424%	14 032	540%
Eels	11 033	7 800	7 984	102%	2 041	26%
Carps	79 300	72 090	79 929	111%	60 738	84%
Catfish	4 490	5 470	9 957	182%	10 315	189%
Tilapias	150	550	677	123%	1 670	304%
Other freshwater fish	595	495	444	90%	646	131%
Sturgeon	265	332	-255	-77%	663	200%
Total	**1 288 098**	**1 417 095**	**2 151 979**	**152%**	**1 568 718**	**111%**

*2004 data ** Increase /decrease from 2005.
Source: Delgado *et al.* (2002)

Sustaining growth is a challenge, as there are a number of key constraints that may limit expansion of aquaculture. These are briefly reviewed below:

- *Environmental:* The major constraint to the expansion of aquaculture is the lack of suitable sites for new development and the need to ensure that existing sites are used in a sustainable manner. In many northern European countries, such as the United Kingdom and Denmark, gaining planning permission for both coastal and freshwater sites is increasingly difficult in a highly regulated environment. This has led to investigation into new cage technologies for deeper, more exposed sites, larger production units and improved diets with greater digestibility and less waste. There is also a trend towards less intensive farming techniques that are compatible with maintaining wetlands important for nature conservation at a favourable conservation status. Another emerging restraint is the need to use genetically benign species that will not impact on local fish populations if they escape.
- *Market*: Achievable ex-farm prices are critical to determining the economic viability of farming ventures and thus the uptake of evolving and often increasingly expensive aquaculture technology. It is important to understand the extrinsic factors that affect European aquaculture economics, such as competition from Chilean salmonid production. The

FIGURE 5
Past, current and predicted European aquaculture production (tonnes)



Source: Delgado *et al.* (2002)

markets for farmed fish have also been affected by persistent negative publicity over the safety of farmed fish, e.g. the possible health risks associated with high levels of persistent organic pollutants (POPs) in salmon cultivated in Europe (Hites *et al.*, 2004).

- *Raw material:* Allied to the last point above, variability in raw material costs and availability are increasingly important in dictating aquaculture viability. The main input is fish feed, especially for the high-protein diets that are required for over 95 percent of European finfish production. The demand for fishmeal and fish oils from developing economies such as China has a profound impact on feed prices as they operate within a commodity market. A shortage of fishmeal imports into the United Kingdom during 2003 and 2004 was one of the primary reasons for the dip in salmonid production over those years.
- *Implications for food security and poverty alleviation*: As discussed above, the demand for seafood products from Europe will remain strong, and with most capture fisheries reaching or exceeding their sustainable yield, aquaculture is expected to provide an increasing proportion of raw material for human consumption. However, when compared with developing regions, aquaculture in Europe does not make a strong contribution to food security or poverty alleviation. In terms of food security, the vast majority of aquaculture products (e.g. salmon, trout, seabass, seabream) are relatively high-value species that reflect the high cost of their high-protein dietary requirements and, therefore, cannot be considered as a "basic" food commodity[5]. Essentially, they are luxury items that compete with other similarly placed products in the market. It is possible that as aquaculture contributes a greater proportion of seafood products in Europe, the cost of production might fall to allow greater economic access to aquaculture products, but this is unlikely to contribute to improved food security on an individual basis. However, it might mean a reduced need to source fish products from outside of Europe and thus contribute to food security on a world level.

Regarding poverty alleviation, the intensive nature of European aquaculture means that there is only a minor contribution to improving the economic well-being of poor communities. Despite this, there is no doubt that aquaculture does have an important role to play in rural communities, both for remotely located intensive aquaculture (e.g. the highlands and islands of Scotland) and for the low yield, semi-extensive aquaculture practiced in places such as the Po River delta[6] in Italy. There are also upstream and downstream employment dependencies in feed fisheries and processing, respectively, with the latter providing opportunities to replace those lost as white fish processing contracts.

3. USE OF FISH AND OTHER AQUATIC SPECIES AS FEED FOR AQUACULTURE AND ANIMAL FEEDS IN EUROPE

In Europe, there are three main sources of marine-based raw material for aquaculture and animal feeds:

- feedfish caught in European waters for reduction into fishmeal;
- feedfish caught outside European waters for reduction into fishmeal; and
- trimmings, fish off-cuts, offal and landed bycatch for reduction into fishmeal.

The only direct use of whole, unprocessed fish for aquaculture (i.e. "trash fish") is

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5 "All people at all times have both physical and economic access to the basic food they need." (FAO Committee on World Food Security).

6 Valliculture (vallicoltura) was developed by the upper Adriatic populations to exploit the seasonal migrations of some fish species from the sea into the lagoon and delta areas, which were more suitable for their growth. Large brackish areas were enclosed to prevent the fish returning to the sea and complex permanent capture systems (fish barriers) were developed to catch the adults. Many such systems are now supported by artificial hatcheries.

in tuna fattening in the Mediterranean Sea. This section examines the nature and source of the raw materials used as well as the subsequent utilization of fishmeal and fish oils in Europe.

3.1 Landing of fish and other aquatic species destined for reduction

Fish destined for reduction into fishmeal and fish oil for use by the European aquaculture industry originate from either (i) the feed fisheries within European waters themselves or (ii) external fisheries, such as the anchovy and chub mackerel fisheries of South America or to a lesser extent, the Antarctic krill fisheries. The choice of where aquafeed compounders purchase their fishmeal depends largely upon the following:

- *Price*: Fishmeal is a global commodity whose price is interlinked with that of its main competitor, soybean meal. The level of substitution within fish feeds is limited, however, and varies between different dietary formulations (i.e. for starter, grower and finisher diets). Therefore, feed manufacturers can increase or decrease fishmeal incorporation levels within predefined limits.
- *Quality:* Quality is an important factor that also has an influence on price. The quality of fishmeal depends upon its freshness (measured by its volatile nitrogen content at conversion), the process used (e.g. processing temperature) and the stabilization techniques used.
- *Specification*: Fishmeal from North Atlantic stocks tends to be higher in protein content (68–71 percent) than southern hemisphere fishmeal (65–68 percent), reflecting the species used. Northern hemisphere fishmeal tends to have higher levels of digestibility – for instance, an Icelandic 71 percent protein meal from capelin/herring with a digestibility of 92 percent gives 65.2 percent digestible protein (DP) as against only 58.8 percent DP from the best Chilean sardine meal. Certain fishmeals (e.g. high performance feeds for some species/growth stages) might be selected to achieve a particular amino acid profile.
- *Contamination levels*: POPs accumulate in oily fish and have become a major food safety issue in Europe. Fishmeal sources from oceanic pelagic stocks in South America tend to have less POPs that those from the continental shelf stocks in the northeastern Atlantic. Although the resultant meals have to be within legal limits – and the technology exists to reduce them further through filtration – this may have an influence on purchasing.
- *Usability*: Individual feed producers' machinery characteristics can rule out the use of fishmeal from some origins.

There are no published figures on the proportion of fishmeal used for European aquaculture that is sourced from South America rather than from Europe's own feed-fish stocks. A recent report on the sustainability of feeds for the Scottish fish-farming industry (Huntington, 2004) suggests that around 54 percent of feed fish-derived fishmeal is currently derived from northern hemisphere sources, 28 percent from southern hemisphere sources and the balance from whitefish trimmings and pelagic offal (Table 8).

Table 8 examines the recent (2003) and predicted (2010) use of fishmeal and fish oil by Scottish aquaculture. These figures, which have been produced by the industry, indicate a number of interesting trends:

- A small (5 percent) increase is predicted in the southern hemisphere proportion of fishmeal by 2010.
- The relative contribution of trimmings and offal to fishmeal and fish oil production will remain around the same.
- Oilseed and legume-derived meals will increase from 17 percent to 24 percent of the total fishmeal protein source contribution, mostly at the expense of northern hemisphere fishmeal.

TABLE 8
Current and predicted fishmeal and fish oil utilization by Scottish aquaculture (tonnes)

A. Fishmeal and protein

Year	Whole fishmeal						Protein derivatives			
	Northern hemisphere		Southern hemisphere		Trimmings and offal		Oilseeds and legumes		Gluten	
2003	53 140	38%	27 600	20%	16 900	12%	24 400	17%	19 250	14%
2010	44 500	29%	30 100	19%	16 000	10%	38 000	24%	27 200	17%

B. Oils

Year	Fish oil						Vegetable oils	
	Northern hemisphere		Southern hemisphere		Trimmings and offal			
2003	41 200	65%	10 600	17%	11 000	17%	300	0.5%
2010	31 300	41%	13 000	17%	12 000	16%	20 000	26%

Source: J Nelson, Agricultural Industries Confederation (AIC), personal communication, 2004

- The relative contribution of southern hemisphere oil supplies will remain unchanged.
- Vegetable oils will become an important source of oils in Scottish aquafeeds, accounting for nearly a quarter of the total by 2010, again at the expense of northern hemisphere feed-fish supplies.

The main species used are primarily small pelagic species that are characterized by early maturation and high fecundity. Their populations respond quickly and strongly to changes in environmental conditions, which increases the uncertainty of stock forecasts, especially in eastern Pacific waters that are vulnerable to the “El Niño” effect.

The main species used for fishmeal reduction from European stocks are capelin, blue whiting and sand eel and lesser volumes of Norwegian pout (Figure 6). Landings of these species by the different European countries are shown in Table 9. In addition, the table shows data for a number of other species that are used for both feedfish and for direct human consumption. Peruvian anchovy and Chilean jack mackerel are both imported from South American sources for use in European fish feed, and Poland and Ukraine both use Antarctic krill as a fishmeal source.

3.1.1 European fish species reduced for fishmeal and fish oils

Blue whiting (Micromesistius poutassou): The blue whiting is a pelagic gadoid (i.e. of the cod family), which is widely distributed in the eastern North Atlantic. Its biology is reasonably well known, and a management plan has been formulated and accepted, with annual quotas set in December 2005. However, fishing mortality remains unacceptably high, far above sustainable rates; populations have only been sustained by recent good year classes, and the International Council for the Exploration of the Sea (ICES) currently considers this fishery to be harvested unsustainably. The dispute over catch allocation has led to the last quota of 650 000 tonnes set by the North East Atlantic Fisheries Commission being exceeded four-fold; fishers caught 2.3 millon tonnes in 2003. It should be argued that until the management plan is implemented and total allowable catches (TACs) fall within the agreed level, this species cannot be recommended as a component stock of fishmeal or fish oil. This issue with blue whiting is recognized by the fishmeal industry, which fully supports implementation of the proposed management plan, yet has relatively little influence in the progression of its adoption (A. Chamberlain, FIN, personal communication, 2006).

Capelin (Mallotus villosus): The capelin is a small pelagic species whose biology is reasonably well known. There are two main stocks in the Barents Sea and Iceland.

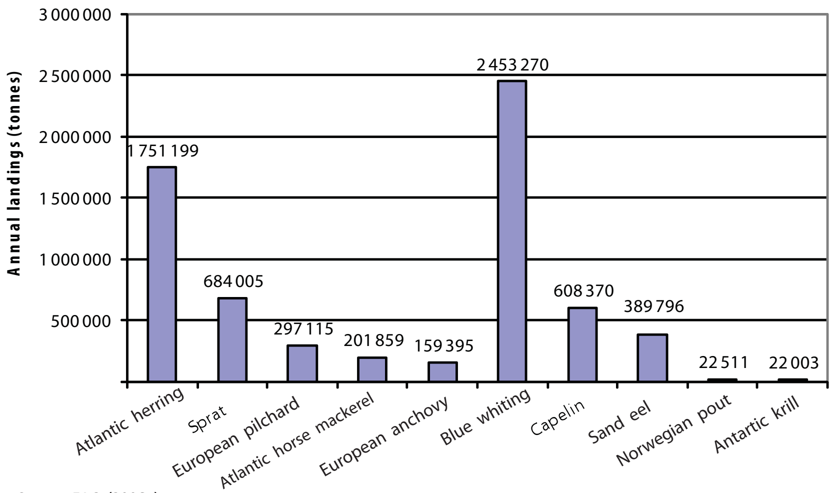
TABLE 9

Landings of European feed-fish species in 2004 (tonnes)

Country	Primarily (>70%) feed fisheries						Mixed feed and food fisheries						Total
	Blue whiting	Capelin	Sand eel	Norwegian pout	Antarctic krill	*Subtotal*	Atlantic herring	Sprat	European pilchard	Atlantic horse mackerel	European anchovy	*Subtotal*	
	Approximate proportion used for fishmeal						Approximate proportion used for fishmeal						
	>95%	c. 95%	100%	100%	c. 70%		<30%	<50%	c. 50%	<20%	n/a		
Bulgaria						–		2 889			88	***2 977***	**2 977**
Croatia						–			16 357		5 044	***21 401***	**21 401**
Denmark	89 500		299 606	13 646		***402 752***	136 809	274 129		23 955	6 936	***441 829***	**844 581**
Estonia						–	27 358	37 306				***64 664***	**64 664**
Faeroe Islands	322 322	33 078	3 476	1 159		***360 035***	50 106			3 867		***53 973***	**414 008**
Finland						–	71 214	16 588				***87 802***	**87 802**
France	19 476		162			***19 638***	36 558	195	31 450	12 828	16 215	***97 246***	**116 884**
Germany	15 293		2 658	107		***18 058***	70 586	26 353	1 398	22 938		***121 275***	**139 333**
Greece						–		138	9 217	609	13 404	***23 368***	**23 368**
Iceland	422 079	524 516				***946 595***	224 580					***224 580***	**1 171 175**
Ireland	75 393					***75 393***	26 234	4 096	13 000	26 432		***69 762***	**145 155**
Italy						–					58 261	***58 261***	**58 261**
Latvia						–	23 559	52 399				***75 958***	**75 958**
Lithuania						–	1 845	6 185			13 774	***21 804***	**21 804**
Netherlands	95 311					***95 311***	129 643	118	46 770	66 678	3	***243 212***	**338 523**
Norway	957 684	49 009	48 667	7 498		***1 062 858***	616 221	1 526		10 747		***628 494***	**1 691 352**
Poland	345		1		8 967	***9 313***	27 914	95 798				***123 712***	**133 025**
Portugal	3 973					***3 973***			75 928	20 761	664	***97 353***	**101 326**
Romania						–		1 350			135	***1 485***	**1 485**
Russian Federation	346 762	1 757			775	***349 294***	123 242	39 433	7 851		14 873	***185 399***	**534 693**
Spain	29 021	10	24			***29 055***		1	64 353		20 615	***84 969***	**114 024**
Sweden	19 083		34 607	88		***53 778***	89 032	90 724	56	800		***180 612***	**234 390**
United Kingdom	57 028		595	13		***57 636***	96 298	3 883	2 682	12 244		***115 107***	**172 743**
Ukraine					12 261	***12 261***		30 894	28 053		9 383	***68 330***	**80 591**
Total	**2 453 270**	**608 370**	**389 796**	**22 511**	**22 003**	***3 495 950***	**1 751 199**	**684 005**	**297 115**	**201 859**	**159 395**	***3 093 573***	**6 589 523**

Source: Derived from FAO capture fisheries data (FAO, 2006a)

FIGURE 6
Landings of European feed-fish species, 2004



Source: FAO (2006a)

The fishery is based upon maturing capelin of ages 3 and 4, and the abundance of the immature component is difficult to assess before recruitment to the adult stock at ages 2 and 3. Given that recruitment is highly dependent upon environmental variables, its high spawning mortality and its importance as a forage fish, a precautionary approach to capelin management is required. Given that immature capelin were absent in autumn 2004 and winter 2005 surveys, the Icelandic quota for the 2005/2006 season was 194 000 tonnes, compared with 803 000 tonnes for the previous year of 2004/2005. The Norwegians closed the capelin fishery entirely for 2006.

Sand eel (Ammodytes spp.): The main elements of sand eel ecology and population structure in the North Sea have been well researched, although the nature of local subpopulations may be less well described. The high natural mortality of sand eel populations and the few year classes make stock size and catching opportunities largely dependant upon incoming year classes, which complicates forward-looking management. The linkages between feed fisheries and non-target species have been investigated, but the complex nature of marine ecosystems means that there is still only a partial understanding of the relationships and interactions, thus indicating a need to be precautionary in the management of this stock. The fisheries are implemented under strictly controlled conditions with high compliance levels. The fishery has a high number of participants that constrains the level of reinvestment but does assist in the redistribution of wealth within the sector and restricts efforts into other fisheries. Most of the vessels and fishmeal plants are operated within a share system. At present, the North Sea sand-eel stocks are considered by ICES to have reduced reproductive capacity and the EU Fisheries Council has set an effort limit of 20 percent of the 2004 effort.

Norwegian pout (*Trisopterus esmarki):* Fishing the stocks in the North Sea and Skagerrak-Kattegat Seas directed fishery was banned over 2005 (extended into 2006) except for when caught as unavoidable bycatch, as the stock biomass is below the sustainable limit reference point (B_{lim}). Catches in ICES Area Via (West Scotland) of small-meshed Danish vessels are highly variable and the state of the stock is unknown. The directed fishery has a history of bycatch of blue whiting, haddock, whiting and herring (ICES, 2005), and Norwegian pout is itself vulnerable as a bycatch to the blue whiting fishery.

Atlantic horse mackerel (*Trachurus trachurus):* The Atlantic horse mackerel has three main stocks – North Sea, western and southern. Most of the catch destined for fishmeal is bycatch from other pelagic fisheries, although there is a directed fishery in western waters. The stock is dependent upon infrequent and very high recruitment pulses, the last major one being in 1982. The current TAC is considered to be too high to sustain the fishery, especially in combination with high levels of juvenile mortality from fishing. Information on the Atlantic horse mackerel's interactions with other species is limited, but it is known to be an important predator of juvenile herring.

3.1.2 Non-European fish species reduced for fishmeal and fish oils for use in Europe

Given that South American fishmeal represents an important component of European aquafeed, it is appropriate that the two main feed-fish species, Peruvian anchovy and Chilean jack mackerel, are included in the species listed for consideration, as is Antarctic krill.

Peruvian anchovy (Engraulis ringens): There is considerable research into the stock ecology and biology and the impacts of fishing, but much of the resulting information is contained in grey literature, difficult to compile and subject to quality assessment. There are also apparent gaps in the information on the effects of fishing on the different stocks' reproductive capacity. Funding limitations have also severely restricted the ability of resident researchers to examine the wider ecosystem implications for stock removal and the impacts on non-target species. In addition, compared with the Danish sand-eel fishery, it is difficult to assess the success of Peruvian monitoring efforts, and compliance levels are less well documented. In the absence of this information, it is difficult to conclude whether the fishery is currently sustainable or not. The recently introduced Individual Tradable Quota (ITQ) system, together with 100 percent sampling of landings by an independent certification company, has induced rationalization into the previously unconstrained fleet structure, and further reductions in capacity are expected. A recent international conference (Lankester, 2005) concluded that the efforts by the Peruvian authorities to control the fishery have been under-reported, although further work was needed to integrate the socio-economic effects of the fishery, as well as ecosystem components, into stock management.

Chilean jack mackerel (Trachurus murphyi): Recruitment into this stock is highly subject to environmental and climatic conditions (in particular the El Niño event) and is thus difficult to assess. However, this stock it is generally considered to be overfished, with an increasing proportion of smaller fish being caught. It is recovering from previous overfishing and has still to recover to previous (1996) levels, despite tight controls on effort.

Antarctic krill (Euphausia superba): In the Antarctic, both Ukrainian and Polish vessels fish Antarctic krill (often as third-parties to Japanese ventures), of which 70 percent is destined for reduction into fishmeal. Krill is central to the Antarctic marine food web, as most organisms are either direct predators of krill or are just one trophic level removed. Traditional, single-species fisheries management principles are not applicable to the Antarctic krill fishery due to the key role of this species in the southern ocean food web. A multi-species management approach is necessary to take into account potential impacts on krill-dependent predators and the Antarctic marine environment as a whole, in case of an expansion of the krill fishery. Although krill catches in the southern ocean are currently well below Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) catch limits, there is potential for a rapid expansion of the fishery in future years, as krill processing technology develops and demand for krill products increases (CCAMLR, 2004). There is also concern over the impact of global warming, as this could affect krill recruitment and krill stock size in the long term.

3.1.3 Trash fish and other fishery by-products

Use in production of fishmeal and fish oils: In Europe, trimmings from other fisheries represent around 33 percent of the total supply of raw material to the fishmeal and fish-body oil industry (IFFO, 2002). It is estimated that 80 percent of the trimmings from fish processing enter the fishmeal and fish-body oil industry in Denmark, although the figure is only 10 percent in Spain. In the United Kingdom, Germany and France, between 33 and 50 percent of fish trimmings enter the fishmeal and fish body oil industry (Table 10).

TABLE 10
Raw material sources for fishmeal and fish body oil in the EU-15, 2002

Country	Feedfish (tonnes)	Trimmings (tonnes)	Total raw material supply (tonnes)	Utilization of trimmings (%)
Denmark	332 000	33 200	365 200	10
United Kingdom	7 800	42 500	50 300	84
Spain		42 000	42 000	100
Sweden	18 750	6 250	25 000	25
France		25 000	25 000	100
Ireland	8 800	13 200	22 000	60
Germany		17 000	17 000	100
Italy		3 000	3 000	100
Total	**367 350**	**182 150**	**549 500**	**33**

Source: Adapted from IFFO (2002)

The United Kingdom and German dependence on whitefish trimmings has fallen. This is in response to a decline in whitefish supplies and a reduction in "black fish". In contrast, a greater proportion of supplies are now derived from pelagic trimmings, where the state of raw material supply is healthy. Salmon also increasingly provides an added source of supply to United Kingdom fishmeal plants, but this fish can no longer be allowed to re-enter the food chain for aquaculture. The introduction of a number of animal by-products regulations[7] by the European Commission (EC), together with the feed industry's own initiatives, have constrained the use of fishmeal and fish-derived waste in both aquaculture and agriculture feeds as a result of concerns over the cross-species transmission of pathogens.

Direct use in tuna farming: In most Mediterranean countries, the tuna farming season extends for about six to seven months, starting typically in June. ICCAT routinely uses a default 25 percent factor for the back calculation of farm inputs from tuna farm production figures – on the assumption that 25 000 tonnes of bluefin tuna were put in cages during 2004, for a feeding period of 180 days and a daily ration of 5 percent, it is estimated that 225 000 tonnes of feedfish were used on tuna fattening farms in the Mediterranean Sea over 2004. A large percentage of the fish feed utilized in the Mediterranean tuna farming industry is imported frozen from outside the region (over 95 percent of total baitfish in the case of Turkey; Lovatelli, 2003). The precise specific composition of feedfish is not known in most cases, but Lovatelli (2003) lists the small pelagic species used as including sardine (*Sardina pilchardus*), round sardinella (*Sardinella aurita*), herring (*Clupea* spp.), mackerel (*Scomber scomber*) and horse mackerel (*Trachurus* spp.). These fish originate mostly from the North Sea/Baltic region and the West African upwelling system.

[7] EC Disposal, Processing and Placing on the Market of Animal By-products Regulations (SI 257, 1994); EC Regulation No. 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption (recently amended by Commission Regulation (EC) No. 808/2003 of 12 May 2003); and the Commission Regulation (EC) No. 811/2003 on the intra-species recycling ban for fish.

3.2 Fishmeal and fish oil production and trade

3.2.1 Production

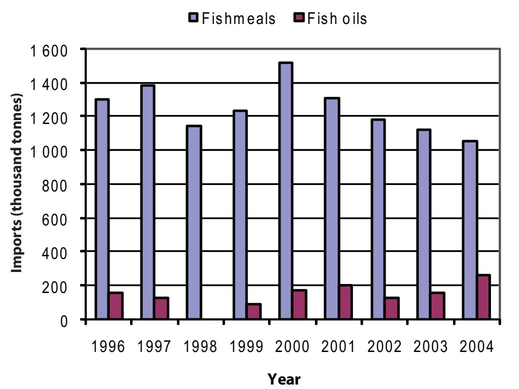
In Europe, fishmeal and fish body oils are derived from directed fisheries for feedfish (providing 67 percent of raw material) and trimmings produced as by-products of processing fish for human consumption (providing 33 percent of raw material). Fishmeal is produced by cooking the fish, before pressing them to remove water and body oil, and finally drying them at temperatures of between 70 to 100 °C depending upon the meal type manufactured. After extraction from the fishmeal, fish body oils are purified through centrifugation. Fish oil represents around 5–6 percent of the total raw material body weight.

In Europe, around 1.1 million tonnes of fishmeal are produced per year (Table 11). Denmark is the largest producer (30 percent), followed by Iceland (23 percent) and Norway (10 percent). Denmark also produces more than half of Europe's fish oil (51 percent), with Norway being the only other significant producer (27 percent).

3.2.2 Imports

Europe is a net importer of fishmeal (~1.6 million tonnes) and fish oil (~240 000 tonnes), although this is a rather simplistic interpretation, as there are significant international product flows based on product specification and price (Figure 7). Norway imports almost half of total European exports (Table 11) and 52 percent of its own net usage. The United Kingdom is the largest importer of fishmeal, of which Iceland (22 percent), Norway (16 percent) and Denmark (12 percent) are the main European sources, and imports represent around three-quarters of all fishmeal usage. South American fishmeal currently accounts for around 19 percent of the United Kingdom's imports, but the amount can vary from year to year and may occasionally increase to around 30 percent. Likewise, Germany only produces a small fraction (7 percent) of its own usage. Norway and Denmark are major European fishmeal producers but also import 64 percent and 41 percent, respectively, of their fishmeal needs. In total, fishmeal imports and consumption are known to have fallen markedly in 2003 and 2004 and are down 18 percent against the preceding years. This is as a result of the ban on the use of fishmeal in ruminant feed.

FIGURE 7
European imports (net) of fishmeal and fish oil, 1996–2004



Source: FIN (2004)

3.2.3 Exports

Denmark exports around 30 percent of its product to the southern countries within the EU (Greece and Italy) and a further 15 percent to Norway. The remaining 55 percent is exported to a number of Far Eastern countries where there is a high demand for high-quality meal and oils. Denmark exported an average of 269 886 tonnes of fishmeal over 2001–2003 and 92 536 tonnes of fish oil (Table 11). The main European exporters of liver oils in 2003 were Norway (1 820 tonnes), Spain (1 940 tonnes) and Portugal (311 tonnes). Most of these oils are cod liver oils. Spain also exports between 900 and 2 500 tonnes of high grade "industrial" shark oils, which are exported to Japan. This is equivalent to 4 500 to 14 000 tonnes of shark (live weight).

TABLE 11
Import, production and export of fishmeal, fish oil and fish waste by European countries (2001–2003 average)

Country	Imports						Production				Exports (including re-exports)					
	Fishmeal		Fish oil		Fish waste		Fishmeal		Fish oil		Fishmeal		Fish oil		Fish waste	
	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%
Bulgaria	4 445	0	3	0	16	0		0		0		0	–	0		0
Croatia	11 398	1	5	0	13	0	510	0	18	0		0	14	0		0
Denmark	142 036	11	30 046	7	531 574	53	350 356	30	114 605	51	269 886	34	92 536	60	52 658	9
Estonia	2 973	0	5	0	34	0	3 600	0		0	3 791	0	23	0	4 271	1
Faroe Islands	151	0	2 710	1	79 838	8	40 950	4	994	0	40 936	5	994	1	137 917	24
Finland	20 358	2	3 158	1	25 174	3		0		0	23	0	4	0	141	0
France	54 621	4	36 340	8	10 061	1	32 350	3	4 433	2	19 560	2	18 539	12	7 191	1
Germany	195 347	15	11 843	3	55 095	5	14 148	1	5 857	3	199 890	25	6 600	4	3 961	1
Greece	85 474	7	9 235	2	2 028	0	2 635	0		0	2 635	0	146	0	18	0
Iceland	37	0	177	0	138 561	14	267 750	23	1 540	1	51 892	7	7 200	5	76 524	13
Ireland	8 711	1	51	0	12 999	1	17 867	2	4 167	2	17 805	2	1	0	6 731	1
Italy	73 161	6	18 595	4	1 681	0	3 361	0		0	5 253	1	97	0	1 330	0
Latvia	3 319	0	1	0	3 402	0	5 432	0	21	0	5 389	1	677	0	63	0
Lithuania	16 027	1	622	0	1 892	0	10 169	1		0	10 169	1	514	0	13	0
Malta	1 519	0	9	0	17	0		0		0		0		0	8	0
Netherlands	78 576	6	44 737	10	3 184	0		0		0	15 474	2	12 790	8	9 267	2
Norway	140 411	11	209 615	48	100 271	10	220 967	19	59 100	27	93 900	12	2 244	1	221 956	39
Poland	16 369	1	1 082	0	689	0	1 231	0		0	15 961	2	1	0	2 379	0
Portugal	12 437	1	553	0	412	0	2 918	0	95	0	978	0	902	1	115	0
Romania	20 306	2	16	0	3	0	277	0		0	11	0		0		0
Russian Federation	114 673	9	958	0	3 052	0	37 471	3	1 940	1	5 507	1	321	0	18 453	3
Spain	95 573	7	21 101	5	5 095	1	101 822	9	14 614	7	20 373	3	3 351	2	6 150	1
Sweden	1 642	0	377	0	7 819	1		0	4 571	2	3 336	0	5 076	3	19 111	3
Ukraine	6 365	0	34	0	21	0		0		0	1 625	0	11	0	114	0
United Kingdom	203 375	16	43 718	10	19 768	2	48 800	4	10 600	5	10 096	1	1 327	1	6 261	1
Total	**1 309 303**	**100**	**434 991**	**100**	**1 002 698**	**100**	**1 162 614**	**100**	**222 555**	**100**	**794 491**	**100**	**153 366**	**100**	**574 631**	**100**

Source: FAO (2005a)

3.3 Utilization of fishmeal and fish oil by aquaculture and other food-producing industries

Table 12 examines the situation in Europe over the last few years and illustrates that overall fishmeal consumption has decreased over the five years between 2002 and 2007. Despite the growth in aquaculture in the region, fishmeal use in aquafeeds has reduced slightly due to its replacement with alternative, mainly vegetable, proteins (A. Jackson, International Fishmeal and Fish Oil Organisation (IFFO), personal communication, 2009). However, as a percentage of fishmeal usage in the region, the proportion used for aquaculture rose from 39 to 50 percent. Fishmeal usage in pig diets has continued to decline, as has its use in poultry diets. The continued ban on feeding fishmeal to ruminants (see Section 6.3) has meant that there has been reduced overall consumption of fishmeal in Europe. If this ban were to be lifted, unlikely in the short term, there could be significant increase in Europe's demand for fishmeal.

TABLE 12
Average annual fishmeal consumption in Europe, 2002 and 2007

Use	Annual consumption (thousand tonnes)	
	2002	2007
Use for aquaculture	552 (39.3%)	537 (49.6%)
Use for pigs	653 (46.5%)	426 (39.4%)
Use for poultry	149 (10.6%)	69 (6.4%)
Other uses, including pet food	50 (3.6%)	50 (4.6%)
Total consumption in Europe	**1 404 (100%)**	**1 082 (100%)**

Source: A. Jackson, IFFO, personal communication, 2009

Two supporting comments should be made with respect to the above points:

a) The ban on feeding meal to ruminants has had a very significant effect on the sales of fishmeal to the United Kingdom (down 70 000 tonnes), Italy (down 35 000 tonnes), the Netherlands (down 20 000 tonnes) and Germany. The United Kingdom and Danish meal manufacturers have borne the brunt of this impact, in particular Denmark, mainly because Italy represented one of its largest export markets. Germany has also suffered particularly badly, as many of its small meal manufacturers used fishmeal as an integral ingredient in their feed supplies for the agricultural sector.

b) The United Kingdom, being the largest single EU market for fishmeal, has seen a significant reduction in imports. Meal manufacturers that once used fishmeal as a component of their product have now eliminated it. The dedicated United Kingdom producers, while suffering from a reduction in the market, have been able to sustain product sales largely because of demand from the aquaculture sector and increased demand from the pig and poultry sector.

3.3.1 Fishmeal and fish oil use in aquafeeds

In contrast with much of aquaculture production in Asia and Africa, European production is focused on the intensive rearing of carnivorous fish such as salmon, seabass and seabream. With the exception of the on-growing of tuna in the Mediterranean Sea, farms use compounded meals that have been optimized for their performance, digestibility and cost-effectiveness.

These feeds vary highly in their protein and oil levels, and use depends upon the species being fed and the stage at which the feeds are given. It can be seen from Table 13 that starter diets are typically rich in protein and lower in oil than grower feeds. Smaller fish also have different nutritional requirements that might favour the use of particular fishmeal, such as the histidine-rich South American feeds. It should also be remembered that starter feeds represent a smaller volume than grower feeds, as it is the latter that are mainly used to contribute to stock biomass.

Fishmeal

Based on the current trends in production discussed in the previous section, a tentative forecast can be made of likely fishmeal usage by European aquaculture over the next ten years (Table 14). This table indicates that fishmeal usage will increase from the present level of around 615 000 tonnes to about 630 000 tonnes in 2015.

TABLE 13
Typical composition of the main feeds used in European aquaculture

Feed type		Protein %	Oil %	Typical FCR*
Salmon starter diets		50–55	14–23	0.90–1.00
Salmon grower diets		34–50	22–38	1.20–1.30
Trout starter diets		50–57	14–22	0.80–0.95
Trout grower diets		38–50	8–33	0.90–1.30
Other finfish diets	Marine fish	50–60	12–24	1.10–1.40
	Freshwater fish	31–55	7–18	

*Food conversion ratio.
Source: J Nelson, Agricultural Industries Confederation (AIC), personal communication, 2004

The increase in demand for fishmeal is not particularly dramatic and is at a lower pace than the predicted increase in production, mainly due to increased efficiencies in fishmeal and fish oil usage that result from improved feed formulation and delivery. The rate at which fishmeal is included in aquaculture diets is expected to drop over the next decade as increasing levels of substitution with vegetable proteins and oils occurs. In addition, continued research into the dietary requirements of particular species reared under particular conditions will refine formulations and improve feed delivery that, with the increased use of automated feeding and consumption monitoring systems, will lead to potential improvements in food conversion ratios (FCRs).

Fish oil

The use of fish oil by European aquaculture is predicted to rise at a slightly higher rate than the use of fishmeal (8 percent as opposed to just over 2 percent), as inclusion rates are set to increase slightly (Table 15). This table indicates that European demand for fish oils for aquaculture will rise to almost 343 000 tonnes by 2015 from the current level of almost 305 000 tonnes.

3.3.2 Fishmeal and fish oil use in agriculture

The agriculture sector uses predominantly Peruvian and Icelandic fishmeal, with fishmeal from Morocco and other minor sources making up the balance. With fishmeal and fish oil production predicted to remain stable over the next decade and the proportion being utilized by aquaculture increasing considerably, there is likely to be a fall in the proportion used by agriculture (Table 16).

For most domestic animal species, fishmeal is included as a feed supplement in order to increase the protein content of the diet and to provide essential minerals and vitamins. In general, fishmeal is considered an excellent protein source for all animal species (including fish), being rich in essential amino acids for non-ruminants, particularly lysine, cystine, methionine and tryptophan, which are key limiting amino acids for growth and productivity of the major farmed species. Manipulation of protein quality during fishmeal production is important in the manufacture of specialist feed supplements. For example, low temperature (high digestibility and biological value, BV) products are used in diets for fish, young piglets and poultry, whereas products for ruminant diets are heated differently to reduce the breakdown of the protein by the rumen microflora (and thus increase the content of rumen undegradable protein, RUP) and to reduce the soluble nitrogen content.

TABLE 14

Past, current and predicted fishmeal use by European aquaculture, 2000–2015

Species	FCR*	2000			2005			2015		
		Production (tonnes)	Fishmeal (%)	Fishmeal use (tonnes)	Production (tonnes)	Fishmeal (%)	Fishmeal use (tonnes)	Production (tonnes)	Fishmeal (%)	Fishmeal use (tonnes)
Seabass	1.3	57 811	55	41 335	80 161	50	52 105	132 332	45	77 414
Seabream	1.3	75 232	55	53 791	97 060	50	63 089	140 941	45	82 451
Salmon	1.3	610 947	40	317 692	712 271	35	324 083	926 852	30	361 472
Trout	1.3	444 251	30	173 258	430 496	28	156 701	264 112	25	85 836
Halibut	1.4	135	45	85	905	42	532	2 513	40	1 407
Turbot	1.4	3 873	45	2 440	6 865	42	4 037	11 863	40	6 643
Cod	1.4	16	45	10	2 600	42	1 529	14 032	40	7 858
Eels	2.0	11 033	50	11 033	7 800	45	7 020	2 041	42	1 715
Carps	2.0	79 300	5	7 930	72 090	4	5 767	60 738	3	3 644
Catfish	1.5	4 490	3	202	5 470	2	164	10 315	2	309
Tilapias	1.7	150	7	18	550	5	47	1 670	4	114
Other freshwater fish	1.7	595	10	101	495	7	59	646	5	55
Sturgeon	1.5	265	25	99	332	20	100	663	18	179
Total		**1 288 098**		**607 995**	**1 417 095**		**615 232**	**1 568 718**		**629 097**

*Food conversion ratio

Source: Federation of European Aquaculture Producers (FEAP) (www.feap.info/feap/aquaculturedata/default_en.asp)

TABLE 15

Past, current and predicted fish oil use by European aquaculture, 2000–2015

Species	FCR*	2000			2005			2015		
		Production (tonnes)	Fish oil (%)	Fish oil use (tonnes)	Production (tonnes)	Fish oil (%)	Fish oil use (tonnes)	Production (tonnes)	Fish oil (%)	Fish oil use (tonnes)
Seabass	1.3	57 811	10	7 515	80 161	11	11 463	132 332	12	20 644
Seabream	1.3	75 232	10	9 780	97 060	11	13 880	140 941	12	21 987
Salmon	1.3	610 947	25	198 558	712 271	22	203 710	926 852	20	240 982
Trout	1.3	444 251	15	86 629	430 496	15	83 947	264 112	15	51 502
Halibut	1.4	135	20	38	905	18	222	2 513	15	528
Turbot	1.4	3 873	20	1 084	6 865	18	1 682	11 863	15	2 491
Cod	1.4	16	20	4	2 600	18	637	14 032	15	2 947
Eels	2.0	11 033	5	1 103	7 800	8	1 170	2 041	10	408
Carps	2.0	79 300	0	–	72 090	0.5	721	60 738	1.0	1 215
Catfish	1.5	4 490	1	67	5 470	0.5	41	10 315	0.5	77
Tilapias	1.7	150	1	3	550	0.5	5	1 670	0.5	14
Other freshwater fish	1.7	595	5	51	495	5	42	646	5	55
Sturgeon	1.5	265	15	60	332	12	60	663	12	119
Total		**1 288 098**		**304 892**	**1 417 095**		**317 580**	**1 568 718**		**342 968**

*Food conversion ratio

Source: Federation of European Aquaculture Producers (FEAP) (http://www.feap.info/feap/aquaculturedata/default_en.asp)

TABLE 16
Fishmeal and fish oil use in world agriculture, 2002 and 2010 (predicted)

A. fishmeal usage (2002 and 2010 (predicted))

Consumer	Fishmeal use (thousand tonnes)		
	2002	2010	Change in use (%)
Poultry	1 755	975	-44
Pigs	1 885	1 430	-24
Ruminants	65	–	-100
Others	585	975	67
Total	**4 290**	**3 380**	**-21**

B. Fish oil usage (2002 and 2010 (predicted))

Consumer	Fish oil use (thousand tonnes)		
	2002	2010	Change in use (%)
Edible	375	175	-53
Industrial	150	88	-41
Pharmaceutical	25	–	-100
Total	**550**	**263**	**-52**

Source: Barlow (2002)

Typical inclusion rates for fishmeal in animal diets are around 2–10 percent for terrestrial animal species. Efficiencies of conversion of feed to live weight gain are usually quoted in terms of FCR (units of weight gain per unit of feed consumed). In general, efficiencies of feed conversion are higher for fish at 30 percent as compared with poultry, pigs and sheep, 18 percent, 13 percent and 2 percent, respectively (Asgard and Austreng, 1995). It is important to note, however, that with the lower inclusion rates of fishmeal in poultry and pig diets, these species requires less fishmeal than do fish to produce a kilogram of edible product.

The use of fishmeal in ruminant diets[8]

Although sheep and cattle consume diets that are predominantly forage-based, there is increased use of concentrate diets and supplements at times of increased productivity, such as during pregnancy and lactation and during rapid growth. The use of fishmeal in these situations has considerable advantages over other protein sources such as soybean meal and bone meal in supplying RUP at times when metabolizable protein requirements may be greater than those that can be supplied by microbial protein synthesis and forage RUP.

Use of fishmeal in diets of non-ruminants

Fishmeal use in pig diets accounts for approximately 20 percent of total fishmeal use, and it is recognized as a key protein source with a good balance of essential amino acids. Pigs' diets containing fishmeal show improved feed conversion efficiencies and generally produce leaner carcasses (Wood *et al*., 1999). The protein is well tolerated in pigs of all ages and has a high digestibility. As with fishmeal used in ruminant diets, however, processing has a significant impact on protein quality in pig diets. Excessive heat treatment results in a significant reduction in digestibility and biological value, due mainly to loss of lysine, a key limiting amino acid in growing pigs. One major environmental benefit in the use of fishmeal in pig diets is the high digestibility of the added protein, resulting in an improved efficiency of dietary protein use with a concomitant reduction in the production of high N-containing effluent.

Use of fishmeal in diets of poultry

As with diets for mammalian species, fishmeal is considered a natural, balanced ingredient for poultry diets with a high protein, high mineral and high micronutrient

[8] Currently, the inclusion of fishmeal and fishmeal products in feed for ruminant animals is banned under EU legislation as a consequence of the bovine spongiform encephalopathy (BSE) crisis. While there is no inherent risk of the transfer of transmissible spongiform encephalopathies (TSE) from fishmeal, the ban was introduced in response to fears about possible contamination of fishmeal products with processed animal proteins.

content. The protein in fishmeal is readily digested by poultry, and it contains all the essential amino acids necessary for adequate growth and production, especially the growth-limiting amino acid lysine. However, as with pig diets, the quality of the fishmeal can seriously affect protein digestion and biological value. Inclusion of fishmeal in poultry diets at about 4 percent results in improved feed conversion efficiency and growth rates. Laying performance is also improved by feeding fishmeal.

3.4 Contribution of feed fisheries to the European economy

3.4.1 Direct employment

The industrial fishing sector is economically very small relative to the EU fisheries as a whole. It accounts for only 0.5 percent of the sector's employment and 2.1 percent of the sector's value added (Megapesca, 1998). Table 17 summarizes the economic significance of the fishmeal and oil sector within the EU. The sector contribution to EU gross value added is €137 million. Approximately 2 220 people are employed directly in the sector. More specifically, the level of economic dependency (value added) on feed-fish fisheries accounts for €137 million or 87 percent of the total and as such is significantly greater than the economic value generated from fish offal.

Of the 2 222 workers in the EU dependent upon feed-fish catching and processing, around 64 percent are dependent on feed-fish supplies (fish catching and processing feedfish) and 35 percent on the trimmings sector (Table 18). Employment in the production of feed-fish related meal tends to be less labour intensive than in offal production (Frid *et al.*, 2003).

3.4.2 Interdependence of the catching sector

Table 17 illustrates the relatively low levels of dependency on feed fisheries in the context of the EU fishing fleet. However, some countries, most noticeably Sweden and Denmark, have fleets that are fully or partly dependent on feed fisheries. Reducing feed fisheries in these countries would have a direct impact on a significantly greater number of vessels than those 60 vessels that are strongly dependent on the fishery. The Danish Research Institute of Food Economics (FOI) explored the potential impact on the Danish fishery sector (Andersen and Løkkegaard, 2002) in the event of (a) a ban on sand-eel fishing (scenario 1) and (b) a ban on all industrial fishing (scenario 2). The assessment took account of changes in turnover and costs resulting from a loss of catch and a reduction in fishing effort. Because of the inter-linkages between human and industrial fishing activity, a ban would not only eliminate the 60 dedicated industrial vessels, it would also result in the removal of 125 vessels under scenario 1 and 194 vessels under scenario 2. This would result in a loss of employment of between 479 (scenario 1) and 750 workers (scenario 2). Applying a similar rational for the Swedish fleet would probably see the loss of 88 and 136 jobs, albeit that there are different species dependencies.

4. SUSTAINABILITY ISSUES OF REDUCTION FISHERIES AND FEEDFISH AS FEED INPUTS FOR AQUACULTURE AND ANIMAL FEED

4.1 Review of the impacts of feed fisheries on ecosystems

4.1.1 Direct effects of feed fisheries

The removal of large numbers of individuals of fish from an ecosystem may directly impact their prey, predators and the viability of target and bycatch populations. The physical effect of fishing activity will also affect the ecosystem directly through the disturbance of habitats (Auster *et al.*, 1996; Langton and Auster, 1999) and the death and injury of non-target species (Kaiser and Spencer, 1995).

TABLE 17
The economic significance of Europe's fishmeal and oil sectors, 2003

Country	Sector	Numbers of employees (FTE)*	Value-added (million €)
Denmark	Fish catching	507	83.0
	Fish processing	395	11.1
Sweden	Fish catching	93	14.0
	Fish processing	35	4.3
United Kingdom	Fish catching	11	1.45
	Fish processing	105	5.0
Ireland	Fish catching	10	1.45
	Fish processing	46	2.5
Spain	Fish catching	0	0
	Fish processing	250	2.6
France	Fish catching	0	0
	Fish processing	270	4.4
Germany	Fish catching	0	0
	Fish processing	62	1.5
Poland	Fish catching	60	2.0
	Fish processing	53	–
Finland	Fish catching	305	3.6
Other	Fish processing	20	–
Total	**Fishmeal**	**2 222**	**136.9**
Total EU fishery sector		**482 374**	**6 416.8**
% Contribution of fishmeal to EU fishery sector		**0.46%**	**2.13%**

*Full time equivalent
Source: Frid *et al.* (2003)

TABLE 18
Employment dependency by producing/processing group, 2003

Sector	Total dependency	
	Number	%
Fish catching	986	45.5
Fish feed processing	417	19.2
Fish trimming and processing	766	35.3
Total	**2 169**	**100**

Source: Frid *et al.* (2003)

Feed-fish stocks

Teleost feed-fish species caught for the production of fishmeal and fish oil are largely small pelagic fish that forage low in the food chain and are preyed upon by fish, marine mammals and seabirds at higher trophic levels. The population dynamics of many small feed-fish species are characterized by their high fecundity and early maturity. The recruitment patterns are highly variable and may rapidly influence stock size due to the short life span of the species, coupled with extrinsic environmental drivers such as sea temperature and associated climatic/hydrological patterns, e.g. the North Atlantic Oscillation (NAO) and the El Niño in the southeast Pacific. This will inevitably lead to uncertainty in the stock forecasts.

Most commercially exploited fish populations are capable of withstanding relatively large reductions in the biomass of fish of reproductive capacity (Daan *et al*., 1990; Jennings, Kaiser and Reynolds, 2001). However, the removal of extremely high levels of spawning stock may impair recruitment due to inadequate egg production. This has been termed "recruitment overfishing" (Jennings, Kaiser and Reynolds, 2001). Pelagic species are particularly vulnerable to this type of overfishing, as they are short-lived (Lluch-Belda *et al*., 1989; Santos, Borges and Groom, 2001).

Beverton (1990) reviewed the collapse of stocks of small, short-lived pelagics by examining the effect of fishing and natural extrinsic drivers. In four of the stocks studied (Icelandic spring-spawning herring, Georges Bank herring, California sardine and Pacific mackerel), the evidence indicated that the reproductive capability had fallen, probably due to environmental conditions, but suggested that fishing accelerated the collapse. Beverton (1990) concluded that although the likelihood of harvesting small pelagic species to extinction was remote, a major population collapse may result in subtle changes to the ecosystem that may change the biological structure of the community.

Other researchers also consider that harvesting an entire industrial fish species to extinction seems unlikely (Hutchings, 2000; Sadovy, 2001), but the treatment of stocks as single, panmictic populations means that if there are relatively local and sedentary stocks, overall catches could conceal community extirpation. This has implications for instance, for the management of localized substocks such as the North Sea sand eel.

Habitats

The pelagic gear and purse seines used to target many industrial fish species – such as sprats, blue whiting and Peruvian anchovy – are deployed in the water column and have minimal contact with the sea floor. Demersal otter trawls are used to catch some species, such as sand eel and Norway pout, and these may have more of an impact on the sea bed and benthos. The degree of impact depends on the targeted species and the location, as specific gears will be used to target specific species, and the impact on the sea floor will depend on both the substrate type and the physiology of the animals that live there.

Typically in the sand-eel fishery, the trawl is kept close to the sea bed, which is usually sandy (Wright, Jensen and Tuck, 2000), but actual contact is kept to a minimum. The gear is also lighter than the other demersal trawls. The effect of this disturbance on the more dynamic sand habitats is less significant than disturbance in areas of lower energy such as muddy substrates and in deep water, as the level of natural disturbance in the more dynamic areas is likely to be greater than that caused by fishing (Kaiser *et al*., 1998).

Although the impact to the sea bed and benthos by each individual tow may be less than with comparable demersal otter trawling operations, as the gears are lighter, the way the fishery operates suggests that local impact on the sea bed and invertebrate communities may be quite intense. This is because the same trawl path tends to be fished repeatedly over a period of several days by several boats operating in any particular region (Frid *et al.*, 2003). Mitigating against this, however, is the fact that these fisheries are seasonal. The local impact may be intense, but it is followed by long periods of recovery. The fishery for Norway pout occurs primarily through the winter months, with little fishing during the summer, which allows six to eight months of the year for the benthos to recover. The sand-eel fishery is constrained by the hibernation of the species in winter.

4.1.2 Indirect effects of fishing

There are a number of indirect effects of fishing feed-fish stocks, largely due to their foraging low in the food chain and, therefore, being preyed upon by fish, marine mammals and seabirds of higher trophic levels. Changes to specific predator-prey relationships may impact the whole food chain and lead to changes in the composition of biological communities (Greenstreet and Hall, 1996; Rijnsdorp *et al*., 1996; Bianchi *et al*., 2000; Hill *et al*., 2001). Removal of a species' biomass reduces the buffering capacity of the stock and makes the population more vulnerable to poor prey availability or climatic conditions. There are also the genetic effects associated with removing large amounts of the gene pool, which may adversely affect populations over long time periods. Indirect effects may also include ghost fishing resulting from lost fishing gears, which may continue to catch and disturb biological communities and habitats unmonitored (Chopin *et al.*, 1996; Laist, 1996).

Bycatch

The incidental catch of non-target species, and in particular the capture of juveniles of commercial species, is one of the most controversial aspects of feed fisheries, as most undersized fish are landed and processed. In North Atlantic waters, juvenile herring are known to shoal with sprat (Hopkins, 1986), while juveniles of other commercial species such as whiting and haddock are known to shoal with industrial teleost feedfish such as Norway pout (Huse *et al.*, 2003; Eliasen, 2003). Bycatch levels are not necessarily high – the bycatch in the Danish and Norwegian North Sea sand-eel fishery (mainly herring, saithe and whiting) has averaged 3.5 percent over 1997–2001 (ICES, 2003a). While levels are low, given the scale of the feed fisheries being prosecuted, actual quantities of bycatch can be significant. In 2002, the Danish sand eel landings accounted for 622 100 tonnes, of which 3.7 percent was considered bycatch, totalling 23 018 tonnes of herring, cod, haddock, whiting, saithe and mackerel. In the same period, the sprat fishery took 27 972 tonnes of bycatch. In 2003, an experimental trawl survey (CEFAS, 2004) used a 16 mm commercial sand-eel net to monitor the whitefish bycatch on the West Dogger sand-eel grounds. Sand eels comprised 50–65 percent of the catch, below that required to meet EU catch composition rules, but sand-eel abundance was exceptionally low in 2003. Adult cod and haddock were not caught in the sand-eel net, which was capable of retaining 0-group gadoids (whiting), but their distribution was patchy, and no juvenile cod were caught.

There is recent evidence of declining bycatch in the sand-eel fisheries and the blue whiting fishery as seen in the Danish feed-fish catches (Table 19). Bycatch is an issue in the sprat fisheries, where increased herring bycatch is largely a result of relative increases in abundance (ICES, 2003b).

The composition and volume of catches from the Norwegian industrial fisheries, which target both blue whiting and Norway pout, was reported by ICES (2003b). Between 2000 and 2002, the average annual landings from the mixed fishery was 109 000 tonnes. Blue whiting formed an estimated 58 percent of this catch, while Norway pout formed approximately 17 percent. The remaining 25 percent, or about 16 000 tonnes, consisted of a range of fish and invertebrates. The six most important bycatch species (in terms of landed catch) were saithe, herring, haddock, Atlantic horse mackerel, whiting and mackerel, each of which represented an annual catch of at least 1 000 tonnes in this fishery. This length distribution analysis suggests that the bycatch of these species consisted primarily of immature individuals.

In the North Sea, this issue has been addressed by closures of part of the North Sea to Norway pout fishing to reduce the bycatch of juvenile commercial species. Similarly, seasonal closures exist for the conservation of fishery resources through technical measures for the protection of juveniles of herring and sprat (EC Regulation 850/98; Council of the European Union, 1998). Bycatch regulations and minimum mesh size are also in place, aimed at reducing juvenile bycatch.

The spatial and temporal distribution of cod bycatch in the herring and sprat fisheries of the Baltic Sea was thought to relate to the co-occurrence of the three species on cod and sprat pre-spawning and spawning grounds. ICES (2001) determined that the share of bycatch in total landings of cod was within the range of 1.3 to 2.0 percent. The bycatch in pelagic fisheries, therefore, appeared to have a minor effect on the cod population.

In a recent study, the majority of haddock and whiting in the bycatch of the industrial fisheries of Denmark and Norway were of age 3 or less (ICES, 2003c). The mortality of haddock caught as bycatch by the industrial fisheries was small for age groups 0 and 1 (less than 1 percent by number and weight), while the mortality percentages of older fish aged 2 and 3 were more varied. The percentages of whiting caught were generally higher. However, the mortality due to industrial fishing was considered small in comparison with the total estimated survivors for the year classes and considering that the natural mortality of haddock and whiting is very high.

Seabirds

Bycatch mortality: The methods for catching fish species depend on the behaviour of the fish. Many fish species shoal, and small-mesh trawls and gillnets are used to capture the shoaling fish. Many of the feed-fish fisheries use trawls, and birds are less likely to be caught by this type of gear (Tasker *et al.*, 2000). A study in the Baltic Sea assessing the bycatch of common guillemot (*Uria alga*) indicated that a small unquantified degree of mortality could be attributed to trawls, but the researchers did not identify the trawls as specifically targeting an industrial fish species (Österblom, Fransson and Olsson, 2002). Bycatch of birds is potentially an issue in the purse-seining for anchovy, but the level of interaction is little researched (Majluf *et al.* 2002), and there are only anecdotal reports of bycatch (S. Austermühle, Mundo Azul, personal communication, 2003).

Availability as prey: Seabirds are long-lived, producing few fledglings that only breed if they survive several years, and normally have various mechanisms to overcome periods of low food supply. Specialist seabirds, such as small, surface-feeding species with energetically expensive foraging methods are the most vulnerable to local depletion and (natural) variability in prey availability. The relationship between the reproductive success in black-legged kittiwakes on Shetland and sand-eel abundance has been proposed as an indicator of local sand eel availability in the North Sea (ICES, 2003c). Potential conflicts between fisheries and seabirds are likely to arise only on a local or regional scale (Tasker *et al.*, 2000). Industrial fisheries can affect seabirds by reducing prey stock biomass, leading to declining recruitment or alterations in the food web structure. Although seabirds consume only an insignificant proportion of North

TABLE 19

Landings and bycatch from four Danish North Sea industrial fisheries, 1998–2001 (average) and 2002

Catch species composition	Landings of four industrial feed fisheries (thousand tonnes)							
	Sand eel		Sprat		Norway pout		Blue whiting	
	1998–2001	2002	1998–2001	2002	1998–2001	2002	1998–2001	2002
Sand eel	564.3	622.1	6.1	4.1	0.0	0.0	0.1	0.0
Sprat	6.6	1.0	152.8	140.6	0.2	0.0	0.0	0.0
Norway pout	1.6	0.0	0.4	0.2	53.8	43.2	3.5	3.7
Blue whiting	1.4	0.7	0.0	0.0	2.6	4.7	31.1	21.1
Herring	2.6	1.6	11.2	16.6	1.8	3.2	0.8	0.2
Cod	0.2	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Haddock	0.7	1.2	0.1	0.0	0.9	1.5	0.2	0.1
Whiting	1.8	1.5	1.4	2.5	1.3	1.7	0.1	0.1
Mackerel	0.4	0.4	0.4	0.7	0.1	0.0	0.1	0.0
Saithe	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1
Other species	2.2	1.4	1.8	2.7	0.9	0.4	3.3	1.6
Total	**581.8**	**630.0**	**174.2**	**167.4**	**61.5**	**54.9**	**39.2**	**26.9**
% bycatch	3.0	1.0	12.3	16.1	12.5	21.5	20.9	22.1

Source: Adapted from Frid *et al*. (2003)

Sea sand-eel stocks compared with fish predators (Bax, 1991; Gislason, 1994; ICES, 1997), this relationship is sensitive to the population levels of key predators such as mackerel and gadoids, which are currently low in the North Sea.

A classic example of how the removal of large quantities of feedfish by industrial fisheries might reduce food supply to seabirds has been reported in Peru. Extrinsically driven dramatic decreases in numbers of guano seabirds occur regularly during El Niño events but, historically, species were shown to recover between events, showing cyclic fluctuations in populations. However, as the Peruvian anchovy fishery increased, seabird numbers began to fail to recover after El Niño driven crashes, and the seabird population fell to only a small fraction of its earlier numbers (Duffy, 1983). Jahncke, Checkley and Hunt (2003) modelled the guano-producing seabirds (cormorant (*Phalacrocorax bougainvillii*), booby (*Sula variegata*) and pelican (*Pelecanus thagus*)) that feed almost exclusively on *Engraulis ringens* to determine if there is a response in the annual population size of the birds to changes in primary and secondary production of the Peruvian upwelling system. The seabirds were shown to respond to the increased productivity of the Peruvian upwelling system, and declines in seabird abundances after El Niño events were likely due to competition for food with the fishery.

Marine mammals

Bycatch mortality: The Ecological Quality Objective for bycatch of small cetaceans adopted under the Bergen Declaration[9] requires anthropogenic mortality to be below 1.7 percent per year. No bycatch of marine mammals has been reported in the industrial fisheries (Dalskov, personal communication, 2003), but Huse *et al.* (2003) provide anecdotal evidence that there are occasional bycatches of cetaceans in the North Sea sand-eel fishery. The opportunistic feeding behaviour of cetaceans and pinnipeds in and around trawls means they are vulnerable to becoming trapped (Fertl and Leatherwood, 1997). There is a need for further investigation of the level and spatial and temporal extent of marine mammal bycatch in the North Sea. Should this prove significant in areas or in certain seasons, pingers could prove an effective management measure (Larsen, 1999).

Bycatch of cetaceans is potentially an issue in the purse-seining for anchovy (Majluf *et al.*, 2002). The dusky dolphin (*Lagenorhynchus obscurus*) is known to take *E. ringens* as a major component of its diet (McKinnon, 1994), and the species was reported as caught by purse seines before cetaceans were protected in the region (law No. 26585: 1996) (Read *et al.*, 1988). Van Waerebeek *et al.* (1997) conducted a survey of Peruvian fishers to estimate mortality on 722 bycaught cetaceans (and direct takes); species reported in multifilament gillnets were 82.7 percent dusky dolphin (*L. obscurus*), with the remainer Burmeister's porpoise (*Phocoena spinipinnis*), long-beaked common dolphin (*Delphinus capensis*) and bottlenose dolphin (*Tursiops truncatus*). Van Waerebeek *et al.* (1997) found that there was no indication of a reduction in dolphin mortality in the industrial purse-seine fisheries, and that large numbers of long-beaked common dolphins are known to be by-caught. Currently, catches are thought to occur, but evidence is anecdotal (S. Austermühle, Mundo Azul, personal communication, 2003).

Availability as prey: Diet composition analyses of cetaceans show the presence of industrial feed-fish species in the diet of harbour porpoise (*P. phocoena*), bottlenose dolphin (*T. truncatus*), white-beaked dolphin (*L. albirostris*), common dolphin (*D. delphis)*, Risso's dolphin (*Grampus griseus*), Atlantic white-sided dolphin (*L. acutus*) and minke whale (*Balaenoptera acutorostrata*) (Fontaine *et al.*, 1994; Santos *et al.*, 1994, 1995; Couperus, 1997; Olsen and Holst, 2001; Kastelein *et al.*, 2002; Borjesson,

[9] Fifth International Conference on the Protection of the North Sea (the Bergen Declaration) of 20–21 March 2002.

Berggren and Ganning, 2003). In some cetaceans, the proportion of feedfish reported in the diet is minimal, but in Scottish waters, sand eels constitute 58 percent by weight of the stomach content in harbour porpoises and 49 percent by weight of the stomach content in the common dolphin. Other feed-fish species, sprat and Norway pout, were less than 1 percent by weight (Santos *et al.*, 1995). In Kattegat and Skagerrak Seas, feedfish (mainly sprat and herring) constitute 13 percent by weight of the contents in juveniles' stomachs and 10 percent by weight in adults' stomachs (Borjesson, Berggren and Ganning, 2003). Sand eels contribute 86.7 percent to the diet by weight of Minke whale in the North Sea and further north, into the Norwegian Sea, the diet of Minke whales is dominated by spring-spawning herring (Olsen and Holst, 2001). The differences in the diet composition reflect the local foraging of cetaceans. Industrial fisheries in the North Sea may, therefore, impact marine mammal populations by altering their food supply in certain areas. It is, therefore, important to consider the local availability of feedfish to cetaceans and their ability to switch to other prey if the stocks are depressed, when assessing the effects of feed-fish fisheries on marine mammals. This, however, has yet to be demonstrated in any cetacean population.

There is some evidence that there is a link with fisheries and grey seal population dynamics. The Effects of Large-scale Industrial Fisheries On Non-Target Species (ELIFONTS) study investigated the grey seal population on the Isle of May, in the North Sea. Grey seals (*Halichoerus grypus*) consumed mainly sand eels (*Ammodytes marinus*), but the greater sand eel (*Hyperoplus lanceolatus*) was also taken. For this study, the proportion of not breeding, but reproductively capable females and the number of breeding failures among marked animals were positively correlated with sand-eel catch per unit effort (CPUE) in the southern North Sea in the years 1990–1997. Effects were only seen when the reproductive performances of known seals were examined in relation to fishery data. It is possible that the reproductive performance of some seals may be more affected by changes in sand-eel availability than that of other seals, reflecting either a tendency to specialize on sand-eels or an inadequacy in hunting behaviour. Also, the body condition of female seals was positively correlated with CPUE for the local stock area. However, the total number of pups increased steadily during the study periods and thus, although there appears to be an interaction between sand-eel abundance and seal breeding success, given the current state of the populations, this interaction does not appear to be a major factor explaining variations in seal populations (Harwood, 1999).

Ecosystem changes

The complexity of marine systems makes it difficult to identify the effects of predator/prey removal on other communities. Marine communities often exhibit size-structured food webs, and changes in the abundance and size composition of populations are likely to lead to changes in the quantity and type of prey consumed (Frid *et al*., 1999). However, these changes may not be predicted by simplistic models of predator-prey interactions, as they do not take into account prey switching, ontogenetic shifts in diet, cannibalism or the diversity of species in marine ecosystems (Jennings and Kaiser, 1998; Jennings, Kaiser and Reynolds, 2001).

Ecological dependence takes account of the ecological linkages in the marine systems. Ecological dependence is already considered in management advice for sand-eel in the Shetland area, and sand eel in Sub-area IV, e.g. the kittiwake/sand eel interaction. ICES (2002) identified several feed-fish stocks for which ecological dependence may need to be considered further in management advice: sand eel in Division IIIa; Norway pout in Sub-area IV and Division IIIa; sand eel in Sub-area IV; Norway pout in Division VIIa and sand eel in Division VIa. However, assessing ecological dependence is problematic, as evidence for the effects of strong ecological interactions on some stocks, e.g. the proposed kittiwake/sand-eel interaction, should not be taken as evidence that they are necessarily a concern to managers of all stocks. ICES (2003c) suggested that the current approaches for assessing ecological dependence could not be widely applied and that fundamental research is needed to develop an appropriate method for assessing and ranking the strength of ecological dependence of species.

Commercial species as predators of feed-fish species

Feedfish tend to feed at or near the bottom of the food chain, so fisheries interactions with the marine food web are more likely to affect their predators. Gislason (1994) reported that the sand-eel and Norway pout fisheries of the North Sea took in the region of 20 percent of the annual production of these fish species. The consumption of sand eels in the North Sea by fish that are targeted for human consumption, seabirds and other species (including some fish species and marine mammals) has been estimated as 1.9, 0.2 and 0.3 million tonnes, respectively (ICES, 1997). Bax (1991) reviewed the fish biomass flow to fish, fisheries and marine mammals using a variety of data sets in the Benguela system, on Georges Bank and in Balsfjorden, the East Bering Sea, the North Sea and the Barents Sea, and calculated that consumption of fish by predatory fish was 5–56 tonnes/km^2 compared with fisheries (of all types), which removed 1.4–6.1 tonnes/km^2, marine mammals, which consumed 0–5.4 tonnes/km^2 and seabirds, which consumed 0–2 tonnes/km^2. Fish predation on teleost feedfish, is, therefore considered to be higher than industrial fisheries removals, and this is especially true in the sand-eel fisheries.

The ICES stomach sampling project in 1981 showed that sand eel, Norway pout and sprat provided more than 50 percent of the food of saithe and whiting and between 1 and 30 percent of the food of cod, mackerel and haddock (Gislason, 1994). Greenstreet (1996) investigated the diet composition of the main predators in the North Sea; Table 20, which gives the consumption of industrial species, shows that industrial or feed-fish species are a valuable food resource for predatory fish.

TABLE 20

Diet composition (%) of the main predators in the North Sea

Prey	Predator					
	Cod	Haddock	Whiting	Saithe	Mackerel	Atlantic horse mackerel
Norway pout	7.7	6.3	8.9	32.2	7.3	0.0
Herring	4.1	0.1	6.6	0.6	3.7	8.8
Sprat	2.1	0.3	9.4	0.4	3.2	0.4
Sand eel	7.3	7.2	27.3	9.7	16.6	0.0

Source: Recalculated from Greenstreet (1996)

However, while bioenergetic estimates of sand-eel consumption in the North Sea show that fish are important predators, predation on sand eels is declining (Furness, 2002), as stocks of large gadoid predators are weak and their spawning stock biomass is declining (Sparholt, Larsen and Nielsen, 2002). Sparholt, Larsen and Nielsen (2002) tested the hypothesis that a reduction in consumption of industrial fish by gadoids such as cod, whiting and saithe should lead to a measurable reduction in the predation mortality of their prey (Norway pout) and found the total mortality of Norway pout for ages 1 and 2 had declined between the 1980s and 2000.

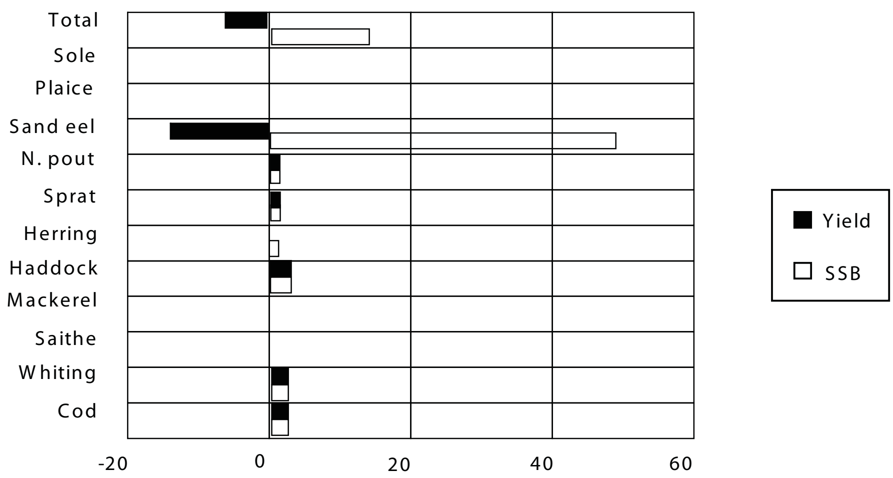
If small pelagic species have become more dominant in marine systems, resulting from a decline in demersal fish predators due to fishing, then there is an argument for management to allow larger harvests of industrial species due to the reduced natural predation pressure on these stocks. However, Naylor *et al.* (2000) argued that in the North Sea, exploitation of sand eel and Norway pout is implicated in the decline of cod. It has been suggested that a reduction in fishing effort on industrial fish stocks will benefit higher trophic predators (including gadoids) (Dunn, 1998; Cury *et al.*, 2000; Furness, 2002). The more recent assessments of the Norway pout stocks in ICES

Sub-area IV and Division IIIa (ICES, 2003d) indicate that fishing mortality is lower than natural mortality, and multispecies analyses have indicated that when F (fishing mortality) is below M (natural mortality), the fisheries are not causing problems for their predators on the scale of the stock. It further noted that locally concentrated harvesting may cause local and temporary depletions of predators and, therefore, harvesting should be spread widely across large geographical areas.

The ICES Multispecies Forecast Programme (MSFOR) (reported in Gislason and Kirkegaard, 1998) predicted that if there was a 40 percent reduction in the industrial fishing effort in the North Sea, the harvested yield of sand eel would decrease by

FIGURE 8

MSFOR predictions of the percentage change in yield and spawning stock biomass (SSB) in the North Sea for 11 North Sea species upon a 40 percent reduction in sand-eel fishing



Source: Gislason and Kirkegaard (1998)

19 percent (compared with the prevailing situation), while the spawning stock biomass would increase by more than 50 percent (Figure 8). The model predicted that reducing the fishing mortality of industrial species, and hence increasing the sand-eel stock, would only have a small effect on predatory species. Such modelling must always be interpreted with caution, as models can only make predictions based on the data available. For example, the overfishing of predatory fish may have perturbed the marine system to such an extent that the recovery of these stocks is unlikely even if there is a reduction of the fishing effort on sand eels (Beddington, 1984). The lack of appropriate modelling frameworks for establishing the ecosystem effects of fisheries is well recognized (Robinson and Frid, 2003). However, it appears that fishing mortality due to the sand-eel and Norway pout feed fisheries is sufficiently low to ensure that prey items are available to predatory fish.

Teleost feedfish as predators of commercial species

The survival of the early planktonic phases of the fish life cycle is essential for stock recruitment (Blaxter, 1974; Chambers and Trippel, 1997; Horwood, Cushing and Wyatt, 2000). Even small variations in the mortality rate between egg fertilization and recruitment can have a profound effect on the subsequent adult abundance (Jennings, Kaiser and Reynolds, 2001). Many industrial fish species prey on the eggs and larvae of commercial fish. Sand eel, Norway pout and capelin consume fish eggs and larvae (www.fishbase.org), and sprat and herring prey on cod eggs (Stokes, 1992;

Köster and Möllmann, 2000). Juveniles of saithe, cod and whiting may also experience competitive interactions with Norway pout (Albert, 1994). As the abundance of the larger predatory gadoids has been reduced to low levels, the industrial feedfish that prey on their juveniles and eggs may now be exerting a higher level of mortality than previously, and may potentially affect gadoid stock recruitment and slow recovery. However, it should be noted that such profound trophic impacts are difficult to verify, given the lack of information and the confounding effect of other impacts.

Genetic impacts

Overfished populations may exhibit the "Allee effect". This is an inverse density dependence at low densities, e.g. the per capita birth rate declines at low densities. The primary factors involved in generating inverse density dependence include genetic inbreeding and loss of heterozygosity and demographic stochasticity, including sex ratio fluctuations (Courchamp, Clutton-Brock and Grenfell, 1999). Common factors behind the Allee effect are not of a genetic nature and can include gregariousness, sperm competition, cultivation effects, etc.

The genetic viability of a stock is harmed if a stock collapses and recovers, due to the reduced number of genes in the population. However, Stephenson and Kornfeld (reported in Beverton, 1990) concluded that the Georges Bank herring, which reappeared after a collapse in 1977 to 1/1000th of the 1967 peak of over 1 million tonnes, have an unchanged genetic constitution. This result may be an artefact of the limited DNA technology of the time.

Teleost feed-fish species are characterized by a tendency to shoal. Fishing pressure causes shoaling fish to reduce their range and maintain the same average school size (Ulltang, 1980; Winters and Wheeler, 1985). Consequently, there can be a high number of individuals in a shoal that may lead to a high level of genetic diversity within the shoal (Ryman, Utter and Laikre, 1995). The next question is what size can a genetically distinct shoal/or population be reduced to and still recover. Beverton (1990) calculated that the smallest population size that a collapsed population dropped to and subsequently recovered is in the order of a million fish, but local density has to play a role.

4.2 Criteria and indicators presently used to measure the sustainability of reduction fisheries

The FAO *Code of Conduct for Responsible Fisheries* (CCRF), adopted in (FAO, 1995), aims to ensure that the right to fish "carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources". Together with its Technical Guidelines for implementation and the other international fisheries instruments developed and adopted within its framework (e.g. International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries, IPOA-Seabirds; International Plan of Action for the Conservation and Management of Sharks, IPOA-Sharks; International Plan of Action for the Management of Fishing Capacity, IPOA-Capacity; International Plan of Action to Prevent, Deter and Eliminate Illegal and Unreported and Unregulated Fishing; IPOA-IUU fishing), the CCRF is now widely recognized by governments and non-governmental organizations (NGOs) as the global standard for setting out the aims of sustainable fisheries and aquaculture over the coming decades and as a basis for reviewing and revising national fisheries legislation.

4.2.1 FIN "Sustainability Dossier"

When most feed manufacturers state that they only procure from "sustainable" sources, this claim is usually based upon the Fishmeal Information Network (FIN) Sustainability Dossier, an annually updated assessment initiated by the Grain and Feed Trade Association (GAFTA) and funded by the United Kingdom Seafish Industry Authority (SFIA). Until recently, this dossier has been limited to examining stock assessment reports and the presence of regulatory frameworks, but it has now been expanded to reflect wider ecosystem impacts based on the latest ICES and FAO advice.

4.2.2 MSC "Principles and criteria" for responsible fisheries

The concept of sustainability is complex and, therefore, has implications for the selection of criteria for "sustainable fishing". The most widely accepted generic model is the principles and criteria for "responsible fishing" developed by the Marine Stewardship Council (MSC). Developed over a long consultation period, the MSC principles and criteria consider whether a fishery is sustainable depending upon a demonstration of:

- the maintenance and re-establishment of healthy populations of targeted species;
- the maintenance of the integrity of ecosystems;
- the development and maintenance of effective fisheries management systems, taking into account all relevant biological, technological, economic, social, environmental and commercial aspects; and
- compliance with relevant local and national laws and standards and international understandings and agreements.

While the MSC criteria respond well to fisheries and ecosystem issues, they do not provide a specific assessment of the economic or social elements. Huntington (2004) took the basic MSC criteria and adapted them to specifically suit feed fisheries, applying them to the five main fisheries that provide the bulk of fishmeal destined for the Scottish fish-farming industry (Table 21).

In the MSC process, indicators are used to assist the scoring of fisheries "sustainability". For each indicator, there are three "scoring guideposts" that assist assessors in determining the score out of 100. For instance, there are guideposts for what passes at 60, 80 and the ideal score of 100.

The advantage of the MSC approach is that it provides a vigorous quantitative approach to assessing the main elements that ensure that a fishery is sustainable. The main question is whether this approach can be successfully applied to feed fisheries, whose main species constitute an important forage prey, unlike many of the top predators that have formed the focus on many fisheries certifications to date. While MSC does look at implications of target species removal on ecosystem structure and function, it has been a challenge to both determine and quantify in practice. With growing interest in ensuring the sustainability of aquaculture products throughout the production chain, the certification of feed-fish stocks has become an urgent priority.

4.3 Sustainable use of available fishery resources for aquafeeds

While a future goal may be the complete or majority use of feedfish from a certified "responsibly managed" fishery, in the mean-time, it is important that the fish farming industry in Europe makes a committed move towards sourcing from the better managed and more sustainable fisheries. As mentioned earlier, the main buying criteria for fishmeal for inclusion in aquafeeds are price and quality. Beyond ensuring that fish are purchased from stocks that are managed within national and international laws and agreements, there is little real attempt to limit fishmeal procurement to "sustainable sources". There are a number of obstacles that must be overcome if the feed-supply chain for the European industry is to become more sustainable. However, it is being increasingly recognized that the long-term future of the aquaculture industry is entirely dependent on sustainably managed fisheries, and all concerned need to take full account of this.

TABLE 21
Summary of principles, criteria and corresponding indicators of feed fisheries sustainability

Principle	Criterion (C)		Indicator
1. Fishing pressure and sustainability	1.1 High productivity of stock maintained		a) Level of understanding of species and stock biology
			b) Knowledge of fishing methods, effort and mortality
			c) Existence of acceptable reference points
			d) Existence of defined harvest strategy
			e) Robust and regular assessment of stocks
			f) Stocks are at an appropriate precautionary reference level.
	1.2 Fishery able to rebuild stock to a predefined level within a specific time frame		
	1.3 Reproductive capacity of stock maintained		a) Information on fecundity and recruitment dynamics
			b) Information on stock age/sex structure
			c) Evidence of changes in reproductive capacity
2. Structure, productivity, function and diversity of dependent ecosystem	2.1 Natural functional relationships between species maintained without ecosystem state changes		a) Understanding of ecosystem factors relevant to target species
			b) General risk factors known and understood
			c) Impacts of gear use and loss known
			d) Ecosystem management strategy developed
			e) Ecosystem assessment shows no unacceptable impacts
	2.2 Fishery does not threaten biodiversity		a) Level of knowledge and implications of interactions
			b) Management objectives set for impact identification/avoidance
	2.3 Recovery of non-target species populations permitted		a) Information on necessary changes to allow appropriate recovery
			b) Management measures permit adaptive change to fishing
			c) Management measures allow recovery of affected populations
3. Information, organizational and legislative capacity for sustainable management	3.1 Management system criteria	C2	a) Clearly defined institutional and operational framework
		C1, 2, 3	b) Management system has clear legal basis
		C2, 5, 7	c) Has a consultative and dispute resolution strategy and pathways
		C6	d) Subsidies or incentives exist that affect fishing practices
		C8	e) Adequate, operational research plan to address information needs
		C7, 9, 10	f) Monitoring and evaluation system for fisheries management objectives
		C11	g) Control mechanisms for enabling and enforcing management objectives
	3.2 Operational criteria	C12, 13	a) Operational mechanisms to reduce impacts on habitats and non-target species
		C14, 15	b) Measures to discourage operational wastes and destructive practices
		C16	c) Fishers aware of/compliant with managerial, administrative and legal requirements
		C17	d) Fishers involved in catch, discard and other relevant data collection
4. Economic and social considerations	4.1 Respects the needs of fisheries-dependent communities, historic rights and cultures		a) Does not impact resource availability or access, directly or indirectly
			b) Fisheries and fishers demonstrate understanding and sensitivity to traditional practices and ways of life
	4.2 Fishery and market operate under natural conditions.		a) Fishery operates in an economically efficient manner
			b) Product trade is not artificially favoured by trade barriers or protectionism
	4.3 Labour conditions conform to International Labour Organization (ILO) standards		a) Freedom from enforced labour
			b) Freedom of association and collective bargaining
			c) No discrimination of individuals and organizations
			d) Non-use of child labour
	4.4 Fishery does not prejudice food security		a) Pricing structure operates within market norm
			b) Supply operates within market norm

Source: Huntington (2004)

4.3.1 Barriers to buying aquafeeds sourced from sustainable feed fisheries

There are a number of practical reasons why it has been difficult for the feed manufacturing industry to source fish feeds entirely from sustainable sources:

- *Lack of recognized criteria for suitability:* At present, there are no feed manufacturing industry standard definitions or criteria for the sustainability of feed fisheries. It currently uses the FIN Sustainability Dossier for guidance, but this is essentially limited to examining stock assessment reports and regulatory frameworks. This dossier does not include some of the elements included in the assessment criteria used in this study, such as non-target species impacts, regulatory compliance levels, availability of key information and knowledge relevant to sustainability, as well as economic and social factors. The MSC-derived framework used by this study is considered an improvement on the FIN Dossier, and one that should be adopted more widely. The setting of sustainability criteria will ultimately enable both fish producer and consumer to purchase selectively, creating a market for a sustainable product.
- *Traceability:* Although the traceability of feed ingredient sources is improving rapidly, it may be difficult to ensure the origin of all fishmeal. For instance, fishmeal is often blended to give constant characteristics of density, flow, digestibility and protein content, and thus species identity tends to be uncertain. Much of the South American fishmeal is blended at the time of loading of tankers (both ship and road) and hence cannot be traced beyond that point. Traceability is high on the feed industry's agenda, and some manufacturers are looking to traceability schemes such as the Universal Feed Assurance Scheme (UFAS) and the Feed Materials Assurance Scheme (FEMAS) to reduce the purchase of feed products where there is not a full traceability chain.
- *Fishmeal nutritional performance:* Restrictions on certain fishmeal stocks may have implications for fishmeal nutritional performance. For instance, smaller fish (i.e. salmon <1 kg) need high levels of amino acid histidine that is found in much higher levels in South American fishmeal – exclusion from these would necessitate much higher fishmeal inclusion levels for European meals and thus higher levels of consumption. There is the potential for substitution with porcine blood meal, but this is likely to meet retail and consumer resistance. Conversely, for larger fish, the use of meals from the northern hemisphere produced at low temperature (LT) is favoured because they are higher in protein and of the highest digestibility. For instance, blue whiting meal is a highly digestible meal and while some users dislike its higher ash level, most processors find it worthwhile using and may be reluctant to reduce its use.
- *Supply assurance:* Should the industry become selective for more sustainable fishmeal stocks, the demand for those stocks will increase. This has a number of implications:
    - o Fishmeal supply may be restricted for reasons outside the control of fishmeal manufacturers and their clients, e.g. the wide inter-annual variability of South American production through the El Niño events.
    - o Connected with the point above, prices may become more variable, with a general shift upwards as the supply base is effectively reduced.
    - o Increased pressure will be put upon sustainable fishmeal stocks. However, this should not be an issue if they are well regulated and controlled (as they should be if deemed as sustainable).
    - o Risk reduction – formulators such as a mix of fishmeals from different sources to reduce the risk of unforeseen quality or contamination problems.

These concerns are only really valid over the short term. Longer-term supply assurance depends on the sustainable management of feed fisheries, and the industry may have to review its approach to fishery exploitation if it is to continue to be viable in the future.

- *Seasonal availability:* Most fishmeal manufacturers use several species throughout the year to reflect seasonal availability and condition (i.e. oil content). Although it is possible to choose or avoid a particular fish species, to do so necessitates increasing purchases of other meals, possibly at higher cost and, given shipping and storage constraints, having to keep larger stocks to get past the seasons involved. Producers are reluctant to hold stock for more than a few months. When forced to do so, they usually reduce prices to clear stock out. If aquaculture buyers have no storage available, then they spot buy almost always above the market, and because they generally beat the market by buying long and at lows in the cycle whenever possible, this severely impacts their buying strategy. Some aquaculture companies have very long-term frame contracts with fishmeal producers. Agriculture feed buyers source fishmeal in smaller quantities, use traders and have shorter term buying positions. They are more numerous than the oligopoly of aquaculture feed buyers, and so their behaviour is more of an approximation to a perfect market.
- *Buying power:* Asia's burgeoning pig and poultry industries require more fishmeal than the aquaculture industry in the western world and thus are an important factor in determining world price and availability. Aquaculture buyers no longer can influence the trade in fishmeal in Peru and elsewhere to the degree they have done in the past. Norway has become a net importer rather than, as once, an exporter. Chile is now a net importer of fish oil. So freedom to avoid or choose certain meals could be constricted by this factor.

4.3.2 Recommendations for improving responsible sourcing of aquafeeds

Huntington (2004) made a number of recommendations to the Scottish fish-farming industry to improve their sourcing of sustainable fishmeal and oils for aquafeeds. These have been reviewed and expanded to apply to European aquaculture as a whole:

- *Better structured feed-fish fisheries sustainability criteria:* The majority of European aquafeed manufacturers use the FIN Sustainability Dossier (FIN, 2003), which is published every year once the EC's annual fisheries management regime has been agreed. As discussed previously, this dossier now includes a review of the wider ecosystem ramifications of feed-fish utilization. To assist this process further, it would be useful to have a formal series of "sustainability criteria" specifically for feed fisheries that could be applied to the main species being sourced and independently verified to provide consumer confidence. This could act as a first stage to pre-assessment and full certification of the more sustainable feed fisheries over the longer term.
- *Improved traceability:* Fishmeal purchasers should request improved information on fishmeal species ingredients, their origin and chain of custody. Such information should be made fully available to the public domain to provide assurance of the industry's transparency.
- *Sustainable purchasing strategies:* Fishmeal purchasers should develop a purchasing strategy that minimizes and, where possible, eliminates the use of those species considered unsustainable. This strategy could be prepared with a number of different timescales:
    - a. *short term*: reduce the purchase of less sustainable species, such as blue whiting or jack mackerel, where possible;
    - b. *medium term:* develop approaches to halting purchases of less sustainable species through a detailed analysis of alternatives; and
    - c. *long term:* develop alternative protein and oil substitutes for fishmeal and fish oil; set a date for and approach to purchasing all fishmeal and fish oils from sustainable fisheries independently verified for "responsible management".

This purchasing strategy could be updated regularly to reflect changes in different fishing practices and the latest "sustainability assessments", together with emerging trends in fish nutrition and alternative feed materials. The use by procurement departments of environmental management systems such as International Organization for Standardization (ISO) ISO 14 001 to ensure that procurement strategies minimize the environmental implications of purchasing should also be considered.

- *Use of non-fish protein and oil:* Greater knowledge should be developed about the options for substituting different fish species with non-fish protein and oil at different times of year to obtain a required fishmeal quality and specification.
- *Premium branding:* European aquaculture, in partnership with its own customers, should seek to develop its premium brand image by encouraging its feed suppliers to move toward targets for achieving sustainable supplies.

5. ENVIRONMENTAL IMPACT OF AQUACULTURE BASED ON FEEDFISH AS INPUTS

While the sourcing of sustainable raw materials for aquafeeds is only just now becoming a serious issue in European aquaculture, the impact of aquafeeds on the environment has been on the agenda for a number of years after the potential magnitude of waterbody eutrophication and other effects of intensive aquaculture were realized. As a result, the content, digestibility and physical structure of pelleted feeds have undergone considerable evolution to minimize wastage and their subsequent effect on the environment.

5.1 Environmental impacts of aquafeed use in Europe

Compounded fish feeds, especially for carnivorous fish such as salmon, trout, seabass and seabream, are now used for over 99 percent of European aquaculture production of finfish. Food-derived waste has four sources (Dosdat, 2003):

- *Uneaten feed.* This is the case with artificial feeding, generally due to poor husbandry, fish diseases or unsuitable environmental conditions.
- *Undigested feed*. This is the case mainly in bivalves when the control of intake and repletion is insufficient. Thus, they ingest more than they can process and release the intact microalgae in the form of faeces called pseudo-faeces.
- *Indigestible compounds*. Complex molecules present in the feed are split into small molecules that either can or cannot cross the intestinal barrier during digestion. Those that cannot, due to their size or their shape, are rejected in the form of particulate matter (faeces).
- *Excreta*. Excretion is the physiological phenomenon by which molecules that come into the body and dissolve in the plasma are released after being processed and degraded. These are soluble compounds that are discharged into the water through particular organs, such as the gills and the kidney. Thus, aquatic animals are directly subjected to the effect of their own waste products.

The impacts of these waste materials can be divided into two main areas of concern:

- *Hyper-nutrification of the waterbody:* Eutrophication is the process of natural or anthropogenic enrichment of aquatic systems with inorganic nutrient elements. The long-term eutrophication of coastal and estuarine waters results from the additions of both dissolved inorganic and organic nutrients and increased biological oxygen demand (BOD). Dissolved inorganic nutrients released by finfish culture and regenerated from sediments enriched with sedimented organic matter may stimulate phytoplankton production and increase oxygen demand. The degree of nutrient enrichment is influenced by the scale of aquaculture, local hydrographic characteristics and the magnitude of other sources relative to aquaculture, and internal processes such as uptake by phytoplankton, algae, internal recycling, resuspension of fine material and uptake by biofouling communities that colonize cage-farming areas. Eutrophication can alter the ratio between essential nutrients (carbon: nitrogen: phosphorus), as well as absolute concentrations by causing a shift in phytoplankton species assemblages. The possible interactions between aquaculture and harmful algal blooms (HABs) are of considerable current environmental and public interest in Europe. This relationship exists on two levels: (i) the role of intensive finfish aquaculture in contributing to HAB events through the ability of fish to input nutrients into the aquatic ecosystem through uneaten food, faecal material and metabolic by-products; and (ii) the impact of HABs resulting from wider anthropogenic and natural sources upon aquaculture systems, especially cultured bivalves. Other studies have looked at the effects of different shellfish and finfish excretion products on phytoplankton growth – shellfish excreta are generally stimulatory; finfish ammonia compounds are also stimulatory, but other metabolic products may have an inhibitory effect (Arzul, Seguel and Clément, 2001).

- *Sedimentation from faecal solids and uneaten food:* Both finfish and shellfish aquaculture produces particulate wastes that mainly result from the undigested organic and inorganic elements of the feed materials. While land-based farms are able to remove these elements from the system through the use of settlement ponds and filtration, they are more difficult to control in cage farms. Particulate loss occurs during finfish feeding, and wastes are usually found directly under the net cages with relatively local impacts. The underlying sediments become enriched with organic matter that degrades more easily than the natural particulates in coastal areas. This may have important consequences for sediment biogeochemistry, especially when microbial activity is engaged. In the marine environment, sulphate reduction is among the most important mineralization processes and is stimulated by enrichment with organic matter. This leads to an increase in the production of sulphides, which may accumulate to levels toxic for benthic fauna. In moderately enriched sediments, opportunistic species may survive, but if enrichment is increased further, the fauna may disappear completely. This leaves the degradation of waste products to microbes only, and such a change is usually followed by increased burial rates of organic matter. It then becomes very difficult for a climax benthic community to re-establish itself. The impact of such sediment deposition may largely be limited to localized effects. However, the change in such coastal benthic faunal communities may have consequences for inshore nursery grounds. These are not necessarily negative, as juvenile stages may benefit from faunal changes, as they are able to consume the copepods or annelids favoured by organic enrichment.

The use of trash fish in European aquaculture is limited to tuna fattening in the Mediterranean Sea. The Worldwide Fund for Nature (WWF) has noted that this has had a number of undesirable impacts, such as increasing the fishing pressure for species that were not previously fished commercially, such as the round sardinella in the western Mediterranean Sea, with possible consequences for one of its main predators, the common dolphin. In addition, they raise the possibility of transmitting viruses from non-endemic feedfish to local wild fish populations, as has been experienced in Australian waters (WWF, 2005).

5.2 Examples of environmental "best practice"

Intensive aquaculture in Europe has been driven to improve efficiency by a combination of lower economic margins and an increasingly strict regulatory environment. This is reflected by the very low FCRs now experienced in salmonid and seabass/seabream culture, as well as by the gradual adoption of joint area management, where companies operating within an enclosed or semi-enclosed area work to reduce the cumulative impact of their production.

Various approaches have emerged from the salmon farming industry in Scotland and Norway that provide useful examples of environmental "best practice" that have potential for wider replication through Europe, especially in the expanding cage-culture subsector.

- *Modelling of sites to set biomass limits:* Computer modelling can provide assessments of both impacts from nutrient loading on waterbody or regional algal productivity, as well as the benthic effects from sub-cage deposition. The particle tracking model *Depomod* has been extensively used in Europe for determining the theoretical carrying capacity of cage-farming areas as well as assessments of the deposition of organic matter beneath finfish cages and mussel rafts. Depomod is limited to near field predictions through the use of a uniform horizontal flow field – detailed modelling at a waterbody and regional scale requires the capability to represent two or three dimensional flows, depending on the degree to which the waterbody is vertically mixed. Various proprietary models exist, for example *Delft3D* and *Mike21*, that can enable detailed assessments of the cumulative effects from aquaculture activity on water quality, such as nutrients and algal activity, in a waterbody. While numerical flow and water-quality models of this nature require considerable effort to set up and calibrate, and the level of effort required increases with the complexity and scale of the model domain and the water quality processes of interest, they can provide useful predictions on the carrying capacity of sites and thus assist in the planning and consenting of aquaculture development.
- *Setting of EQS:* Environmental Quality Standards (EQS) can be used in assimilative capacity model development. EQS values have to be set for the different environmental quality variables (EQVs) defined by regulators and industry bodies, such as dissolved oxygen concentrations. These then provide the basis for setting environmental quality benchmarks and monitoring targets for aquaculture areas.
- *Joint management of sea, semi-enclosed bay, lake and watershed areas*: In Scotland, the use of Area Management Groups has resulted in greater coordination between different farming interests within a single waterbody that allows joint management actions, such as the complete fallowing of sea areas between aquaculture production cycles. This helps control and reduce the cumulative impacts of intensive aquaculture, especially in areas with limited flushing rates.
- *Waste reduction strategies:* Perhaps the greatest change in intensive aquaculture over the last ten years has been the reduction of wastage through better management and monitoring of feeding. Various approaches have been adopted, including maximizing the bioavailability of feed components through applied research, as well as better feed delivery management using computer-controlled, centralized feeding systems. Feeding rates can be further adjusted by the use of underwater cameras and sensors that detect when feed is passing through cage systems and not being utilized by the stock, thus invoking a reduction in feeding rates.
- *Environmental monitoring:* Intermittent monitoring of the benthos and water column will also provide managers with information on the levels of feed utilization, wastage and impact from aquaculture systems, especially when combined with the EQS approach described above.

6. CURRENT AND POTENTIAL ALTERNATIVE USES OF FEEDFISH AND OTHER AQUATIC SPECIES AND THE RELATED MACRO-LEVEL IMPACT ON FOOD SECURITY AND POVERTY ALLEVIATION

6.1 Current and alternative uses of feed-fish catches

Europe differs from Asia in that aquaculture depends upon formulated diets that have been made from fishmeal and fish oils from targeted feed fisheries. Around three-quarters of European fishmeal is derived from targeted feed-fish fishery catch, while one-quarter is from either (i) those fisheries where a portion is used for direct human consumption or (ii) bycatch or trimmings that are utilized for fishmeal when no economically preferable alternative is available.

Table 22 shows the ten main species used to produce fishmeal in Europe. Excluded from this analysis are the feed fisheries of South America, which are considered separately within this volume. This table indicates a number of trends and opportunities:

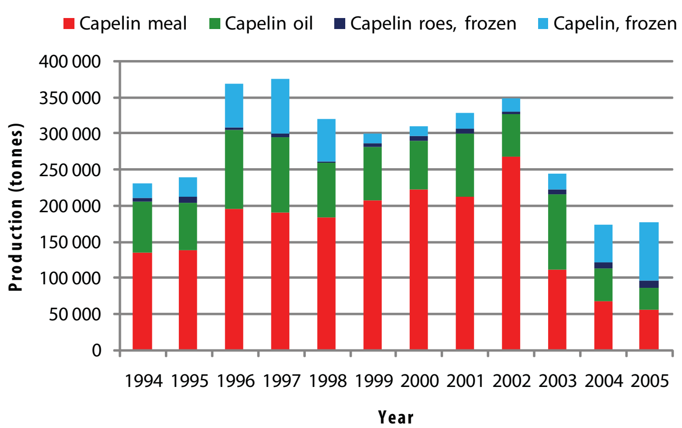
6.1.1 Increased utilization of the feed fisheries for human consumption:

While some of the feed-fish species are too small to use for human consumption (i.e. sand eel and Norwegian pout), others show some potential for direct human consumption, specifically blue whiting and capelin (Table 22).

Blue whiting are unlikely to find a ready market in chilled form, either as whole fish or as fillets – their small size, discoloration due to autolysis and bruising and the presence of parasites all weigh against them in competition with other well established white fish species. However, research some 10–15 years ago (MAFF, undated) showed that skinless fillets can be produced from chilled or frozen whole fish for the manufacture of frozen laminated blocks for finger or portion production. Another possible product form investigated was blue whiting mince prepared from skinless fillets that could also be used to manufacture fish cakes, fish pies and cook-freeze dishes. One possible European export outlet for blue whiting is to Japan as surimi, an intermediate product in mince form used there for the manufacture of *kamaboko*, a speciality product of high value. Uptake of these new technologies has been slow and blue whiting is unlikely to become an important food fish in the near term.

A proportion of capelin is currently used for human consumption (Figure 9). Around 16 percent of the Icelandic catch in 2005 was frozen whole for sale in Japanese and East European markets. Over the early part of the 2006 season, of the 135 000 tonnes reported caught by Icelandic vessels, 58 000 tonnes (42 percent) were frozen for human consumption and 78 000 tonnes (58 percent) were processed into meal and oil. Such low capelin catches favour a higher proportion of these fish going for human consumption – an examination of the trend in Icelandic capelin usage over the last ten years indicates a fairly consistent volume of capelin used for human consumption.

FIGURE 9
Icelandic capelin production by product type, 1994-2005



Source: FAO (2005a)

6.1.2 Non-target, bycatch or trimmings that are utilized for fishmeal

A number of food-fish species are also used for reduction into fishmeal and fish oil, either whole when market conditions

TABLE 22

Principle European feedfish and their uses, 2004

Species (2004 catch, thousand tonnes)	Main use	Proportion used for fishmeal	Uses		Comment
			Current	Potential	
Blue whiting (2 453)	Fishmeal	>95%	Fresh and frozen whole fish for human consumption	Frozen blocks for "economy" meals, mince, surimi	Unlikely to be accepted in chilled form due to their small size, bruising, autolysis and parasite load.
Capelin (608)	Fishmeal	50–85%	Human consumption (especially roe)	Incorporating oil into food products	Of the 633 000 tonnes of Icelandic capelin landed during the 2004/2005 season, 100 000 tonnes were frozen for consumption in Japanese and East European markets.
Sand eel (390)	Fishmeal	100%	None	None	
Norwegian pout (22)	Fishmeal	100%	None	None	
Antarctic krill (22)	Fishmeal	70%	Boiled frozen krill or peeled krill tail and concentrate powders	Aquafeeds, non-nutritional uses	Attractive as an aquafeed due to high levels of astaxanthin for salmonid feeds.
Atlantic herring (1 751)	Human consumption	<30%	Fresh and frozen for human consumption, tuna farming	Added-value for human consumption	Strengthening frozen herring prices have made this fish less attractive for fishmeal use. Atlanto-Scandinavian use for fishmeal has dropped from 68% to 25% since 2001.
Sprat (684)	Fishmeal and human consumption	<50%	Smoked for human consumption, mink food	Added-value for human consumption	Mainly used for fishmeal except in Latvia and Russian Federation. High dioxin levels may have implications for use in fishmeal/oil.
European pilchard (297)	Human consumption	c. 50%	Canned	Added-value for human consumption	
Atlantic horse mackerel (202)	Human consumption	<20%	Block frozen for Russian Federation and Africa	Added-value for human consumption	
European anchovy (159)	Human consumption	?	Canned	Added-value for human consumption	

Source: Compiled by the author

TABLE 23
Levels of herring processed for fishmeal and human consumption, 2001–2005

Icelandic herring	2001/2002		2002/2003		2003/2004		2004/2005	
	Thousand tonnes	%	Thousand tonnes	%	Thousand tonnes	%	Thousand tonnes	%
Processed on land for human consumption	35	35	28	29	33	26	33	29
Processed at sea for human consumption	21	21	19	20	27	21	37	32
Total processed for human consumption	56	56	47	49	60	47	70	61
Total Processed for fishmeal*	45	45	49	51	66	52	45	39
Total processed	**101**	**100**	**96**	**100**	**126**	**100**	**115**	**100**

Atlanto-Scandinavian herring	2001/2002		2002/2003		2003/2004		2004/2005	
	Thousand tonnes	%	Thousand tonnes	%	Thousand tonnes	%	Thousand tonnes	%
Processed on land for human consumption	7	6	2	2	0	0	3	2
Processed at sea for human consumption	33	26	48	39	47	53	102	73
Total processed for human consumption	40	32	50	41	47	53	105	75
Total processed for fishmeal*	86	68	73	59	42	47	35	25
Total processed	**126**	**100**	**123**	**100**	**89**	**100**	**140**	**100**

* It has been assumed that 50 percent of the catch processed on land will be trimmings that are going to the fishmeal industry.
Source: www.srmjol.is/displayer.asp?cat_id=47&module_id=220&element_id=207, accessed May 2007

make reduction an economically preferable alternative or as trimmings from processing waste.

Atlantic herring stocks are improving and support a number of economically important fisheries. The majority of herring catches are landed as either fresh or frozen whole fish. In the EU, controlled herring fisheries (west of the United Kingdom, the North Sea, the Skagerrak and Kattegat Seas) food grade can only be sent for reduction if there is no market for human consumption. All fish caught in the Baltic Sea can be offered as feed grade.

As shown in Table 23, the proportion of herring processed for fishmeal by the Atlanto-Scandinavian fisheries has decreased from 68 percent in 2001/2002 to 25 percent in 2004/2005 due to a combination of greater land and sea freezing capacity as well as strengthening prices for the frozen whole product for human consumption.

Antarctic krill demand is likely to increase due to its excellent value as a nutrient source for farmed fish and crustaceans (protein, energy, essential amino acids). Other outstanding properties of krill are its natural pigment content (particularly appropriate for salmon farming), its palatability, its low content of pollutants and its likely improvement of larval fish survival. These attributes make krill a more attractive feed than potential competitors such as squid meal, clam meal, artemia soluble and fish soluble (Sclabos, 2004).

The western European catch of sprat has largely been used for fishmeal, but it is a popular food fish in eastern European Baltic states. However, with the increased awareness of dioxin contamination of oily fish in the Baltic Sea, it may be that the demand for human consumption will decrease and a greater proportion will be used for reduction (FAO, 2005b). There is, therefore, the possibility for increased human utilization by the countries of Eastern Europe of the "low-value" feedfish from the cleaner waters of the North Atlantic. However, this potential is likely to be constrained by the continued low demand for low-value fish[10] from this region – in 1985, the regional annual consumption of low-value fish was 2.5 million tonnes but dropped to 150 thousand tonnes by 1997 – and is not predicted to increase to much more than 161 thousand tonnes per year by 2020 (Delgado *et al.*, 2002).

In summary, the use of the main feed-fish species for direct human consumption is driven by market and other economic factors rather than technical or product development constraints. As a result, there is unlikely to be any dramatic change in the production of feed-fish species being used directly as food over the medium term. However, this depends upon a number of extrinsic factors such as the availability and price of other feed protein commodities such as soya meal.

6.2 Comparative analysis of use in aquafeeds versus for human consumption

As the section above indicates, there are few alternative uses of feedfish for the main feed fisheries supplying fishmeal production in Europe that are not already being utilized. In European feed fisheries, a more fundamental question is whether it is more ecologically efficient if these feed-fish stocks – which are often prey items for both commercial fish species as well as an integral mid-level component of the food chain in many European seas – are left in the sea. Essentially, is it more effective to harvest low trophic-level species in industrial fisheries and convert the biomass obtained to human consumption fish protein in aquaculture systems, or is it better to leave low trophic-level fish in the sea where they can be consumed by their natural predators, and then to harvest species from higher trophic levels in fisheries for human consumption?

This question was asked of ICES by the EC's DG Fisheries, and its response was published in the annual report of the ICES' Working Group on Ecosystem Effects of Fishing Activities (ICES, 2004). Its conclusions were as follows:

- *Transfer efficiencies in natural marine food webs*: The transfer efficiency of both energy and carbon between trophic levels along a food chain is not 100 percent. Energy is required for metabolism and maintenance, and only a fraction of the food consumed by a predator is actually converted to predator biomass. Transfer efficiencies in the range from 10 to 15 percent are generally accepted for predator-prey interactions involving fish predators in marine temperate shelf-sea food webs (Jennings, Kaiser and Reynolds, 2001).
- *Transfer efficiencies in aquaculture systems:* Taking into account the levels of fishmeal inclusion and food conversion ratios, the total conversion efficiency of, say, a sand eel-derived salmon diet in producing a harvestable biomass is around 10–17 percent, which is much in line with natural food webs.
- *Other energetic factors:* In addition to the above efficiencies, the energy/material "costs" need to be considered. Additional materials are required for production of fish feeds, as well as the energy involved in processing. However, while the trophic energy efficiency in marine food chains may be around 10–15 percent, this does not account for natural mortality due to predation, which may reduce this efficacy considerably.
- *Conclusions:* ICES concluded that "if one is only concerned about the efficiency of converting sandeel biomass to human consumption fish biomass, then the exploitation of sandeels by industrial fisheries for the aquaculture industry is at least as efficient ecologically". ICES then goes on to ask the question as to whether it is of greater benefit to society to exploit lower trophic-level marine fish resources in industrial fisheries and rely on an aquaculture industry to provide mankind's human consumption fish requirements, or is it better to leave these fish to be processed through the natural marine food web and then to harvest fish in the higher trophic levels in fisheries for human consumption?

[10] Low-value fish according to the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) include herrings, sardines, anchovies and mackerels.

ICES examined the premise that if industrial fisheries are reduced, then gains reflecting 10 percent of the reduction will be made in human consumption landings. Runs of a Multi-Species Virtual Population Analysis (MSVPA) model were used to examine this assumption, as were data on the consequences of a four-year closure of the East of Scotland sand-eel fishery on local gadoid (cod, haddock and whiting) populations. The results provided no evidence to support the contention that ceasing industrial fisheries will stimulate catches in the fisheries for human consumption at the current time and under the prevailing circumstances. ICES goes on to state that so long as the food conversion efficiencies are regularly reviewed, then a closely regulated combination of industrial fisheries and fisheries for human consumption may provide the only solution to the long-term demand for fish protein.

6.3 Risks of utilizing feedfish in the food chain

With European aquafeeds so reliant upon fishmeal from wild sources, the aquafeed industry is potentially vulnerable to economic factors that might change the price of fishmeal, with significant consequences for what is now a low-margin farming process. The industry is also vulnerable to health issues arising from contamination of fishmeal and fish oil raw materials, either through concentration of pollutants through the food chain or via the production and distribution process, that affect consumer confidence in the farmed product.

Two potential problems have become particularly important recently (New and Wijkström, 2002). The first problem is the presence of dioxin, polychlorinated biphenyl (PCB) and other persistent organic pollutant (POP) residues in human food products of animal origin and the potential carryover of these substances from animal feeds. The second problem is the relationship between meat and bone meal and the incidence of bovine spongiform encephalopathy (BSE) in ruminants, coupled with the linkage with Creutzfeld-Jacob Disease (CJD).

6.3.1 Persistent organic pollutant (POP) residues

Salmonids, which represent around 80 percent of European aquaculture production by volume, are relatively oily fish that easily bioaccumulate lipophilic POPs such as PCBs, dioxins and polybrominated diphenyl ethers (PBDEs), should they be present in the diet. It is widely recognized that contamination levels of forage fish from the industrialized waters of the Baltic Sea and coastal waters elsewhere in the northeastern Atlantic are higher than those found in Pacific waters, and this may be mirrored in feeds manufactured from fishmeal originating from these waters.

The levels of POPs (PCBs, dioxins, toxaphene and dieldrin) in farmed fish were brought to wide public attention with a much quoted study reported in the journal *Science* (Hites, *et al.*, 2004) that investigated contaminants in a variety of fish feeds and farmed salmon products. Hites *et al.* (2004) concluded that salmon produced in Europe had significantly higher contaminant levels than those produced in both North and South America, reflecting higher contaminant concentrations in forage fish from the industrialized waters of Europe's North Atlantic as compared with forage fish from the waters off North and South America. Indeed, fishmeal and fish oils of European origin have been reported by the Scientific Committee on Animal Nutrition (SCAN) of the European Commission to contain much higher levels of dioxin than those originating from the cleaner waters off Peru and Chile (SCAN, 2000). Such differences in dioxin content not only affect fishmeal and fish oils but also influence the residue levels in wild fish caught for direct human consumption. In a study of European fish cited by Klinkhard (2001), one of the highest dioxin contents found in samples taken between 1995 and 1999 was in wild salmon from the Baltic Sea (Sweden). Of the farmed salmon and trout analysed during this period from Finland, Germany, Norway, Sweden and

TABLE 24

Current limits on dioxins in fishmeal, fish oils and aquafeeds

Product	Maximum level (ng/kg product)	Action level (ng/kg product)
Fishmeal	1.25	1.0
Fish oil	6.00	4.5
Compounded fish feed	2.25	1.5

Source: University of New Castle upon Tyne and Poseidon Aquatic Resource Management Ltd . (2004)

the United Kingdom, the highest level of dioxin reported was only 15 percent of the level found in Baltic wild salmon.

In order to improve food safety, the EU has adopted a two-fold strategy of (i) reducing POP inputs into the environment and (ii) restricting the level of POPs that can enter the human food chain by setting the maximum and action levels[11] of dioxins in fishmeal, fish oil and aquafeeds over the period 2002–2005 as shown in Table 24. These levels are close to the levels found in fishmeal and fish oil of European origin but much higher than the highest levels found in products originating from Chile and Peru.

The comparisons between different sources of fishmeal and fish oil show very low levels of dioxin. SCAN commented that "no adverse effects from dioxins would be expected in mammals, birds and fishes exposed to the current levels of background pollution" (SCAN, 2000). Despite this, a considerable proportion of the population of Europe (and undoubtedly other regions) is exceeding the tolerable weekly intake (TWI) levels for dioxins set by various authorities. As there is a considerable safety factor imposed on TWI, this does not necessarily mean that there is an appreciable risk to individual health. However, exceeding TWI levels erodes the protection of this safety factor.

European exposure to dioxins and PCBs is decreasing (by a factor of about 50 percent over the last 10–15 years) due to improved waste management and restrictions on the use of these materials.

6.3.2 Transmissible spongiform encephalopathy (TSE)

First, it is important to state that there is no epidemiological evidence for the transmission to humans of a variant of CJD caused by prions that use fish or fish products as vectors (GLOBEFISH, 2001).

A temporary EU ban on the use of animal proteins in certain livestock feeds was approved in 2000 (Commission Decision 2000/766/EC; Council of the European Union, 2000) over the period to June 2003 and has since been extended to June 2005. The main purpose of this action by the EU was the removal of meat and bone meal from European animal feeds, together with the destruction of stocks of this material, in an effort to contain the spread of BSE. A permanent TSE Regulation (1234/2003) amending regulation 999/2001 covering feed controls came into effect in September 2003 (although the ban on the use of blood products and blood meal was lifted). The EU ban is still in force at the time of writing.

The EU ban on the use of animal proteins includes the use of fishmeal in ruminant feeds but does not ban its use in feeds for pigs or poultry, or its use in aquafeeds. The EU ban on the use of fishmeal in ruminant feeds was initiated because meat and bone meal has unfortunately been used at times to adulterate fishmeal in order to alter its protein content. While the use of fishmeal is not banned in feeds for other animals, including fish, the ban concerning ruminant feeds causes a further problem for feed manufacturers generally. This problem is that cross-contamination may occur between

[11] Action levels act as an "early warning", triggering a proactive approach from competent authorities and operators to identify sources and pathways of contamination and to take measures to eliminate them.

batches of feeds made for one type of livestock and batches made for other types of animals – the current EC regulation has a zero tolerance, and thus manufacturers have been forced to mill ruminant and non-ruminant feeds at different factories. It is possible that the current ban may stay in place for some time. However, the tolerance level has been lifted to 1 percent, which should ease the situation for feed producers.

7. REGIONAL ISSUES ON THE USE OF FISH AND/OR OTHER AQUATIC SPECIES AS FEED FOR AQUACULTURE

7.1 Issues of regional importance

Given the high level of dependence of European aquaculture on compounded feeds in intensive systems, the issues of regional importance reflect the sourcing of raw materials included in the feeds rather than the environmental impact of their actual use. It is considered that there are three issues of immediate concern:

- *Improved sustainable management of feed-fish stocks:* Feed fisheries, which are largely composed of small, bony pelagic fish, require quite distinct management approaches compared with the often larger and slower-growing fisheries for human consumption. As described earlier in this report, their management needs to recognize the dynamic turnover of the stock and the high degree of inter-annual variability that may depend upon extrinsic, often climate-related factors. Furthermore, they may be highly migratory and, therefore, often shared among more than one fishing nation.

  Within Europe, the majority of the northern feed stocks are managed through the European Commission Common Fisheries Policy (CFP), mainly acting upon the advice of the International Council for the Exploration of the Seas (ICES). Other major fisheries – most notably those managed by Norway and Iceland – are also subject to national, EC and international management agreements. Mediterranean fisheries within EU Member States' waters operate under the CFP as well as within the wider General Fisheries Council for the Mediterranean (GFCM) management regime with the FAO.

  While it is possible to provide science-based precautionary management of feed -fish stocks, political and economic reality may combine to reduce management effectiveness, as typified by the long period in which it took to finalize the joint management of the northern blue whiting stock. Furthermore, the ecosystem linkages between feed fisheries and natural predators such as white fish, tunas, sea birds and marine mammals are still not fully understood, and thus further precautionary thinking is necessary in many cases.
- *Increased utilization of feedfish for human consumption:* As mentioned earlier, while catchs of a number of food fisheries are not suitable for direct human consumption, catchs of other food fisheries are. The main barriers to their direct use are not so much technical but more related to market and other economic or cultural influences.
- *Greater substitution by protein and oil substitutes:* Substitutes for fishmeal protein and marine fish oils are continuously being sought and progress is being made. Protein substitutes are already used in fish feed in the United Kingdom and Norway, with up to 25 percent of the protein in the feed derived from plants. The uptake of fish oil substitutes has been slower. Concerns over the dioxin and PCB levels in the northern hemisphere fish oils have increased the pressure on fish oil manufacturers to produce oils with reduced levels of dioxins. Scottish Quality Salmon (SQS) has revised its Quality Manual (Product Certification Scheme for Scottish Quality Farmed Salmon) to allow up to 25 percent of the oils added to the fish feed to be of plant-based origin. However, the level of substitution of fish-based meals and oils possible is limited by their lack of essential amino acids (such as lysine, methionine and histidine). Substitution at higher levels may limit

grow. Another issue facing the plant meal and oil substitution option in Europe is consumer opinion and the affect that vegetable oil substitutes may have on the continued acceptance of farmed fish as a "high-quality" product similar to its wild counterpart. To produce a product as "near to the wild product as possible", research is also focusing on the "dilution" of vegetable oils in the flesh when fish are fed diets containing 100 percent marine fish oils for six months prior to harvest. In addition, vegetable oil substitutes do not necessarily improve the environmental sustainability of the product (e.g. increased soybean production may lead to further rainforest clearance).

7.2 Ongoing work of interest

7.2.1 Improved sustainable management of feed-fish stocks

In Europe, most work on northern stocks is through ICES, which includes a number of relevant working groups:

- Planning Group for Herring Surveys
- Planning Group on Northeast Atlantic Pelagic Ecosystem Surveys
- Regional Ecosystem Study Group for the North Sea
- Study Group on Assessment Methods Applicable to Assessment of Norwegian Spring Spawning Herring and Blue Whiting Stock
- Study Group on Regional Scale Ecology of Small Pelagics
- Study Group on the Estimation of Spawning Stock Biomass of Sardine and Anchovy
- Working Group on Ecosystem Effects of Fishing Activities
- Working Group on Northern Pelagic and Blue Whiting Fisheries
- Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy

These working groups feed information into the decision-making process through the ICES Advisory Committee on Fishery Management (ACFM). The ACFM meets twice a year (summer and late autumn) to prepare its advice, which is then translated into effective management by the national governments and the EU.

EU fisheries management in the Mediterranean Sea tends to be focused upon coastal fisheries. In general, EU catch limits or quotas are not applicable in the Mediterranean Sea, with the exception of limits on bluefin tuna that have been introduced in response to recommendations by the International Commission for the Conservation of Atlantic Tuna (ICCAT). In contrast, the GFCM's work has focused on shared or straddling stocks, particularly those involving demersal and large pelagic species. GFCM's Sub-Committee on Stock Assessment (SCSA) recently assessed the stocks of 11 small pelagic species, which assessment will result in the development of management programmes controlling the pelagic trawling and purse-seine fisheries exploiting anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*) and sprat (*Sprattus sprattus*) (FAO, 2006b).

The EU is currently finalizing a strategy and action plan to improve scientific advice and research in stock evaluation in the waters of third countries. This strategy will combine actions to (i) improve data collection, management and use; (ii) increase the level of research, especially into ecosystem considerations; (iii) strengthen the role of Regional Fisheries Organization (RFOs) and (iv) provide greater cooperation with European research and advisory organizations, as well as improve the capacity of national fisheries administrations to operate within a regional context.

Ultimately, pressure for improved management of feed-fish stocks must come from both the aquaculture industry and consumers. One of the barriers to the environmental certification of aquaculture in Europe has been the inability of the feed manufacturers to assure the sustainable sources of fishmeal and fish oils in compounded feeds. As mentioned earlier, this has become an increasingly important issue, with feed manufacturers looking to FIN for reassurance (see Section 4.2.1). There has also been growing pressure for independent certification through such schemes as MSC's standard for responsible fishing (see Section 4.2.2).

7.2.2 Impact of fisheries on marine ecosystems

There have been an increasing number of reviews of the impact of fisheries upon marine ecosystems, including:

- ICES/SCOR (Scientific Committee on Oceanic Research) Symposium on Ecosystem Effects of Fishing (*ICES Journal of Marine Science,* 57(3), June 2000);
- The Workshop on the Use of Ecosystem Models to Investigate Multispecies Management Strategies for Capture Fisheries (*Fisheries Centre Research Reports,* Vol. 10(2), 2002);
- The IWC Modeling Workshop on Cetacean-Fishery Competition (*Journal of Cetacean Research and Management,* 6 (Suppl.), 2004); and
- The Workshop on Ecosystem Approaches to Fisheries in the southern Benguela (*African Journal of Marine Science* 26, 2004).

7.2.3 Increased utilization of feedfish for human consumption

Small-pelagic fish tend to be highly perishable – the high oil content of the flesh makes them susceptible to oxidative rancidity, makes the flesh soft and more susceptible to physical damage and faster spoilage than white fish. The high catch rates also mean that fish to be used for human consumption must be landed, chilled and processed in large quantities, and they must be handled rapidly. Much research was carried out in the 1980s in the United States of America into the use of menhaden for surimi, but uptake was limited because it was not possible to de-fat the flesh to achieve a shelf-stable product without affecting the taste and texture of the flesh. The Nordic Industrial Fund supported a Nordic network project entitled "Pelagic fish–New Possibilities" which includes a homepage that collates technical, scientific and industrial information about catching and processing small pelagic fish with the specific aim of facilitating diversification of small pelagic fish products, especially for direct human consumption. Otherwise, there has been extensive private sector interest in developing processing techniques both to stabilize small pelagic material and to extract the main protein components for use in more versatile forms such as surimi.

7.2.4 Greater substitution with protein and oil substitutes

The potential for including higher levels of non-fishmeal protein sources in aquafeeds has been explored for a number of years with gradual but significant success. As discussed earlier, the proportion of oilseed and legume-derived meals in aquafeeds will increase from 17 percent to 24 percent by 2010, resulting in the reduction of northern hemisphere fishmeal, while vegetable oils will become an important source of oils in salmonid aquafeeds, accounting for nearly a quarter of the oil content by 2010, again resulting in the reduction of northern hemisphere, from the feed-fish supplies.

Research is currently being conducted by the major aquafeed manufacturers in Europe and is being supported by research initiatives from both individual governments and the European Commission. Current or recent initiatives of interest include:

- *Perspectives of Plant Protein Use in Aquaculture (PEPPA) project:* a €2.5 million project over 2001–2004 to (i) replace the greater amount of fishmeal with plant protein sources in fish diets while improving muscle protein growth, fish quality, health, reproductive potential and environmental quality; (ii) understand the metabolic fates of dietary amino acids and carbohydrates as carbon donors and as an energy source; and (iii) strengthen our understanding of the relationships between nutritional factors and endocrine control of muscle growth and adiposity using cellular and molecular approaches.

- *Researching Alternatives to Fish Oil in Aquaculture (RAFOA):* an EU-funded project studying the effect of substitution of fish oils with plant oils on growth performance, fish health and product quality during the entire life cycle of salmon, rainbow trout, seabream and seabass.
- *The Directorate of the Fisheries Institute of Food and Nutrition in Norway* has also conducted research similar to that of the RAFOA project. In addition, a second project, "Fish Oil Substitution in Salmonids" (FOSIS), is currently investigating whether fish oil can be replaced by vegetable oils in the diet without reducing the nutritional value or the growth performance of the fish, while minimizing fat deposition in the flesh.
- *Two EU research projects* are studying the effects of plant oils on fish digestion and metabolism, "GLUTINTEGRITY" and "FPPARS". In addition to vegetable oils, an EU research project "PUFAFEED" is investigating the use of cultivated marine micro-organisms as an alternative to fish oil in feed for aquatic animals.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

European aquaculture differs from aquaculture in other parts of the world in that it is a maturing industry focusing on a limited number of high-value, mainly carnivorous species. As such, the dynamic growth seen over the 1980s and 1990s has slowed, and European aquaculture is now going through a period of consolidation. This said, while growth in salmon and trout farming has slowed, the farming of seabass and seabream, as well as temperate marine species such as cod and turbot, has expanded to take advantage of the strong market as technological barriers are broken. This study considers that, based on recent trends, a cautious growth in production of around 2–5 percent per year is likely, mainly in the production of these "new" marine species.

In Europe, the intensive production of mainly carnivorous species requires a high demand for fishmeal and fish oil. With typical grow-out diets containing between 30 and 50 percent protein and 10 and 25 percent oil, European aquaculture currently uses around 615 000 tonnes of fishmeal and 317 000 tonnes of fish oil per year, thus requiring around 1.9 million tonnes of feedfish[12]. The main sources of these feedfish are the small pelagic stocks of northern Europe, as well as the Peruvian anchovy and jack mackerel of South America. In addition, approximately a third of fishmeal is produced from trimmings and the bycatch of food fisheries. The utilization of fishmeal for aquaculture is likely to fall on a per unit basis as inclusion rates drop through the use of alternative vegetable-based substitutes and greater efficiencies in feeding and nutrition. With the conservative rise of European aquaculture production of 2 percent per year, the use of fishmeal and fish oil is likely to rise to 629 000 tonnes and 343 000 tonnes, respectively, by 2015.

The feed fisheries make a low economic contribution to the fisheries sector as a whole, providing an estimated 0.5 percent of the EU's fisheries-related employment and 2.1 percent of the sector's value added. Nearly half (45 percent) of this employment is in the catching sector, with the remainder in feed-fish processing (19 percent) and fish trimming (35 percent). The adoption of technically advanced catching and processing methods has ensured that feed fisheries-related employment remains low. However, this low level of dependency hides localized relatively high levels of dependency in the fleets of Denmark and Sweden, where feed fisheries are interwoven into a substantive part of the fisheries sector as a whole.

The main impacts of this demand for fishmeal and fishoil are on the feed-fish stocks and linked elements of the food chain. Feedfish are mainly bony small pelagic fish with

[12] This assumes that 66 percent of fishmeal is derived from feed fisheries and that it takes 4.8 tonnes of feedfish to produce 1 tonne of fishmeal.

short lives and a high level of inter-annual variability that may depend upon extrinsic, often climate-related factors. As such, they are difficult to manage on a multi-annual basis when compared with longer-lived stocks for which the state of successive year classes entering the fishery can be monitored in advance. Fortunately the high levels of fecundity allow stocks to recover relatively quickly, and thus they are protected to a certain degree from high levels of exploitation. What is less certain is the consequences of stock variability on natural predators such as gadoids, marine mammals and seabirds, as well as the contribution of fishing mortality to these effects. Recent research suggests that as long as fishing mortality remains below natal mortality, feed fisheries may not cause problems for the predators on the scale of the stock. However, locally concentrated harvesting may cause local and temporary depletions, which might affect subpopulations of species such as sand eel and their natural predators at a local level.

As can be inferred from the above, judging the sustainability of feed-fish stocks is complex. Although quality and price are the main determinants for fishmeal purchasers in the aquafeeds industry, the sustainability of feed-fish sources is beginning to be more important. At present, most buyers depend upon the FIN "Sustainability Dossier" for information on what stocks are "sustainable" or not, but there is a recognized need for a comprehensive analytical framework that integrates target stock assessment with the wider ecosystem linkages. To a degree this exists with the development of ecosystem models and approaches such as the MSC criteria for "responsible fishing". Once such a framework has been created and is accepted as a suitable benchmark by the aquafeed industry and its detractors, then it will be easier for purchasers to purchase only from sustainable feed-fish stocks. This process will inevitably have consequences, such as greater pressure on those stocks deemed as sustainable, as well as possible effects on market economics. This implies that greater use of vegetable-based substitutes will be essential, which in turn may require a change in consumer attitudes towards their inclusion in farmed-fish diets.

There are a number of impacts of compounded feed use, especially in poorly flushed lakes and semi-enclosed waterbodies with limited flushing, with increased nutrient levels leading to limnological change as well as benthic change due to increased sedimentation. However, the high cost of feed, combined with increasingly strict environmental legislation, has meant that European aquaculture must become generally very efficient, with minimum wastage and production being limited to the assimilative capacity of sites. The rapidly expanding use of whole fish, usually small-pelagic species, for tuna fattening also has its problems, with the possible introduction of exotic pathogens into local coastal fish populations and increased pressure on the target stocks themselves.

The various feed fisheries targeted for fishmeal in Europe have little alternative uses. However, some, such as blue whiting, capelin, anchovy, herring and sprat, can be used for direct human consumption. The proportion that goes for human consumption depends largely on economic and cultural factors rather than technical limitations, and these factors are more difficult to address directly by the industry. Despite the relatively low cost of products from small pelagic fisheries, these products are not considered to contribute significantly to ensuring food security in any part of Europe, due to the ready availability of other nutritional options. In particular, while Eastern European markets have shown interest in utilizing feed-fish species such as capelin for human consumption, the volumes used are low and are not likely to grow significantly. However, the potential for greater utilization of feed-fish fisheries stocks by Eastern European consumers warrants further investigation, with a focus on the price sensitivity of these markets and recommendations on how products can be developed that might better utilize this raw material. However, expectations should be limited –the recent reductions in capelin catches due to low stock availability may impact investment opportunities and confidence.

At an ecological level, recent work by ICES questions the immediate assumption that the reduction of fish into fishmeal and subsequent use in aquaculture is less efficient than leaving the fish in the sea to supply predators further up the food chain. It then goes on to state that so long as the food conversion efficiencies are regularly reviewed, then a closely regulated combination of industrial fisheries and fisheries for human consumption fisheries may provide the only solution to the long-term demand for fish protein.

The European aquaculture industry has proven to be vulnerable to health issues arising from contamination of fishmeal and fish oil raw materials – either through the concentration of pollutants through the food chain or via the production and distribution process – that affect consumer confidence in the farmed product. Two potential problems that have become particularly important recently include (i) the presence of dioxin, PCB and other POP residues in human food products of animal origin and (ii) the relationship between meat and bone meal, and the incidence of BSE in ruminants, coupled with the linkage with Creutzfeld-Jacob Disease (CJD). These problems have resulted in a number of pieces of strict legislation that have banned the use of fishmeal in ruminant diets and increased the logistics and costs of feed milling and compounding in order to achieve greater levels of traceability.

In summary, although feed-fish fisheries capture and processing only make a small contribution towards European fisheries-related employment (0.5 percent) and value added (2.8 percent), they help support an important aquaculture industry that has been dependent upon regional fishmeal and fish oil production to sustain its growth. Although the relative contribution of regional feed-fish stocks is likely to fall as alternative protein products become increasingly used, it is considered that they will have a continued role to play in the production of European aquafeeds as part of a balanced strategy of sustainable use and responsibility.

8.2 Recommendations for further action

Based on the above, a number of recommendations can be made to ensure that the moderate forecasted growth in European aquaculture can continue – against a background of increased global demand for fishmeal and fish oils – and yet improve its environmental performance, particularly in regard to the sustainable sourcing of raw materials for aquafeeds. Recommendations include:

- Management of European feed fisheries should be improved through a combination of greater political will and cooperation, as well as the gradual adoption of the ecosystem approach as implementation mechanisms evolve.
- Technical and other assistance should be provided to feed fisheries outside European waters, in particular South American and Antarctic resources, through greater cooperation and the strengthening of relevant regional fisheries management organizations.
- Piloting of innovative management approaches should be done, such as the certification of responsibly managed feed fisheries to provide a market incentive to influence fishmeal and fish oil purchasing.
- Barriers to the sourcing and use of sustainable fishmeal and fish oils should be addressed by (i) adopting well-structured feed-fish fisheries sustainability criteria to guide buyers; (ii) improving traceability of materials, especially if blended during manufacture or distribution; (iii) encouraging sustainable purchasing strategies through the use of formal environmental management systems, and (iv) premium branding of aquafeeds and aquaculture products produced using sustainable raw materials.
- Markets for European feedfish and their by-products in eastern Europe and the Far East should be investigated. These markets currently absorb between 60 000 and 100 000 tonnes of Icelandic capelin per year, which might be increased.

An investigation might focus particularly on the Russian Federation, Romania, Poland and Ukraine, which have traditionally been a keen market for small pelagic products, as well as other emerging markets. Such an investigation would examine why import levels have remained static over the last five years and determine the sensitivity of price, stock availability and other key factors constraining trade. The study should also recognize the recent falls in capelin availability and the likely impact on investor confidence.

- Food products for direct human consumption should be developed from species that are currently reduced to fishmeal and oils. These products should be economically competitive, appeal to European and export markets and be resistant to the cyclical nature of fishmeal and oil commodity pricing.
- Plant and other substitutes for fishmeal and fish oil in aquafeeds should be further developed. These substitutes must be able to provide cost-effective alternatives to fish-based products, be acceptable to consumers and not generate sustainability issues in their own right.

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Current and potential alternative food uses of the Argentine anchoita (*Engraulis anchoita*) in Argentina, Uruguay and Brazil

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SUMMARY

A comparative assessment between the use of the Argentine anchoita (*Engraulis anchoita*) for reduction fisheries and human food and/or value-added products is the focus of this case study. General biological aspects, spatial and seasonal distribution and available biomass estimates of the target species are examined. Currently applied and promising potential methods of processing anchoita in Argentina, Brazil and Uruguay are described and compared in terms of economic and nutritional impact.

Engraulis anchoita is a small pelagic fish that occurs in the South West Atlantic Ocean (SWAO) with Brazil, Uruguay and Argentina sharing the so-called anchoita "Bonaerense" stock. Annual abundance estimates vary between 600 000 tonnes and 4.5 million tonnes, with significant regional and yearly variations in biomass estimates along the shelves of the three countries. Fishing takes place predominantly between July and November. Catches in 2006 were reported to be around 30 000 tonnes in Argentina and 17 000 tonnes in Uruguay. It is estimated that up to 135 000 tonnes of anchoita could be sustainably exploited along the southern Brazilian coast. However, despite its abundance, this species is not fished there.

The three countries exhibit different approaches to the utilization of *E. anchoita*. Argentina is the pioneer in the exploitation and manufacture of anchoita and the main manufacturer of different kinds of products for human consumption directed to both the domestic and export markets. More than 80 percent of this production is salted fish and the remainder is prepared as value-added food. In 2005, Argentine exported anchoita-based products at a value of US$26 million. At present, Uruguay processes its anchoita catch exclusively as fishmeal for export, although the preparation of products for human consumption is planned for the near future.

Due to its unexploited fishery resources as well as considerable demand, Brazil has great potential for manufacturing new products that could contribute to both the domestic and export markets. Trial products have been developed that could address food security and poverty alleviation in the region and elsewhere. Alternative potential uses for new products from anchoita were assessed on the basis of prototypes developed in Brazil. It is concluded that novel products such as dehydrated risotto, soup and sausage have considerable strategic marketing value.

An assessment of the costs and benefits of the production of fishmeal and new products for human consumption in Brazil revealed that the transformation of anchoita for human consumption results in significantly higher direct positive impacts on poverty and food security. Governmental social programmes supporting school meals and hospital diets are a promising entry point for the introduction of novel products to nutritionally challenged parts of society. The search for common solutions for improved utilization of anchoita should evolve from a strong technical-scientific interaction and mutual collaboration among the governments of the three countries.

1. THE BIOLOGICAL ASPECTS AND DISTRIBUTION OF ANCHOITA IN THE SOUTH WEST ATLANTIC OCEAN

1.1 Distribution

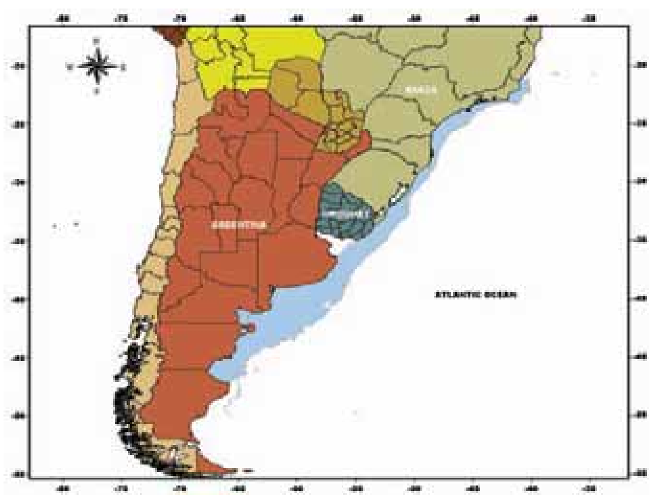
The Argentine anchoita (*Engraulis anchoita*) (Figure 1) is a small pelagic fish that occurs in the South West Atlantic Ocean (SWAO), from around Vitória (20°19' S) in Brazilian waters to San Jorge Gulf (47º S) in Argentine waters (Figure 2) (FAO, 1988). The species is found throughout this region, including in Uruguayan waters, at a depth of between ca. 10 and 200 m and, especially in Uruguay and Argentina, down to the continental slope. Preferred temperature and salinity range from 8 to 23 °C and 14 to 35 ppt. The highest concentrations of anchoita usually occur where sharp gradient sea fronts are recorded (Hansen, Cousseau and Gru, 1984; Hansen and Madirolas, 1996). The thermo-saline preferences may change according to the time of the year, latitude and developmental stage of the species, larvae and juveniles being environmentally more tolerant than adults. Like other engraulids, anchoita forms compact schools in different strata during the diurnal cycle. The individuals disperse at night, forming layers near the surface (Angelescu, 1982; Hansen and Madirolas, 1996; Castello, 1997).

FIGURE 1
Argentine anchoita (*Engraulis anchoita*)

Courtesy of INIDEP, Argentina

Evidence suggests the occurrence of three subpopulations of anchoita (see latitudinal coordinates in Figure 2): (i) Patagonian, between 47° and 41° S; (ii) Bonaerense, between 41° S and southern Brazil; and (iii) a population occurring between the capes of Santa Marta Grande (29° S) and Vitória (20° S), Brazil (Hansen, Cousseau and Gru, 1984).

FIGURE 2
Distribution of anchoita on the shelf waters of the South Western Atlantic Ocean



Source: Modified from Castello (2007)

1.2 Abundance estimates

Abundance has been calculated on several occasions by Brazilian, Uruguayan and Argentine researchers. With one exception abundance was estimated with acoustic methods (Table 1). As expected for a small pelagic fish, there are regional and yearly variations in biomass estimations.

TABLE 1
Acoustic estimates of anchoita abundance for different regions and years in Argentina, Brazil and Uruguay

Country	Region	Year	Abundance (thousand tonnes)
Brazil[a]	32°–34°40´S	2005 (August)	601.2–753.9
Brazil[a]	32°–34°40´S	2005 (September)	597–744
Brazil[b]	27°– 30°S	1997 (May)	468
Uruguay[c]	34°40´– 36°S	1975–1988	231–1720
Argentina*[d]	35°–41°S	1990–2005	800–4 500
Argentina[e]	41°–47°S	2006	600–2 200

*Estimates combined commercial data with acoustic indexes.
Source: [a]Brazilian National Council for Scientific and Technological Development (pers. com., 2007); [b]Madureira *et al.* (2004, 2005); Castello *et al.* (1991); [c]Nion and Rios (1991); [d,e]Hansen, Buratti and Garciarena (2006)

In Brazilian waters, the oceanic limit of anchoita distribution is related to the Subtropical Shelf Front (STSF) that divides the cold, low-salinity Subantarctic Platform Waters (SAPW) from the warm, high-salinity Subtropical Shelf Waters (STSW). High anchoita biomass values were restricted to areas under the influence of SAPW. In Uruguay and Argentine waters, anchoita schools occur in shelf waters with coastal and sub-Antarctic waters.

1.3 Age structure

In Argentine and Uruguayan waters, five-year-old anchoitas occur frequently, whereas in Brazilian waters the maximum age is four years. Thus, life expectancy seems to rise according to latitude and lower water temperature. As a multiple spawner, anchoita may have up to three cohorts in a single year, growing at different rates.

1.4 Condition factor, length, weight and sizes

The condition factor (K), calculated as $K = W(g) * 10^5 / Lt\ (mm)^3$, where W = weight and Lt = total length, slightly increases with individual sizes in all populations. The mean value is at its maximum during the months that precede reproduction (spring in Argentine waters and winter-spring in southern Brazil), when gonads reach their largest size (Hansen, 2004). The condition factor is lower in the post-spawning period and in autumn (Castello, 1997). The weight-length relationship shows a latitudinal trend. Length exponentials are higher at southern latitudes and lower at northern positions. The anchoita, being a partial spawner, shows relatively short gonadal resting periods, spawning every 15 days on average (Christiansen and Cousseau, 1985). The size gradient at first maturation ($L_{50\%}$) is 85 mm in southern Brazilian waters, approximately 100 mm in Argentine waters off Buenos Aires and 120 mm for the Patagonian population.

In southern Brazil, the reproductive peak is in winter and spring. Nakatani (1982) identified two spawning peaks in the southeast, one between the end of winter and beginning of spring and another, of higher intensity and in clear association with low-temperature waters of the South Atlantic Central Waters (SACW), between the end of spring and beginning of summer (Matsuura, Spach and Katsuragawa, 1992; Kitahara, 1993; Katsuragawa *et al*., 1993; Matsuura and Kitahara, 1995). In Argentine waters, the reproductive peak occurs in spring.

1.5 Growth and mortality rates

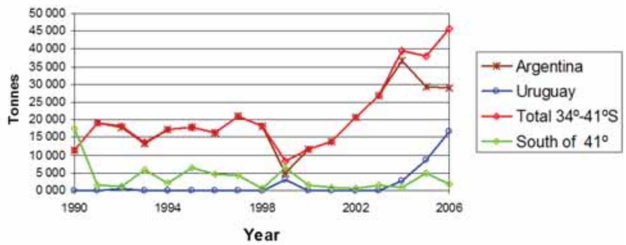
Castello (1997) and Hansen (2004) demonstrated that anchoita reaches larger body sizes in Patagonian waters and tends to be smaller in the warmer waters of southern Brazil. Instantaneous natural mortality rates are high (0.9–1.0), as expected for a small pelagic fish.

1.6 Commercial exploitation in Argentina and Uruguay

Fish captured south of 41°S are landed in Puerto Madryn and those captured north of that region are landed in the ports of Necochea and Mar del Plata (95.5 percent of the total landed anchoita), both in Argentina. Recent data on the commercial exploitation of anchoita were provided by Garciarena and Hansen (2006) in their analysis of anchoita captured between 34° and 41°S and south of 41°S (Figure 3). From 1990 to 2006, a 303 percent increase in anchoita catches was recorded for the Bonaerense population compared to 9 percent for the Patagonian anchoita.

In the Argentine-Uruguayan Common Fishing Zone (ZCPAU), captures took place predominantly between July and September. Eighty-one mid-water trawlers operated around 700 fishing trips in the region. Artisanal coastal vessels (approximately 30) were responsible for a small fraction of the total captures. Capture samples indicated average sizes of 160 mm total length (~ three years of age). In Uruguay, industrial captures are landed in the port of La Paloma.

FIGURE 3
Catches of the Bonaerense population of anchoita by Argentina and Uruguay and captures of Patagonian anchoita (south of 41°S), 1990-2006



Source: Garciarena and Hansen (2006)

1.7 Perspectives on sustainable exploitation and capture in Brazil

Information on anchoita in southern Brazil, including acoustic abundance estimates, seasonal movements and behaviour, environmental preferences, stock, mortality rates and the role of anchoita as forage species in the neritic ecosystem was used to simulate the impact of fishing exploitation using the "Ecopath with Ecosim" model (Christensen and Walters, 2000). The results of this simulation showed that at annual exploitation rates of 0.2 and 0.4 for a five-year period, the original biomass of anchoita would suffer a reduction of 10 and 20 percent, respectively (Velasco and Castello, 2005).

Considering an exploitation rate of 0.10, the impacts of this fishing effort on the ecosystem could be summarized as follows:

- moderately negative impacts for juvenile and adult nectophagous fish, with a 15–20 percent reduction of the current biomass, since anchoita is an important part of their diet;
- 30–35 percent reduction of current biomass of tuna and tuna-like fish;
- approximately 20 percent increase in biomass of juvenile and adult benthophagic fish; and
- 10 percent increase of benthic invertebrate biomass.

The most recent estimates of anchoita biomass in southern Brazilian waters indicate an average of 675 500 tonnes (Brazilian National Council for Scientific and Technological Development, Personal Communication, 2007). This estimation did not fully cover the distribution area of anchoita. A cautious exploitation rate of yield/biomass (Y/B) of 0.2 would represent a theoretical capture of 135 000 tonnes per year, which is a significantly high figure. It is unlikely that an exploitation rate of 0.2 would be achieved in the short term, because anchoita fishing does not occur in southern Brazil.

2. ANCHOITA PROCESSING IN SOUTH AMERICA

2.1 General considerations

Anchoita is a species with high-lipid content with significant variations in concentration according to the time of the year (Bertolotti and Manca, 1986; Yeannes and Casales, 1995). The maximum lipid values are found between January and August and the minimum from August to December, with moisture levels ranging from 66.1 to 76.3 percent, lipids from 4.1 to 15.1 percent, protein from 16.1 to 17.9 percent, and ash from 3.5 to 15.1 percent (Bertolotti and Manca, 1986). One of the parameters of raw material quality for preserved and salt-cured products is the lipid content, which is best at 10–15 percent levels.

The high polyunsaturated fatty acids characteristic of the species, a nutritional factor of excellence, makes it suitable for use in a diverse range of products. The unsaturated fatty acids, a positive feature that characterizes this raw material as very healthy, also implies that this species is highly perishable due to lipid oxidation.

Table 2 shows the chemical composition of anchoita captured in September in different locations and analysed by three laboratories representing the participant countries. Table 3 also shows the proximal chemical composition of the raw material at different times of the year (Yeannes and Casales, 1995).

2.2 Anchoita exploitation and manufacturing in Argentina

Of the three countries assessed, Argentina is the pioneer in the exploitation and manufacture of anchoita and the main manufacturer of products for human consumption. Commercialization started with salted raw material before the First World War, opening new perspectives to fishery exploitation.

TABLE 2
Chemical composition of anchoita captured in September in different locations and analysed by three laboratories in Uruguay, Argentina and Brazil

g/100g	A (Uruguay)	B (Argentina)	C (Brazil)
Moisture	72.20	78.07	77.33
Protein	16.90	17.95	16.36
Lipid	6.90	4.25	3.36
Ash	3.50	1.26	2.62

Source: A: Mattos, Torrejon and Rodriguez (1977); B: Cabrera, Casales and Yeannes (2002); C: Garcia and Queiroz (2007)

TABLE 3
Proximal chemical composition of anchoita in different months

Month	Moisture	Lipid	Protein	Ash
May	69.47	9.43	19.24	2.05
June	71.05	6.79	19.00	3.16
July	77.26	4.13	17.80	1.45
September	75.75	3.93	18.59	1.73
October	76.99	3.55	16.38	3.08
November	79.59	1.68	15.83	1.18

Source: Yeannes and Casales (1995)

Anchoita fishing transformed the port of Mar del Plata, where the largest quantity of this fish is landed, into the processing center (Table 4; INDUPESA, 2006). Anchoita processing plants started proliferating by the 1970s, when the fishery for the European anchovy (Engraulis encrasicolus) declined in Europe. Producer countries, particularly Spain and Portugal, resorted to importing salt-cured anchoita (Bertolotti and Manca, 1986), and Argentina was encouraged to expand the plants (Zugarramurdi and Lupin, 1977).

Anchoita fishing grounds are over the shelf at distances between 10 and 80 km from Mar del Plata. The fleet operates in dedicated fishery from August to November, when minimum lipid contents are recorded (Table 3). Anchoita is easily detected by standard echo sounders because they aggregate in dense schools during the day. Capture is by suction and bycatch is minimal. Anchoita landings in Argentina totaled 37 276 tonnes in 2004 (Table 4).

TABLE 4
Landings of anchoita in the ports of Argentina, 2004

	Landings (tonnes)						
Ports	Bahía Blanca	Mar del Plata	Quequén	Comodoro Rivadavia	Madryn	Rawson	Total
Amount	0.5	35 580	800	6	481	399	37 276
Percentage	<1	96	2	<1	1	1	100

Source: INDUPESA, Mar del Plata

Companies such as INDUPESA in Mar del Plata and Engraulis S.A. Industrialization in Quequén supply a wide range of products, such as anchovy fillets in oil, vacuum-packed anchovy fillets, anchovies in brine, salt-cured anchovies, anchovy fillets marinated in vinegar (or boquerones), whole frozen anchovies and tinned Argentine sardines.

2.3 Anchoita exploitation and manufacturing in Uruguay

According to data collected in La Paloma in 2007, ca. 54 000 tonnes of anchoita were fished in 2001, with main catches of approximately 200 tonnes/day and landings every 48 hours. The entire catch was destined for fishmeal production. This estimate is far below earlier estimates by Mattos, Torrejon and Rodriguez (1977), who reported that in 1977 a projection of the utilization of pelagic species for fishmeal, oil and preserves indicated that 240 000 tonnes/year would be processed in the port of La Paloma, with a minimum of 5 percent destined for human consumption.[1]

The production of fishmeal from anchoita stopped in 2005, and resumed in 2006, with exports mainly to Germany, Italy, Russian Federation and China.

A processing plant for anchoita-based products for human consumption began operations in early 2006. With Spanish investment, this plant will manufacture salt-cured anchoita and marinated fillets. The company will start production based on the results achieved from trials with large volumes of anchoita. The trials were performed to produce salt-cured, "boquerón"-type marinated and block-frozen anchoita. The process was adapted to the climatic conditions of Uruguay to achieve the desired quality and productivity according to the demands of the European market.

Future exploitation and manufacture of this small pelagic fish is likely to focus not on fishmeal production, but rather on products for human consumption. However, fishmeal production using waste from the processing lines is likely to continue.

2.4 Anchoita exploitation and manufacturing in Brazil

Of the three countries assessed, Brazil is the only one where this potential fishing resource is not currently exploited. In 2005, the Conselho Nacional de Ciência e Tecnologia do Brasil (CNPq) financed a project for the assessment and processing of anchoita. The implementation of the project resulted in the production of four anchoita-based prototypes: 1) risotto-type dehydrated product obtained from anchoita protein base; 2) fermented anchoita fillet; 3) soup-type dehydrated product formulated with hydrolyzed protein; and 4) surimi-based emulsified fish sausage. Fishmeal production was also tested.

[1] This projection used data collected during 1975 and 1976 by the National Fisheries Institute (INAPE), assisted by the Food and Agriculture Organization of the United Nations (FAO), as part of a programme of exploitation and assessment of pelagic resources. This report gathered basic information for the projection of a fishery industry based on these resources and the major effort was devoted to anchoita.

In Brazil, the trend is for the development of anchovy-based alternative products that would open new markets and could be directly included in governmental social programmes to fight poverty, similar to the Fome Zero Programme (see www.fomezero.gov.br). School meals, hospital diets, and programmes providing nutritional advice to workers could incorporate the products developed. Research for optimizing a formula to respond to specific demands is necessary, especially regarding processed dehydrated products.

As an example, the risotto-type dehydrated product is characterized as a high-protein, calorific product with low-fat levels. Nutritionally, this product can be compared with foods traditionally consumed, such as eggs, milk and meat. This consideration becomes relevant, because the protein requirement of a 70-kg person is 56 g of protein per day (Sgarbieri, 1987). If an individual had a 30 percent protein-based rice product as the only source of protein, his/her daily protein requirement would be met with 170 g of the anchoita-based risotto, as shown in Table 5. This means that a meal with 170 g of anchoita risotto would meet the daily protein requirements of the consumer.

TABLE 5
Daily amounts of products manufactured with rice and anchoita protein base (APB) necessary to meet the daily protein and caloric requirements of a 70-kg person

APB percentage	Risotto weight (g)	Protein (g)	Kcal
15	341	56	327
30	170	56	351
66	85	56	399

Source: Brazilian National Council for Scientific and Technological Development (2007)

The intake of anchoita-based risotto is thus recommended both as a protein and calorie source. Another relevant factor is the quality of the available protein, which can be verified by the data in Table 6 that compares the essential amino acid contents of rice and fish with the FAO/WHO (1973) reference standard for the daily requirements of a healthy 70-kg male adult. It shows that the lysine content in rice (3.8 g/16 g nitrogen) is much lower than in fish (8.96 g/16 g nitrogen), where the concentration is higher than that recommended by FAO. In this way, the balance of amino acids resulting from the association between rice and anchoita protein base (APB) meets the food security requirements and can contribute to poverty alleviation.

Products like dehydrated risotto, soup and sausage have a strategic marketing value when the world's low intake of fish protein is considered. In Brazil, this factor is even more significant, because the national intake of 8 kg/year is lower than the minimum value of 12 kg/year recommended by FAO (Parmigiani and Torres, 2005). The socio-economic situation of consumers and their eating habits are among the factors that explain this low intake (Trondsen *et al.*, 2003). Therefore, a meat-flavoured convenience product with regional characteristics that associates the energetic value of carbohydrates with fish protein without the fish taste could increase the intake of this

TABLE 6
Estimate of essential amino acids (g/16 g N) for anchoita-based risotto and recommended intake suggested by FAO/WHO (1973)

Amino acids	Rice	Fish	Recommended intake
Isoleucine	4.89	5.12	4.2
Leucine	7.84	7.52	4.8
Lysine	3.80	8.96	4.2
Methionine	3.37	2.88	2.2
Meionine + Cysteine	4.97	4.00	2.8
Phenylalanine	6.02	3.68	2.8
Threonine	4.34	4.48	1.4
Tryptophan	1.21	1.12	2.8

Source: FAO/WHO (1973)

kind of food by the market segment that rarely consumes fish protein. Furthermore, including such products in governmental programmes and hospital diets could raise the possibility of offering a healthy diet to the population.

2.5 Manufactured products using anchoita

2.5.1 Argentina

Argentina is the leading producer of salt-cured anchoita, whole frozen anchoita, tinned anchoita fillets and more recently, marinated anchoita and anchoita paste.

- ***Salt-cured anchoita processing*** – The 1978 Argentine Food Code characterizes salted or brined anchoita as an edible product treated with salt or brine for at least five months (Bertolotti and Manca, 1986). Salt-cured anchoita is currently the main product manufactured using anchoita as raw material in Argentina (Baima Gahn *et al*., 2005). The processing of salt-cured anchoita (Figure 4) follows two steps: 1) salting with an osmotically balanced saturated brine and fish muscle; and 2) maturation, a process that can take from 8 to 12 months (Zugarramundi and Lupin, 1977). Figure 5 illustrates the salt-cured product in a tin.
- ***Anchoita fillets*** – After salting and curing, the anchoita is gutted manually and washed (three steps) to remove excess salt. It is then skinned and the pieces are centrifuged. The final product is presented as fillets packed in glass jars with sunflower or olive oil (Figure 6). The anchoita fillets are produced and as well as packed by the same companies, using their own brands. They are exported to countries such as Spain, Portugal and France that reprocess the fish and to consumer countries, such as the United States of America, Mexico and Brazil (Figure 7).
- ***Whole frozen anchoita*** –The raw material is frozen whole in a convection forced-air tunnel and delivered to the international market using very little labour.
- ***Anchoita processed as "Argentine sardine"*** – The Argentine Food Code Art. 456/1978 registered Argentine sardine as an anchoita (*E. anchoita*)-based product processed as sardine. The processing is similar to the one used with Brazilian sardinella (*Sardinella janeiro*) and follows the Argentine Food Code Art. 478/1978. Anchoita may be packed in sunflower oil, olive oil or tomato sauce. Argentine sardines usually target low-income consumers and almost the entire production is for the internal market.

FIGURE 4
Barrel filled by hand with anchoita displayed in crown shape

FIGURE 5
Salt-cured anchoita displayed in a tin

FIGURE 6
Anchoitas fillets in oil and packed in a glass jar

Source: INDUPESA (2006)

FIGURE 7
Vacuum-packed anchoita fillets

• ***Marinated anchoita products*** – Products are obtained by adding acetic acid and sodium chloride to retard the action of bacteria and enzymes in the fish. Argentina has been using this method to process different kinds of fish, and anchoita has proven to be the most suitable species (Yeannes and Casale, 1995; Yeannes, 2006). Marinated anchoita fillets are traditionally known as "boquerones" (Figure 8).

• ***Anchoita paste*** – Anchoita paste is a product developed by researchers at Mar del Plata National University and CONICET in Mar de Plata, Argentina, in partnership with Empresa Pesqueira Centauro S.A. The goal was the utilization of fillet trimmings. This product is characterized as a spread similar to paté with reduced salt content (Baima Gahan *et al*., 2005). The final product contains 8.6 percent NaCl, with a shelf life of six months at 8°C. Figure 9 shows anchoita paste in jars and in tins.

2.5.2 Uruguay

There are no manufactured products for human consumption produced in Uruguay.

2.5.3 Brazil

Anchoita is not yet processed in Brazil. A prototype-scale production of some alternatives to traditional products manufactured in neighbouring countries was performed in the laboratory, as described below.

- ***Risotto-type dehydrated product obtained from an anchoita protein base*** – This is a prototype of the risotto-type dehydrated product as previously mentioned (Figure 10), with regional character, targeting a new market and advertising anchoita to the consumer. The purpose was to transform anchoita "meat" into a product similar to beef, which could increase fish consumption, particularly in southern Brazil where beef risotto is a traditional local dish. With that in mind, anchoita was used to obtain a fish protein base, generating a high protein, low fat, deodorized product. Once the washing process was defined, meat flavour concentration, seasoning preparation and formula optimization were studied. The best proportion of rice, protein base and seasoning was defined and the final product was tested by the target population of the local state schools, with the aim of including it in school meal programmes.
- ***Fermented anchoita fillets*** – The fermentation process was developed with a *Lactobacillus sakei* starter culture previously reactivated and categorized according to its metabolic characteristics. The conditions that favoured lactic

bacteria growth formed predominantly by *L. sakei* included pH < 4.2, 2 percent NaCl, 4 percent glucose, and operational temperature between 20 and 21 °C. During the 21-day fermentation period, proteolysis depended not only on the nature of the microbiota but also on the processing parameters, with direct influence on the activity of proteases and peptidases involved in the fermentative process. Following fermentation, anchoitas were packed in 130 g glass jars with corn oil (Figure 11).

FIGURE 8
Marinated anchoita

Source: INFOPESCA (2001)

FIGURE 9
Anchoita paste

Source: INFOPESCA (2001)

- ***Fishmeal*** – A fishmeal production test was carried out during the CNPq project (Brazilian National Council for Scientific and Technological Development, 2007). Fishmeal was produced with anchoita captured in Brazilian waters and processed following three steps: cooking (whole fish), cake pressing and drying. The raw material with 74.5 percent moisture, 4.5 percent lipid and 19.5 percent protein produced fishmeal containing 73 percent protein, 9 percent lipid and 11 percent moisture (Figure 12).
- ***Soup-type dehydrated product with anchoita protein*** – Enzymatic hydrolysis of fish protein and drying technique were used to find technologically feasible alternatives for the utilization of anchoita. Adding enzymes to hydrolyzed protein in foods is an important process that can improve the bioavailability of nutrients and the functional and sensory proprieties of proteins without affecting the nutritional value. The purpose of enzymatic hydrolysis is the solubilization of proteins, adding value to the product. The enzymatically modified muscle of anchoita is a protein concentrate with characteristics different from the unmodified protein base, because functional properties such as solubility, water and oil retention capacity, emulsification and foam formation are improved. Sensory proprieties also improved, making it more attractive. The digestibility is significantly increased, resulting in better nutrient absorption by the consumer. A dehydrated soup (Figure 13) was produced with enzymatically modified anchoita muscle using a spouted bed dryer. The soup is practical and nutritionally appealing, because the protein is highly digestible and easily absorbed. The enzymatically modified muscle can be dehydrated with low-cost drying technology in a small-scale production plant and implemented in cooperatives, generating jobs and income.
- ***Surimi-based sausage*** – This product (Figure 14) was characterized as frankfurter sausage. It is different from conventional fish products in that it is

FIGURE 10
Risotto-type dehydrated product obtained from a fish protein base, using anchoita as raw material

Courtesy of Luciano Gomes Fisher

FIGURE 11
Fermented anchoita fillets in corn oil in a jar

produced from surimi of anchoita and not directly from minced anchoita to avoid possible consumer rejection for the flavour and the strong fish smell. The product was presented as a sausage in collagenous casing, with considerable shelf life due to pasteurization and neutral taste (Prentice and Lempek, 2006). Minced anchoita was treated with diluted solutions, washed and centrifuged. Cryoprotectans to protect

FIGURE 12
Fishmeal using anchoita as raw material

Courtesy of Kelly de Moraes

FIGURE 13
Soup-type dehydrated product manufactured with anchoita protein

Courtesy of Kelly de Moraes

the myofibrillar protein against the denaturation caused by cold temperatures were added. The surimi obtained was frozen and reserved for the second phase, when it was thawed at room temperature, mechanically chopped and mixed with ingredients (salt, textured soy protein, seasoning, potato starch and artificial coloring). The mixture was then homogenized and taken to a casing machine where it was fed into sausage casings. The filled casings were divided in segments of uniform size, washed and pasteurized at 90 °C. Finally, the sausage was cooled in cold water, properly packed and reserved for shelf-life analysis. The heating temperature exerted the greatest influence on the gel strength of the sausage. It is a high-protein product (18 percent) with reduced quantity of lipids (4 percent). It successfully passed sensory acceptance tests, conducted with aim of allowing this product to be included in school meal programmes.

FIGURE 14
Sausages processed with anchoita-based surimi

3. ECONOMIC AND SOCIAL ASPECTS OF CURRENT AND POTENTIAL ALTERNATIVE USES OF ANCHOITA IN ARGENTINA, URUGUAY AND BRAZIL

3.1 Costs of alternative uses for human consumption and for reduction

3.1.1 Human consumption

This section describes the comparative cost analysis of three important manufactured anchoita-based products for human consumption in Argentina: salted anchoita, marinated anchoita and anchoita paste (Table 7). Unfortunately, costs were not available for whole frozen anchoita and anchoita in oil.

Marinated anchoita is sold in 170 g jars, anchoita paste is packed in small 90 g jars and salted anchoita is wrapped in individual 1 kg packs. The most expensive item in the production of salted anchoita and anchoita paste is the raw materials, corresponding to 67 percent and 50 percent of the production costs, respectively. Raw materials include anchoita, salt, margarine, oil, seasoning, etc., depending upon the product. Packaging is an important part of the total production cost of marinated anchoita and anchoita paste, accounting for 31 percent of the cost for each product. Around 81 percent of the total production cost of anchoita paste corresponds to raw material (50 percent) and packaging (31 percent). The production cost of marinated anchoita is more equally distributed: raw material, 26 percent; packaging, 31 percent; labour, 22 percent, accounting for 79 percent of the total production cost. Table 8 shows the variable production costs of the products mentioned above.

The variable cost to produce 1 kg of salted anchoita was US$1.44; 52 percent of the cost was raw material. The total cost to produce 170 g of marinated anchoita was

TABLE 7
Structure of production cost of three anchoita-based products, 2001

Cost items	Salted anchoita (%)	Marinated anchoita (%)	Anchoita paste (%)
Raw material	67	26	50
Packaging	8	31	31
Labour	11	22	5
Services and maintenance	2	1	1
Depreciation, insurance and tax	4	2	3
Supervision, laboratory, administration and direction	6	12	3
Sale cost	1	6	7
Total	**99**	**100**	**100**

Source: Avdalov and Pereira (2001)

TABLE 8

Variable costs of three processed products, 2005 (US$/unit)

Cost items	Salted anchoita (1 kg pack)	Marinated anchoita (170 g jar)	Anchoita paste (90 g jar)
Raw material			
Anchoita	0.75	0.08	0.12
Other raw material	0.37	0.12	0.31
Packaging	0.14	0.24	0.26
Labour	0.18	0.16	0.04
Variable cost (US$/unit)	1.44	0.60	0.73
Variable cost (US$/kg)	1.44	3.53	8.11

Source: Avdalov and Pereira (2001), data were corrected to 2005 prices

US$0.60, packaging being the most expensive item (US$0.24). Anchoita accounts for 39 percent of the raw material used in this product, while other raw materials amount to 61 percent. The production of 90 g of anchoita paste costs US$0.73, the costlier items being raw materials other than anchoita and packaging, respectively 42 percent and 33 percent of the total variable costs. Anchoita provides 28 percent of the raw material used in this product, and other materials (seasoning, salt, etc.) provide 72 percent.

The variable costs presented in Table 8 show that anchoita is the most expensive item in the salted anchoita production. Packaging and labour are the costlier items in marinated anchoita production, while both packaging and raw materials other than anchoita amount to nearly 80 percent of the variable costs presented. The variable cost per kilogram is the lowest for salted anchoita.

Of the prototype products developed in Brazil, only the costs of the risotto production were possible to calculate. Costs for the other products are still being evaluated. The fixed and variable production costs of anchoita risotto were calculated based on laboratory experiments, extrapolating to an industrial scale, keeping the respective proportions of each item used. The estimated total cost of production was US$0.67 per pack of 0.175 g.

3.1.2 Reduction fisheries

Neither reduction fisheries nor fishmeal production are well developed in any of the three countries assessed. Anchoita fishing for fishmeal production is forbidden in Argentina (www.cedepesca.org.ar), and Brazil does not have any anchoita processing plants.

Only one plant was identified in Uruguay, processing ca. 54 000 tonnes of anchoita during the nine months of annual capture. The yield obtained was 23 percent, generating 12 420 tonnes of fishmeal. The main importers are Germany, Italy, India, the Russian Federation, Japan, China and Chile. The entire Uruguayan production is exported for use in aquaculture. Consequently, Uruguay does not manufacture any fishmeal by-products or products for human consumption at present.

A structure of the annual costs of fishmeal production based on a FAO study (1986) was prepared in order to discuss the utilization of anchoita in reduction fisheries to produce fishmeal (Table 9). The calculation was based on a plant with capacity to process 150 tonnes of fishmeal per day using two-thirds of its productive capacity. The price of raw material (anchoita) refers to the ex-vessel price of US$60 per tonne.

Given a fishmeal yield of 23 percent, the final cost per tonne is US$483.45. Assuming a fishmeal market FOB price of US$800 (using the anchoveta fishmeal FOB price in Peru), the profitability is US$316.6 or 39.6 percent.

TABLE 9
Structure of daily production costs of fishmeal

Production costs	%	US$
Fixed plant costs	29	3 225
Variable costs		
Raw material	54	6 000
Other variable costs	17	1 895
Total production costs per day	**100**	**11 120**

Source: FAO (1986)

3.2 Potential alternative anchoita uses and their impact on food security and poverty

The potential anchoita annual biomass exploitation in Brazil is estimated at around 135 000 tonnes (see Section 1.7)[2]. At present, Brazil imports around 60 000 tonnes of sardines to supply the domestic market. Based on this figure, some projections for potential alternative uses of anchoita are presented, specifically for risotto and soup, as well as fishmeal. The projections are important for future investments into such products as a basis for food security and poverty reduction in Argentina, Brazil and Uruguay.

The minimum daily protein requirement for a person is 1.25 g protein/kg/day (Sgarbieri, 1987). Thus, the minimum protein intake required by a Brazilian school-aged child[3] waghing 45 kg on average would be ca. 56 g/day or 20.5 kg/year. Every 100 g of anchoita risotto contains 30 g of anchoita protein base, consequently a school-aged child would need to eat ca. 187 g/day of risotto to meet his/her protein requirements, or ca. 68 kg of risotto in a year. This corresponds to ca. 126 kg/year of anchoita, as each kilogram of processed anchoita generates 0.540 kg of risotto (Brazilian National Council for Scientific and Technological Development, Personal Communication, 2007). In this scenario, the anchoita risotto would provide 100 percent of the protein requirements of a school-aged child.

Considering the dehydrated product, 171 kg/year of dehydrated anchoita soup would provide the minimum protein intake of a student. This corresponds to an annual processing of 401 kg of anchoita, because each kilogram of processed anchoita generates 426.5 g of dehydrated soup.

Given a modest capture of 5 000 tonnes of anchoita, the production of risotto and soup could provide the minimum protein requirements of 39 451 or 12 469 school children, respectively, for a year. Based on the same 5 000 tonnes of anchoita, a production of 1 150 tonnes of fishmeal can be obtained (assuming a yield of 23 percent as mentioned by Tacon, Hasan and Subasinghe, 2006).

Nile tilapia (*Oreochromis niloticus*), an intensely farmed species in Brazil with a guaranteed international market, was used in an impact simulation on job generation as a result of the use of anchoita-based feed. Given a 1.56:1 food conversion ratio (FCR) of tilapia feed at US$1.21/kg to the producer, the production cost represents ca. 85 percent of the sale price (Estado de São Paulo, 2007). With the Brazilian monthly minimum wage of US$197.43 (DIEESE, 2007), the production of ca. 737 tonnes of tilapia using 1 150 tonnes of fishmeal feed could generate around 680 monthly minimum wages. These wages would pay around 57 people per year. Considering that each person provides for a family of four, around 228 people would be supported by the production of tilapia fed with 1 150 tonnes of fishmeal produced from 5 000 tonnes of anchoita.

A second analysis considers the farming of carnivorous fish of higher market value, such as Brazilian flounder (*Paralichthys brasiliensis*) priced at US$4.85/kg. As the FCR

[2] It should be noted, however, that to achieve this level of exploitation would require addressing the current lack of infrastructure and tradition of anchoita fishing in Brazil.
[3] School children between 7 and 14 years of age, according to INEP/ME (www.inep.gov.br).

for sole is 2:1, using the same production cost references (85 percent of the sale price) and the minimum wage, approximately 2 121 monthly wages could be generated by the production of 575 tonnes of sole fed with anchoita-based feed. This represents ca. 177 jobs a year supported by sole production and 708 people supported by the production of fishmeal.

As previously mentioned, the scenario with 60 000 tonnes of effective capture in Brazil would allow a wide production margin that could have an effect on food security through school-meal policies. The initial 60 000 tonnes of anchoita per year could supply the protein requirements of 473 412 students. Likewise, the production of tilapia using 60 000 tonnes of anchoita feed would generate 684 jobs a year, supporting 2 736 people. The aquaculture of high-value fish could generate 2 124 jobs, supporting 8 496 people.

Profitability results for risotto and fishmeal were estimated based on yield, costs and revenue information. These products are relevant due to the nutritional capacity of risotto and the global demand for fishmeal for use in aquaculture.

A biomass of 1 tonne of anchoita can generate a profit of US$316.6 or 39.6 percent of the market price (US$800), assuming fishmeal is the target product. In contrast, the same fish biomass would generate 540 kg of risotto at a cost of US$2 067. Considering the final market price of a similar product such as beef risotto sold at US$2 per 0.175 kg in Brazil, a revenue of US$6 171 is estimated if risotto were the target product. This would generate a profitability of 66.5 percent. The same anchoita biomass could provide the protein requirements of 4 881 people with an average weight of 70 kg, if risotto were produced. If used for aquaculture, such biomass would be reduced to 230 kg of fishmeal, which would generate 115 kg of flatfish or 147 kg of tilapia.

The results indicate that the production of protein-rich foods for human consumption would have a significant direct impact on food security and, consequently, on poverty reduction. The revenue generated from anchoita processed as a risotto ingredient is twenty-fold the revenue generated from fishmeal production! Similarly, the absolute numbers of people that could be supplied with the minimum daily protein requirements (based on the consumption of risotto and/or anchoita soup) projected by this report is significant. The production of fishmeal indicates indirect impacts on food security and poverty reduction, and direct social effects through the generation of jobs and income, boosted by the performance of the aquaculture sector.

Pauly (2006) states that we should think of small pelagic fish not as forage fish in the first place, but as a way to augment the current fish supply. This case study has shown that converting raw fish into a risotto-type dehydrated product obtained from anchoita protein base and/or a soup-type dehydrated product formulated with hydrolyzed protein would have much greater impact on food security than reducing the same amount of fish into fishmeal for aquaculture. Further arguments in favour of these products are that they do not need cold storage and hence can be safely and cheaply transported to distant places, reaching the rural poor.

Incentives for the production of anchoita-based products can be provided through relevant public policies, generating significant social benefits. Therefore, besides the sustainable exploitation of fishery resources, the alternative manufacture of anchoita-based products shows positive results for future investment in these products as a basis for food security and poverty reduction in Argentina, Brazil and Uruguay. Importantly, the search for common solutions for the utilization of anchoita should evolve from a strong technical-scientific interaction and mutual collaboration among the governments of the three countries.

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Status of and trends in the use of small pelagic fish species for reduction fisheries and for human consumption in Chile

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SUMMARY

The main aim of this report is to review the status of and future trends in Chilean small pelagic fisheries. The report discusses the implication of using small pelagic fish species for direct human consumption and as the main protein ingredient in aquafeeds for the sustainable development of the Chilean fisheries and aquaculture industries.

The fisheries sector represents an important industry in Chile, and its contribution to both the national economy and global supplies is significant. However, future development will require an increased emphasis on the sustainable use of natural resources. Chile is making concerted efforts to regulate all fishing activity and has given special priority to ensuring the sustainable development of this industry.

The total Chilean fishery landing in 2006 was around 4.9 million tonnes, which represents a significant decrease in comparison with the previous year and a volume that is 5 percent lower than the average for the period 2001–2005. This volume originates from two main sources: the capture fisheries sector, with 4.08 million tonnes and the aquaculture sector, with an estimated production of around 822.7 thousand tonnes. In 2006, 61 percent of the capture fisheries sector was contributed by pelagic resources, a figure that is slightly less than the value reported for the previous year. Trends in Chilean fishery and aquaculture production over the last ten years reveal the increasing importance of the aquaculture sector. With the increase in aquaculture production, the use of fishmeal and fish oil in aquafeeds has increased significantly in Chile.

The main pelagic species used for the production of fishmeal and fish oil, and the most important pelagic resources in Chile, are the Inca scad or Chilean jack mackerel (*Trachurus murphyi*), the anchoveta (*Engraulis ringens*) and two sardines (the South American pilchard, *Sardinops sagax,* and the Araucarian herring or common sardine, *Strangomera bentincki*), which contributed 45, 30 and 13 percent of the total accumulated landings for 2006, respectively. However, marked reduction in the captures of these species has been constant. The main species destined for the production of fishmeal and fish oil come from the industrial and artisanal pelagic fisheries. Anchoveta contributes 41 percent of the total fishmeal production, followed by jack mackerel with 27 percent; trash fish/low-value fish represent 15 percent, while other species contribute only 3.3 percent. In the last decade, the fishmeal production declined by almost 50 percent because of the substantial decrease in landings from these fisheries.

In 2005, 1.78 million tonnes of processed fishery products were produced. Fishmeal and fish oil represented around half of the products processed, followed by frozen products, with a 27 percent share, while fresh chilled and canned products together comprised 17 percent. From the second half of the decade 1995–2005, the production of fishmeal from overall pelagic fish landings was more or less constant, averaging 21 percent; however, canned product production from the same species increased slightly, rising from 2.1 to 2.8 percent. This means that the increased production of canned products from pelagic fish is directly correlated with the reduction in fishmeal production.

Of the total fishmeal produced in Chile, approximately 40 percent (340 thousand tonnes) is used for domestic consumption. Given that Chilean aquafeed production is on the order of 850 thousand tonnes, the inclusion of fishmeal in these feeds is around 240 thousand tonnes. The limited availability of fishmeal, unstable prices and a principle of economic and environmental sustainability has driven the aquaculture industry to look for alternative protein sources. Consequently, the reduction in fishmeal inclusion levels seen over the last few years has been substantial, a great portion of the fishmeal component in aquafeeds having been replaced by different plant and animal protein substitutes. Fishmeal substitution in the Chilean aquafeed industry was initiated around ten years ago as a direct result of the reduction in capture volumes of small pelagic species.

During the last decade, the capture fisheries sector has been characterized by a remarkable reduction in the labour force. Two of the main causes of this diminution are a reduction in the fishing fleet and an increased efficiency of processing plants. A sustained

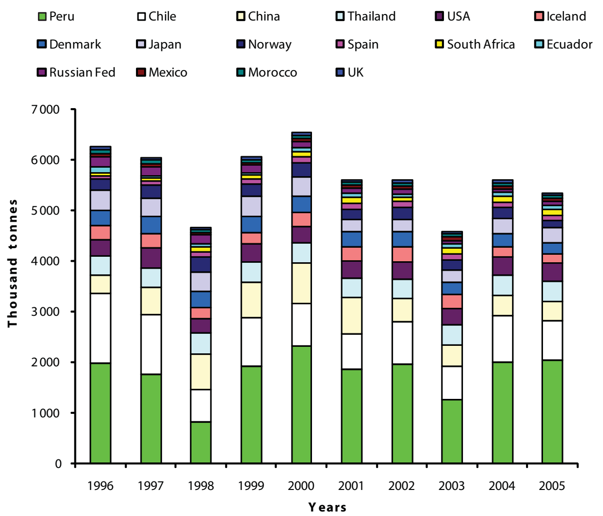
increase in the labour force in the aquaculture sector might compensate for the reduced employment in the capture fisheries sector. The salmon aquaculture industry is one of the most important employment generators in many areas of Chile, where poverty levels are much lower than the national average. The employment generated by this rising industry has a positive impact on poverty indicators for rural communities.

The hypothetical scenario of redirecting the use of jack mackerel from fishmeal production to the production of food for direct human consumption might have a positive effect. However, from the point of view of increased food security and poverty alleviation, the impact of the alternative use of this resource for human consumption might not be very significant, given that its products are not in high demand and would be mainly destined for export. Lowering the production of fishmeal will not have a negative impact on national salmon aquaculture, considering that at the present levels of fishmeal inclusion in salmonid aquafeeds there is still a surplus of fishmeal that is generally destined for export. Still, there could be a socio-economic benefit resulting from increased employment though greater processing opportunities.

1. INTRODUCTION

Global fishmeal production is principally utilized for animal feeding (livestock, poultry and aquaculture) and fish oil production is utilized for aquaculture and human consumption (Tacon, Hasan and Subasinghe, 2006). Fishmeal and fish oil are mainly produced from pelagic fisheries operating at an industrial level. Pelagic fishing is conducted all around the world, but the main fisheries are located along the Peruvian and Chilean coasts where the cold Humboldt current generates wide oceanic upwelling and consequently, high primary productivity (Bertrand *et al.*, 2004). Global fishmeal production during the last decade is shown in Figure 1. As described in this figure, global fishmeal production is concentrated in ten main countries. The two largest producers and fishmeal exporting countries are Peru and Chile, which produce 31 and 15 percent of the global total, respectively. In 2004, the estimated global fishmeal production was around 6.33 million tonnes, valued at over US$3 billion. Global fish oil production for the same year was estimated at around 930 000 tonnes, worth approximately US$0.56 billion (IFFO, 2005). These values are a clear indication of the importance of fishmeal and fish oil to the global economy and particularly to the Peruvian and Chilean economies.

FIGURE 1
World fishmeal production trends among the major producers during the decade 1996–2005



Source: IFFO (2005)

During the last 40 years, Chile has made significant strides in increasing both volume and value of capture fisheries and aquaculture production. From the mid-1960s to the present, the value of fisheries exports has increased from US$50 million to US$3 billion. Table 1 summarizes the value of total Chilean fish exports during the period 1995–2005 (SalmonChile, 2006).

Chilean total export values have doubled since 1995 and the production of farmed salmonids contributed around 60 percent of exports in 2006. Recent investments in new technologies, fishing vessels, processing plants and skilled human resources have made the Chilean fishing and aquaculture industries highly competitive in a global context. Chile is making concerted efforts to manage its fisheries in a sustainable and appropriate manner. However, future fisheries and aquaculture developments will require an increased emphasis on sustainability. For this reason, the Chilean Government is giving special priority to ensuring the achievement of this objective.

The contribution of the Chilean fishing sector to the national economy and global supplies of fishmeal and fish oil is significant (FAO, 2004). Hence, the responsible use of this finite commodity, principally by the animal feeds industry but also as human food and for pharmaceuticals, is very important. With the increase in aquaculture production, the use of fishmeal and fish oil in aquafeeds has increased significantly in Chile. However, because of fluctuating and lower pelagic catches, considerable cuts have been made in the inclusion rates of fishmeal in salmonid feeds over the last decade (Visión acuícola, 2006).

The price of fishmeal is determined by supply and demand, both of which are subject to a multitude of external factors. Probably the most important factors to have a

TABLE 1
Total Chilean export values, during the period 1995–2005 (values are given in million USD (FOB))

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006*
Fishmeal	633	612	552	349	282	235	257	320	373	362	487	466
Salmon and trout	489	538	668	714	818	973	964	973	1 147	1 439	1 721	2 010
Other products	660	621	652	611	684	667	639	666	726	777	869	831
Total	**1 782**	**1 772**	**1 873**	**1 674**	**1 784**	**1 875**	**1 861**	**1 959**	**2 246**	**2 579**	**3 077**	**3 307**

*Estimated values.
Source: SalmonChile (2006)

strong impact are those related to environmental changes, such as the El Niño Southern Oscillation event. However, it is possible that the fishmeal price would be high and over US$1 000 per tonne if there is an associated reduction in the stocks and catches (Mitrano, 2007). For this and many other reasons, most of them related to the negative environmental implications and concerns about the use of fishmeal in fish diets, there is a tendency to lessen or eliminate the fishmeal portion included in aquafeeds. In fact, for some species, including salmonids, fishmeal has been almost completely replaced as main protein source by other alternative ingredients (plant-derived proteins), not only in experimental diets but also in commercial feeds (Watanabe *et al.*, 1993; Storebakken, Shearer and Roem, 2000; Tacon, Hasan and Subasinghe, 2006; Visión acuícola, 2007).

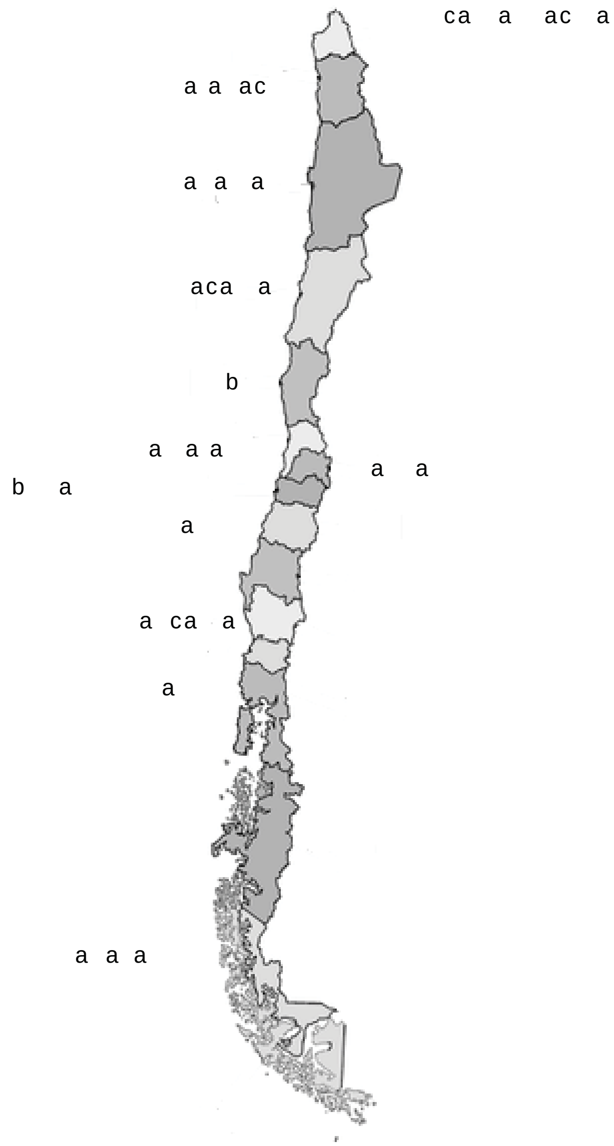
Fisheries and aquaculture are complementary activities and represent important industrial sectors of the Chilean economy. The development and implementation of a particular fishery or aquaculture management system has important repercussions in terms of environmental, economic and social outcomes. Consequently, the Chilean fishery industry needs to have important modifications in the different stages of its productive practice, including extraction and processing, as well as in the development and expansion of aquaculture. In this sense, the low accessibility and availability of resources together with the increasing demand to address the environmental problems posed by this activity and the concerns about its sustainability will have a huge impact on national fisheries management and future development.

In view of the magnitude and importance of Chilean fisheries in both national and international contexts, the purpose of the present report is to discuss and review the current status and trends of pelagic species and the implications of their use as aquafeed ingredients for the sustainable development of Chilean fisheries and aquaculture industries. This review examines the present situation of the Chilean small pelagic fisheries and identifies the future trends and activities. The data used in preparing this report come mainly from the updated database, registers and statistical yearbooks of the Government of Chile's Subsecretary of Fisheries and the National Fishing Service. In addition, some collected information was obtained from key sources like the industrial fishery associations, fishmeal and fish oil exporters, and National Fishing Zone Counsels.

The report is structured in five main sections. This first part provides a brief and basic introduction to the document. The second section illustrates the Chilean fisheries sector and its organization, considering the types of fisheries and regulations, as well as the historical trends in and present production of the main pelagic species. The third section analyes the present situation with regard to fishmeal and fish oil production in Chile: the trends, prices and interrelation with direct human consumption or processed products. The fourth section deals with the use of fishmeal and fish oil in Chilean aquaculture and includes a brief description of the novel use of alternative protein sources as fishmeal substitutes in the national aquafeed industry. The final section discusses the social and economic impacts of the fishery and aquaculture industries in

Chile, offering a hypothetical study of the particular case of the jack mackerel resource in Region VIII (Bio-Bio), which represents around 45 percent of the total pelagic fish landings in Chile.

FIGURE 2
Map of Chile showing the country administrative divisions



Each region is designated by a name and a Roman numeral (I, Tarapaca; II, Antofagasta; III, Atacama; IV, Coquimbo; V, Valparaiso; VI, Libertador Bernando O'Higgins; VII, Maule; VIII, Bio-Bio; IX, Araucania; X, De Los Lagos; XI, Aisen; XII, Magallanes y Antártica; RM, Metropolitan Region, Santiago; and the new recently created regions: XIV, Los Rios; XV, Arica-Parinacota)

2. CHILEAN PELAGIC FISH PRODUCTION

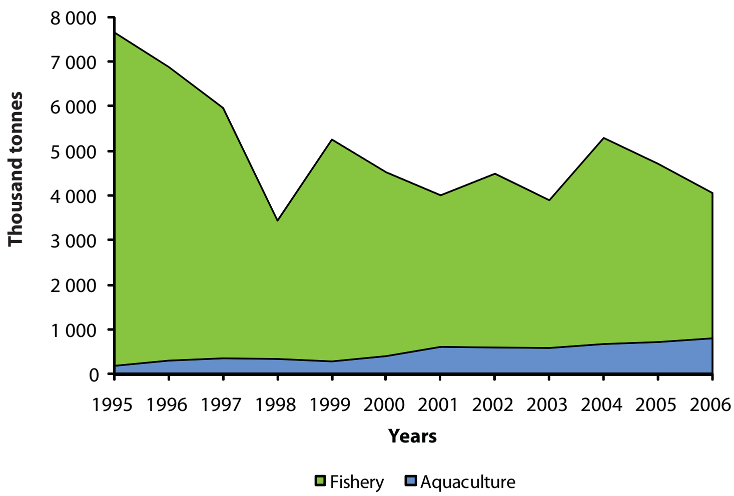
2.1 Chilean fisheries: the context

Chile possesses a unique geography, and the importance of its fishing industry is determined by its long seaboard, which extends approximately 4 300 km from its boundary with Peru at latitude 17°30´S, to the tip of South America at Cape Horn, latitude 56°S, a point only about 667 km north of Antarctica (Figure 2). The country is divided into 15 administrative regions (each region is designated by a name and a Roman numeral), including the Metropolitan Region of Santiago where 38 percent of the total population is concentrated (INE, 2005).

The extremely high biological productivity of Chilean coastal waters represents a source of fishery resources of great commercial value. Chile is one of the biggest producers and exporters of fish in the world, just behind countries like China, Peru, India, Japan, the United States of America and Indonesia. The Chilean fisheries industry is one of the main industrial sectors of the country, together with mining, agriculture and forestry. The fishery industry plays a major role in Chile's export-led economy. Chile's fisheries exports reached US$1.24 billion during the first ten months of 2006, which represents a 7.9 percent increase over the same period a year ago according to the Sociedad Nacional de Pesca (SONAPESCA, 2007).

FIGURE 3

Fishery and aquaculture production trends in Chile, 1995–2006



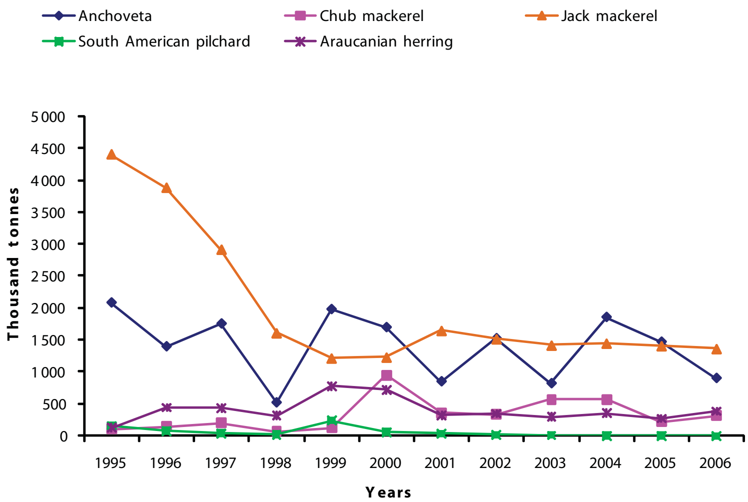
Source: SERNAPESCA (2006)

During the last half of the 1990s, the Chilean fishery industry went through a continuous decline in production volumes and in 1998 reached its lowest historical level as a direct result of the unfavourable environmental conditions induced by the El Niño over the period 1997–1998 (Arcos, Cubillos and Núñez, 2004; Pinochet and Villagrán, 2004). This drastic reduction is clearly evident in Figure 3, the total fishery production reached in 1998 is represented by the lowest point (only 3.9 million tonnes). The overall fishery production decrease was strongly influenced by the low availability of small pelagic species (jack mackerel, anchoveta and sardines) that sustain most of the reduction fisheries. These species contribute an important fraction of the national total landings but are very sensitive to environmental changes (Figure 4).

The Chilean fishing sector has made important changes in its productive structure, mainly with regard to the supplying of raw materials, a situation consistent with trends observed elsewhere. Aquaculture represents an important driver of these changes (Figure 3). The Chilean aquaculture industry supplied a major portion of the salmonids, molluscs and other cultivated aquatic resources.

Many of the world's fisheries are approaching full exploitation. As a result, aquaculture production is an important alternative to increase the raw materials supplying seafood processors. The Government of Chile is very concerned about this fact and based on the stabilization of traditional fisheries through capture quotas, has oriented its efforts to wards towards:

FIGURE 4
Variation in the main pelagic fish landings in Chile, 1995–2006



Source: SERNAPESCA (2006)

- establishing responsible management for the most important Chilean fisheries – in order to maintain sustainability, Chilean fisheries are well regulated, with restricted access to main fisheries zones; and
- developing a sustainable aquaculture industry – aquaculture represents the best alternative to increasing production and developing a sustainable national fishing industry. For this reason government policies aim to generate and promote the best conditions to support the aquaculture industry's sustainable development, on the basis of diversification, production of high-value species for international markets, and the development of environmentally sound methods and high sanitary standards.

In this way, Chile has been aiming to strengthen its position as an important fish producer. The total Chilean fishery landing in 2006 was 4.91 million tonnes, which represents a decrease of 10.4 percent from the previous year and a volume that is 5.0 percent lower than the average for the period 2001–2005. This volume is provided by the productions of two main sources: the capture fisheries, with 4.08 million tonnes, and the aquaculture sector, with an estimated production of 822.7 thousand tonnes (Figure 3). Trends in Chilean fishery and aquaculture production over the last ten years reveal the increasing importance of the aquaculture sector. The 61.4 percent of capture fishery production represented by pelagic resources in 2006 is slightly less than the 62.4 percent registered for the previous year (Figure 3).

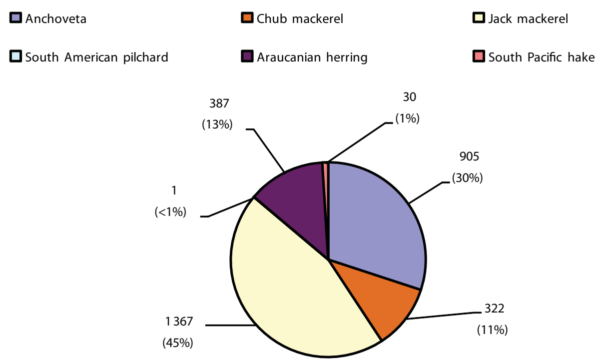
2.2 Main pelagic species

The upwelling of subsuperficial colder water towards shallower depths is induced by the action of the persistent winds that blow parallel to the coast, which in combination with the earth's rotation (the Coriolis effect), cause a displacement of the surface waters and their movement away from the coast. When this movement takes place, the superficial water displaced towards the open sea is replaced by deep waters, causing a reduction in the superficial temperature of the sea. This water, which is usually abundant in nutrients, enriches the superficial layer, allowing a high primary production (CONA, 2006).

This upwelling phenomenon occurs along a great part of the Chilean coastline as a result of the north-south shore orientation and the wind direction (Strub *et al.*, 1998). However, it is usual that these processes are specially localized in specific coastal areas, for example those areas associated with mountainous peaks and capes where there is a

FIGURE 5

Total accumulated landings by main pelagic species captured in Chile, 2006 (thousand tonnes)



Source: SERNAPESCA (2006)

high incidence of strong winds. Along the Chilean coast, the main areas of upwelling are located south of Arica, from south of Iquique to Punta Lobos, south of Coquimbo, south of Valparaiso, San Antonio and the zone between Talcahuano and the Gulf of Arauco (CONA, 2006). As a consequence of the upwelling process, these regions are some of the most productive on the planet, and they provide an abundant source of the main pelagic species that form an important part of the Chilean and global fisheries. In 1996, 20 percent of the world landings were caught in the area of the Chile-Peru Current System, which that represents only 0.09 percent of the ocean surface (Yañez *et al.*, 2001).

These areas support a significant industrial fishery for jack mackerel (*Trachurus murphyi*), anchoveta (*Engraulis ringens*) and sardines (South American pilchard, *Sardinops sagax* and Araucarian herring or common sardine, *Strangomera bentincki*) (Cubillos, Núñez and Arcos, 1998; Atkinson *et al.*, 2002; Escribano *et al.*, 2004), which are the main pelagic species used for the manufacture of fishmeal and fish oil. However, these zones are also directly affected by the El Niño Southern Oscillation (ENSO), which is characterized by an increase in the surface temperature of the ocean (Escribano *et al.*, 2004). Small pelagic fish such as sardines, anchoveta and herring respond dramatically and quickly to changes in ocean climate (Cubillos, Bucarey and Canales, 2002). Most are highly mobile and have short, plankton-based food chains, some even feeding directly on phytoplankton. They are short-lived (3–7 years) and highly fecund, some even being capable of spawning all year round. These biological characteristics make them highly sensitive to environmental changes and thus extremely variable in their abundance (Alheit and Niquen, 2004). The change in the normal conditions of the water induced by the ENSO causes the migration of pelagic species and the disappearance or replacement of some species, as happens, for example, with the anchoveta and sardine, and can produce, in addition, a diminution of the upwelling processes and intense precipitation in coastal zones (Yañez *et al.*, 2001).

As mentioned previously, the most remarkable among the important pelagic resources in Chile are the jack mackerel, the Peruvian anchoveta and the Araucarian herring

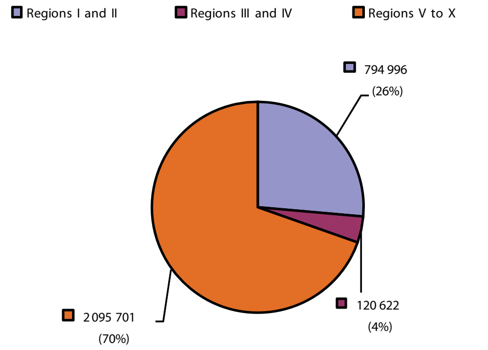
TABLE 2

Pelagic fish landings in Chile by year for the main captured species (thousand tonnes)

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Anchoveta	2 086	1 401	1 757	523	1 983	1 701	853	1 527	823	1 860	1 473	905
Chub mackerel	110	147	212	72	120	958	365	343	572	577	223	322
Jack mackerel	4 404	3 883	2 917	1 613	1 220	1 234	1 650	1 519	1 421	1 452	1 412	1 367
South American pilchard	162	81	40	28	246	60	33	19	11	5	2	1
Araucarian herring	127	447	441	318	782	723	325	347	304	356	275	387
South Pacific hake	207	375	71	354	310	91	162	133	86	71	33	30
Total	**7 096**	**6 334**	**5 439**	**2 907**	**4 661**	**4 767**	**3 388**	**3 889**	**3 217**	**4 321**	**3 417**	**3 011**

Source: SERNAPESCA (2007)

FIGURE 6
Distribution of pelagic fish landings by fishing zone for the year 2006 (tonnes)



Source: SERNAPESCA (2006)

Fresh fish stall at the fish market in the port city of Coquimbo, Chile

Fresh fish stall at the main artisanal fish market in the port city of Coquimbo, northern Chile. In spite of the abundant fish stocks, annual consumption of fish is low in Chile, at about 7 kg per person. It may look like smoked fish but in fact is an optical effect of the picture.
Courtesy of Adrian Hernandez

or common sardine, which contributed, respectively, about 45.4, 30.0 and 12.9 percent of the total accumulated landings for 2006 (Figure 5).

Jack mackerel is the main fishery resource that sustains the industrial activity from Atacama (Region III) to Los Lagos (Region X). Along the Chilean coast, jack mackerel has been considered a key target species for national fisheries. This species represents, in terms of volume, one of the most important fishery resources in Chile and the world (Arcos, Cubillos and Núñez, 2001). In Chile, the maximum historical total landing for this species was 4.4 million tonnes in 1995. From 1996, a marked reduction in the captures of this species was observed, and catches have been constant during the last five years, with an average close to 1.4 million tonnes (Table 2).

Common sardine or Araucarian herring (*Strangomera bentincki*) together with anchoveta (*Engraulis ringens*) represent the second most important resource for the fishery activity in the center-south of Chile. Sardine is largely distributed along the Chilean coast from Coquimbo to Chiloe, while anchoveta occurs from Peru to Chiloe. In Chile, the fishery activity for these species is mainly localized in Bio-Bio (Region VIII). There has been a reduction in the landings for these two species as a result of increased regulation and reduced effort by the industrial fleet for these resources.

The major proportion of pelagic fish landings in Chile is principally concentrated in the area between Regions V and X, with landings of almost 2.1 millions tonnes (70 percent), while in Regions I and II, the total landings reached around 795 thousand tonnes (26 percent). Regions III and IV, with 120.6 thousand tonnes, represent only the 4 percent of the national landings (Figure 6).

2.3 Fishing zones

For administrative purposes, until 2006 Chile was divided into five fishing zones, each of which was headed and regulated by a Fishing Zone Council that was integrated with the Chilean Fisheries Subsecretary. The Fishing Zone Councils contribute to the decentralization of the administrative measures adopted by the national authority and promote the participation of regional agents in activities related to fisheries and aquaculture. The five zones are as follows:

Zone 1 Regions I and II (Tarapacá and Antofagasta)
Zone 2 Regions III and IV (Atacama and Coquimbo)
Zone 3 Formed by a wide area extending from Regions V to IX (Valparaiso to Araucania) and oceanic islands
Zone 4 Regions X and XI (Los Lagos and Aysen)
Zone 5 XII Region (Magallanes) and Chilean Antarctica

From the point of view of the fishing industry and the types of fishing activity conducted, Chile is divided into three main zones: North Chile, South Chile and Austral Chile.

- **North Chile.** This zone is located from Regions I to IV (from Tarapacá to Coquimbo), where the main pelagic reduction fisheries are conducted. This zone is essentially a fishmeal producing area, with an annual production of around 220 thousand tonnes.
- **South Chile.** This is the main fishing zone of Chile and extends from Region V to X (Valparaiso to Los Lagos). In this zone, most products are produced in large-scale processing plants. The main processed products are frozen jack mackerel and South Pacific hake (*Merluccius gayi gayi*), with annual volumes surpassing 250 thousand tonnes. Around 550 thousand tonnes of fishmeal are produced annually in this zone.

Medium-size boats, used for seine fishing in Bio-Bio, Chile

Medium-size boats, 80 to 100 tonnes, used for seine fishing of pelagic species in Region VIII (Bio-Bio, Chile). This fishing method is known in Chile as "pesca de boliche".

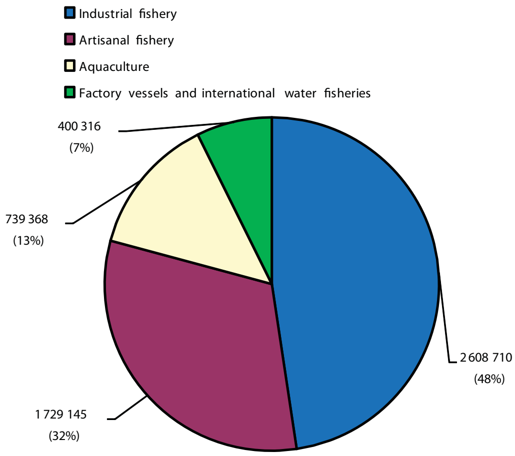
Courtesy of Adrian Hernandez

Fishmeal and fish oil processing factory in Talcahuano, Chile

Fishmeal and fish oil processing factory in the city of Talcahuano, Region VIII, (Bio-Bio, Chile). The major fishing industries are located in this region and process 70 percent of the pelagic species caught in Chile.

Courtesy of Adrian Hernandez

FIGURE 7
Fish production in Chile by type of source (tonnes)



Source: SERNAPESCA (2006)

- **Austral Chile.** This zone is basically dedicated to deep-water demersal fisheries and aquaculture production. The capture fisheries have a high artisanal component and depend principally on South Pacific hake. Aquaculture is the most significant activity in this zone, with the greatest development in Aysen and minor activity in the southern regions.

2.4 The structure of Chilean fisheries

Chilean fisheries can be divided into four main groups according to the source and method of production: artisanal fisheries, industrial fisheries, international-waters fisheries and aquaculture. In the year 2005, these four production groups reached a total volume of 5.48 million tonnes. The industrial fishery represents 48 percent of the total landings, the artisanal fishery 32 percent and aquaculture 13 percent, whereas the fishery in international waters and factory vessels represent only 7 percent (Figure 7).

The industrial fishery produced 2.6 million tonnes based on the operation of a total of 224 vessels. Ninety-five percent of the industrial landings were represented by the pelagic resources, with anchoveta and sardines contributing 1.14 million tonnes (43.6 percent) and chub mackerel (*Scomber japonicus*) and jack mackerel contributing 1.34 million tonnes (51.4 percent). The zone where the bulk of landings of these species is concentrated is the Bio-Bio (Region VIII), with a total of 1.3 million tonnes, which represents 49.9 percent of the national industrial fishery. During 2005, industrial landings of pelagic fish decreased by 18 percent from the previous year.

The artisanal fishery captured 1.73 million tonnes and operated with a total of 1 439 boats. Pelagic resources represented 44 percent of the artisanal landings. Anchoveta and sardines contributed 704 thousand tonnes (41 percent), while chub mackerel and jack mackerel accounted for 50 thousand tonnes (3 percent). Again, Region VIII accounted for the largest landings of pelagic species, with a total volume of 414 thousand tonnes (23.9 percent). Other species used for human consumption accounted for the remaining 56.3 percent (974 thousand tonnes) of the production.

In 2005, factory vessels operating in national waters captured a total of 76 thousand tonnes, with 100 percent of the catch being fish (as opposed to molluscs), while vessels operating in international waters captured a total of 3.14 thousand tonnes (1.97 thousand tonnes of fish and 1.17 thousand tonnes of molluscs). The volume captured by international industrial vessels was 320 thousand tonnes.

During 2005, a total of 1 020 aquaculture operations was registered in Chile, and the subsector produced approximately 739 thousand tonnes. Fish represented 82 percent (614 thousand tonnes) of production, molluscs 15 percent (109 thousand tonnes) and seaweed 3 percent (15 thousand tonnes). Eighty-three percent of the aquaculture centres were located in Region X (Los Lagos), where 28 percent of the centres corresponded to fish farming (mainly salmon and trout), 39 percent of the centres to mollusc culture and 33 percent to seaweed farming.

2.5 Fishing regulation and restrictions

Given its significant contribution to global fisheries production, Chile recognizes the importance of regulating all fishing activity in the country. The Government of

Chile undertakes and promotes regular monitoring surveys to establish the state of the national fishery resources, using the results of these surveys to set the control measures required to protect and manage the fishery stocks. In Chile, the exploitation, use and conservation of the living marine resources have been based on the concept of maximum sustainable yields, the application of seasonal and geographical closures, the definition of catch areas, and regulations on the use of fishing gear and minimum size limits. The General Law on Fisheries and Aquaculture was promulgated in 1991 to establish the legal framework that currently prevails in the Chilean fisheries (Gobierno de la Republica de Chile. Ley No. 18.892, 1991). This law was created with the objective of preserving the marine resources and to set up a series of national rules that maintain a general regime of free access to fisheries resources, with the exception of those considered endangered or in recovery. For this reason, the national fishing authority, represented by the Chilean Subsecretary of Fisheries, has strengthened the application of regulatory measures aimed at restricting the entry of new vessels or fishing methods in order to avoid increased pressure on current fisheries and to establish limits or capture quotas with the objective of maintaining the sustainability of these resources. In addition, all fishing boats in Chile are fitted with a Vessel Monitoring System (VMS) to ensure that they do not operate inside prohibited areas (such as designated areas of recovery) or the zone reserved for small artisanal fisheries (first five miles offshore).

To protect the spawning stocks, closed seasons for anchoveta and sardine appropriate to their spawning cycles are set on an annual basis, usually between August and September of each year in the northern part of the country. Closed seasons are also imposed during December to mid-January to protect the recruitment process of anchoveta. In the central-southern part of the country, closed seasons are set for anchovy and sardine to protect the spawning period (usually July and August) and also from mid-December to mid-February (SERNAPESCA, 2007).

The Government of Chile has introduced legislation to establish an annual total allowable catch (TAC) for each species declared in full exploitation for each owner of a boat or group of boat owners. The capture quotas approved for 2007 by the Chilean Subsecretary of Fisheries were published in December 2006. The quotas established by the national authority have not varied significantly and have been kept at almost the same levels during the last years in order to preserve the fisheries resources within acceptable limits of exploitation. These measures aim to relieve the pressure on the resources and to sustain an activity that has demonstrated to be very vulnerable during recent times. The main pelagic species for which capture quotas for the year 2007 were increased are anchoveta, sardines and jack mackerel. Although minimum landing sizes are applied for jack mackerel, there is the possibility that several fishing bans can be imposed during the year to protect small-sized fish. These measures reinforce controls to protect stock recruitment. The approved capture quota for jack mackerel during 2007 was 1.6 million tonnes, an increase of around 14 percent from the previous year. In the case of anchoveta and sardines, the official quotas during 2007 for Regions V to IX presented an increase of 44 percent for anchoveta and 29 percent for sardine (288 and 280 thousand tonnes, respectively). Total capture quotas permitted by the Chilean

TABLE 3

Official capture quotas established by the Chilean Subsecretary of Fisheries, 2007

Fishery	Anchoveta	Sardine	Jack mackerel	South Pacific hake	Total
Industrial	1 272 314	73 400	1 444 000	154 000	2 943 714
Artisanal	341 766	203 700	76 000		621 466
Research	49 920	8 400	80 000	4 000	142 320
Total	**1 664 000**	**285 500**	**1 600 000**	**158 000**	**3 707 500**

Source: SUBPESCA (2006a)

Talcahuano Port, Chile

Talcahuano Port, Talcahuano, Region VIII (Bio-Bio, Chile)

fisheries authority for anchoveta and sardine are 1.66 million tonnes and 285 thousand tonnes, respectively (Table 3).

3. PROCESSING AND PRESERVATION OF PELAGIC FISH AND FISH-BASED PRODUCTS IN CHILE

3.1 Fishmeal and fish oil production

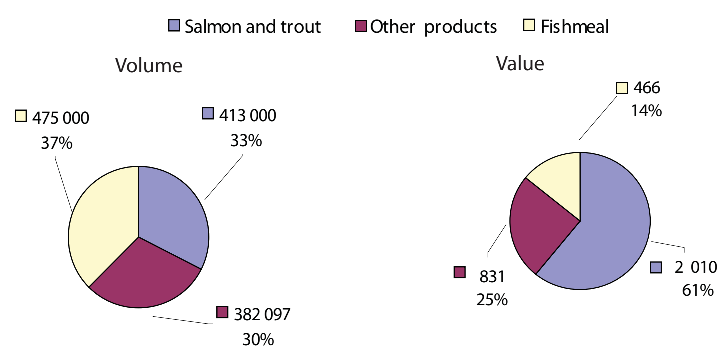
3.1.1 Present fishmeal and fish oil production and values

Nowadays the Chilean production of fishmeal and fish oil is around 900 and 170 thousand tonnes, respectively. Preliminary values for November 2006 indicate that the accumulated volume of fishmeal exported represents 37 percent (475 thousand tonnes) of fishery product exports, with an estimated value of approximately US$466 million, representing about 14 percent of the total value of fishery products exported by Chile (Figure 8).

The capture of the main pelagic species in 2005 was close to 3.5 million tonnes, while for November 2006 alone, the accumulated landings totaled 3.1 million tonnes (Table 2). The main species destined for the production of fishmeal and fish oil come from

FIGURE 8

Preliminary volumes and values of exports for the main Chilean fish products (tonnes and millon US$)



Source: SERNAPESCA (2006)

the industrial and artisanal pelagic fisheries. In 2005, 49.7 percent of total fishmeal production was contributed by anchoveta, 7.2 percent by chub mackerel, 29.4 percent by jack mackerel, 9.2 percent by sardine and 0.4 percent by South Pacific hake (Table 4). In 2005, these species combined represented 95.9 percent of all the pelagic fisheries landings used for the production of fishmeal and fish oil. The fishmeal production are presented in Table 4. It can be observed that 41 percent of the total fishmeal produced was made

TABLE 4
Capture volume of the main pelagic species used for fishmeal production and fishmeal production by species used, 2005, (thousand tonnes)

Species	Capture volume	% of total contributing to fishmeal production	Fishmeal production	% of total fishmeal production
Anchoveta	1 531	49.7	341	41
Chub mackerel	221	7.2	53	6
Jack mackerel	906	29.4	221	27
Sardines	284	9.2	58	7
South Pacific hake	14	0.4	2	0
Others	127	4.1	27	3
Trash fish/low-value fish	-	-	125	15
Total	**3 082**	**100**	**827**	**100**

Source: SERNAPESCA (2006)

TABLE 5
Production of fishmeal by species, 1995–2005 (thousand tonnes)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Anchoveta	439	306	392	117	424	387	194	333	183	417	341
Chub mackerel	25	34	49	14	26	2	77	69	123	115	53
Jack mackerel	956	834	594	260	204	216	302	243	227	233	221
Sardines	50	103	99	73	214	153	72	71	60	74	58
South Pacific hake	36	70	12	69	58	16	28	15	2	0	2
Other fish	1	3	6	3	2	3	4	1	11	17	27
Trash fish	45	49	72	106	72	81	100	104	99	128	125
Total	**1 553**	**1 399**	**1 225**	**643**	**1 000**	**858**	**778**	**836**	**705**	**984**	**827**

Source: SERNAPESCA (2006)

FIGURE 9
Fishmeal production trends by species, 1995–2005

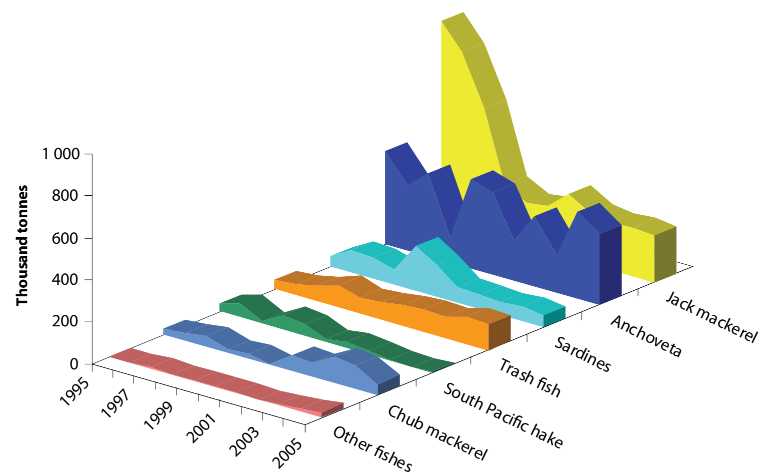
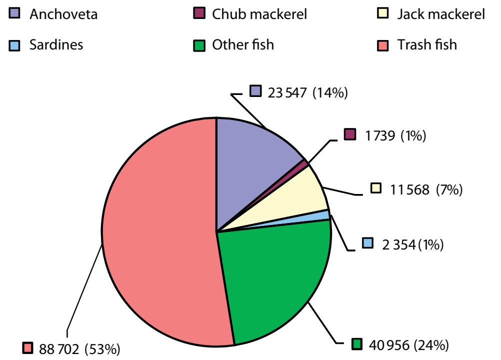


FIGURE 10
Fish oil production by species in Chile, 2005 (tonnes)



Source: SERNAPESCA (2006)

from anchoveta, 27 percent was made from jack mackerel and 15 percent was made from trash fish and only 3 percent was made from other species.

3.1.2 Fishmeal and fish oil production trends during the last decade

Table 5 and Figure 9 present the trends in fishmeal production in Chile over the period 1995–2005. During this period, fishmeal production declined by almost 50 percent because of a substantial decrease in landings. The species with a noticeable reduction in capture volume and as a consequence, a reduction in contribution to fishmeal production, is jack mackerel. The capture volume of this species in 1998 was only a quarter of that taken in 1995, and since 1999, annual landing volumes have stagnated at around 235 thousand tonnes, with authorized capture quotas on the order of 1.5 million tonnes. The contribution of anchoveta to fishmeal production remained broadly stable over the last decade with an annual average of 321 thousand tones, varying between 183 and 439 thousand tonnes, not considering the landing of 117 thousand tonnes in 1998 (a year in which the El Niño phenomenon had a high impact on Chilean fisheries).

An important increase in fishmeal production using species not traditionally destined for fishmeal occurred during the last three years; annual average production reached 27 thousand tonnes, which corresponds to a capture of around 127 thousand tonnes in 2005 (Table 4). In the same way, the production of fishmeal from chub mackerel and trash fish shows an increase that began in 2001 and maintained an annual average of 87 and 111 thousand tonnes, respectively. In the case of production from trash fish, during the first half of the decade 1995–2005, the annual average production did not exceed 71 thousand tonnes.

At present, more than 53 percent of the fish oil is produced from trash fish and 24 percent is produced from species other than the main pelagic species usually destined for fishmeal production. Only 22 percent of fish oil was derived from anchoveta, sardine and mackerel (Figure 10). Of the most abundant pelagic species, anchoveta shows the largest fish oil contribution of 23 547 tonnes or 14 percent of the total fish oil produced in 2005.

The trend in fish oil production over the period 1995–2005 is shown in Table 6 and Figure 11. In the first half of the decade, the annual average production was around 219 thousand tonnes, while the annual average during the period 2001–2005 was on the order of 153 thousand tonnes of fish oil, which represents a decrease of around 40 percent. With regard to fish oil production, the item "other fishes" includes not only the main pelagic species (anchoveta, jack mackerel, chub mackerel and sardines), which only contributed 23 percent of the total fish oil produced during 2005, but also other smaller species like king gar or agujilla (*Scomberesox saurus scombroides*), starry butterfish

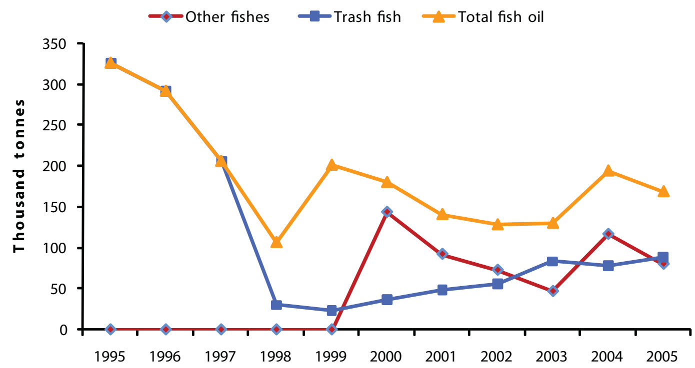
TABLE 6
Annual fish oil production in Chile, 1995–2005 (thousand tonnes)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Other fishes	0	0	0	77	178	144	92	73	47	117	80
Trash fish	326	292	206	30	23	37	49	56	83	78	89
Total fish oil	**326**	**292**	**206**	**107**	**201**	**181**	**141**	**129**	**130**	**195**	**169**

Source: SERNAPESCA (2006)

or pampanito (*Stromateus stellatus*), cabinza grunt (*Isacia conceptionis*) and other fish that as a whole contributed approximately 24 percent of the oil. By contrast, trash fish contribute around 47 percent of the total fish oil produced in Chile. These trash fish originate mainly from the canning and fish processing industry.

FIGURE 11
Annual production of fish oil, 1995–2005



Source: SERNAPESCA (2006)

3.1.3 Fishmeal and fish oil prices and markets

In 2005, approximately 40 percent (340 thousand tonnes) of the total fishmeal produced in Chile was used for domestic consumption. Given that the Chilean aquafeed production was on the order of 850 thousand tonnes, the volume of fishmeal included in these feeds was around 240 thousand tonnes. The remaining amount was devoted to other uses in animal production. Between 1991 and 1994, domestic use of fishmeal was more or less 70 percent of the total national production. In 1995, the domestic use was reduced to 60 percent of total production, and by 1998 only 45 percent of the total production. During 1998, national fishmeal production was at its lowest at any time the last decade (643 thousand tonnes), and coincided with one of the most devastating El Niño events ever to affect the coasts of the South Pacific (Avaria *et al*., 2004). In 1999, the production of fishmeal increased significantly (1 million tonnes), with domestic consumption accounting for around 70 percent of the total fishmeal production.

FIGURE 12
Fishmeal use in Chile, 1991–2005

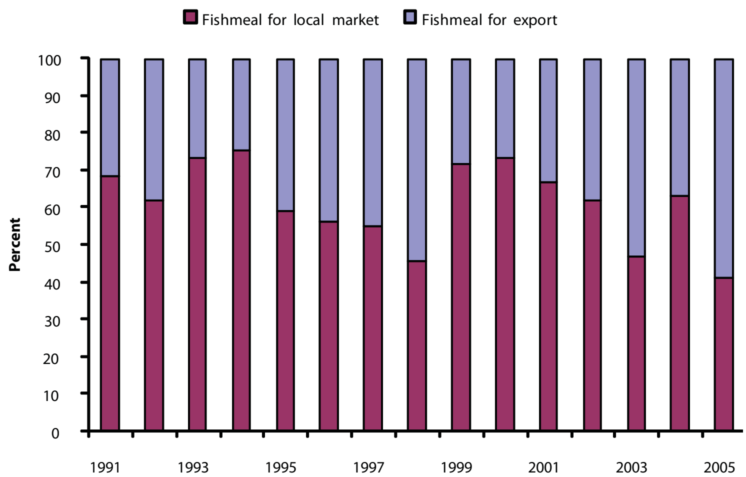


TABLE 7
Annual production of fishmeal and volumes for domestic use and export (thousand tonnes)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Fishmeal production	1 471	1 423	1 383	1 841	1 553	1 399	1 225	643	1 000	877	778	843	705	988	827
Fishmeal for export	465	540	366	453	633	612	552	349	282	235	257	320	373	362	487
Fishmeal for domestic market	1 006	883	1 017	1 388	919	786	672	294	718	642	520	523	332	626	340

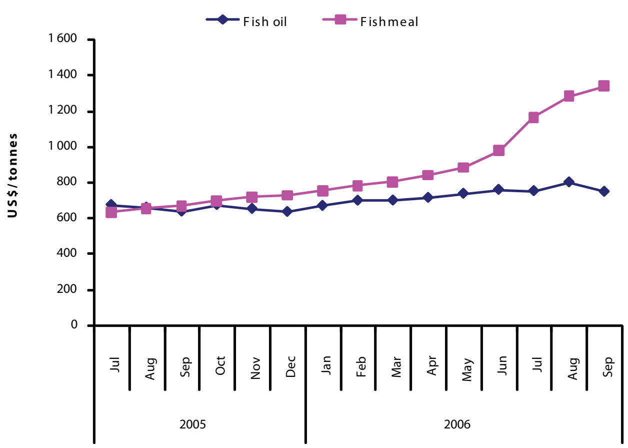
Source: SUBPESCA (2006b)

TABLE 8
Main importers of Chilean fishmeal

Country	Value (US$ thousand)		Volume (tonnes)	
	2005	2006	2005	2006
China	165 841	152 853	260 234	151 545
Japan	61 213	78 399	95 914	78 081
Taiwan POC	43 991	42 788	68 952	45 909
Germany	14 554	29 114	19 983	26 448
Republic of Korea	20 604	28 538	31 443	27 780
Viet Nam	19 320	24 329	30 625	26 656
Italy	16 949	23 465	27 502	24 672
Spain	19 440	22 520	29 968	22 893
Indonesia	14 492	13 807	23 372	14 966
Other countries	60 065	49 385	91 277	55 882
Total	**436 470**	**465 198**	**679 269**	**474 832**

Source: SUBPESCA (2006b)

FIGURE 13
Variation in fishmeal and fish oil prices, 2005–2006



Source: SERNAPESCA (2007)

From 2000 until 2005, there was a sustained decline in the domestic use of fishmeal, even though the annual average fishmeal production stabilized around 836 thousand tonnes (Table 7 and Figure 12). Table 8 shows the main destinations for Chilean fishmeal. To November 2006, the main markets were China with 153 thousand tonnes, followed by Japan with 61 thousand tonnes and together accounting for 52 percent of the fishmeal exported from Chile. As regards the use of fish oil, 100 percent was for internal consumption, mainly for the salmon aquafeed industry.

Figure 13 shows that the price of fishmeal (US$636/tonne) reached a peak in September 2006 (US$1 340/tonne). The average price during 2006 was US$983/tonne (Table 9). The price of fish oil during the period from July 2005 to September 2006 varied between US$637 and US$803/tonne (Figure 13). The average price in 2006 was US$733/tonne (Figure 13). Estimations of the Asociación de Industriales Pesqueros (ASIPES) from the Bio-Bio Region forecasted that the price of fishmeal would be over US$1 000/tonne during the year 2007.

Exapesca S.A. is a Chilean company founded in October 1994 and dedicated to the commercial development of fish oil. At present, it has nine large Chilean fishery subsidiaries located throughout southern Chile and represents 90 percent of the total fishery production in Regions V to X and 64 percent of the total national pelagic fishery production. In terms of national production for 2006, it produced 74 percent of the fishmeal and fish oil.

3.2 Fish-preserving industry

The most important fishery products produced in Chile are fishmeal, fish oil, and frozen, fresh chilled and canned products. In Chile, there are a total of 760 plants for the processing and preserving of fishery products. Around 41 percent of the plants are dedicated to frozen products, and only 5 percent of the plants to the manufacture of fishmeal and fish oil. Figure 14a shows the distribution of these plants by type of process line, whereas Figure 14b indicates the distribution of plants by region. Sixty-eight percent of the plants are concentrated in the south-Austral zone. Regions VIII, X and XII contain a total of 457 processing plants, representing 18, 33 and 10 percent of all the plants in Chile, respectively. Table 10 shows the number of processing plants by region and by type of process line.

In 2005, 1.78 million tonnes of processed fish products were produced, which represents 39.4 percent of the total landings in Chile (4.53 million tonnes). Fishmeal and fish oil represent around 56 percent of the products processed, followed by frozen products with 27 percent, while fresh chilled and canned (preserved) products together represent 17 percent (Figure 15).

During the period 1995–2005, the production of fishery-processed products declined in line with the decline in total landings, which decreased by 39 percent, while the production of processed products dropped by 22 percent (Table 11 and Figure 16). However, if the development of processed products for human consumption is compared (adding frozen, fresh chilled and canned products) with fishmeal and fish oil production (Figure 17), we can observe that while fishmeal has maintained a constant reduction of 47 percent during the period 1995–2005, development of products for human consumption shows a sustained growth of 166 percent during this period.

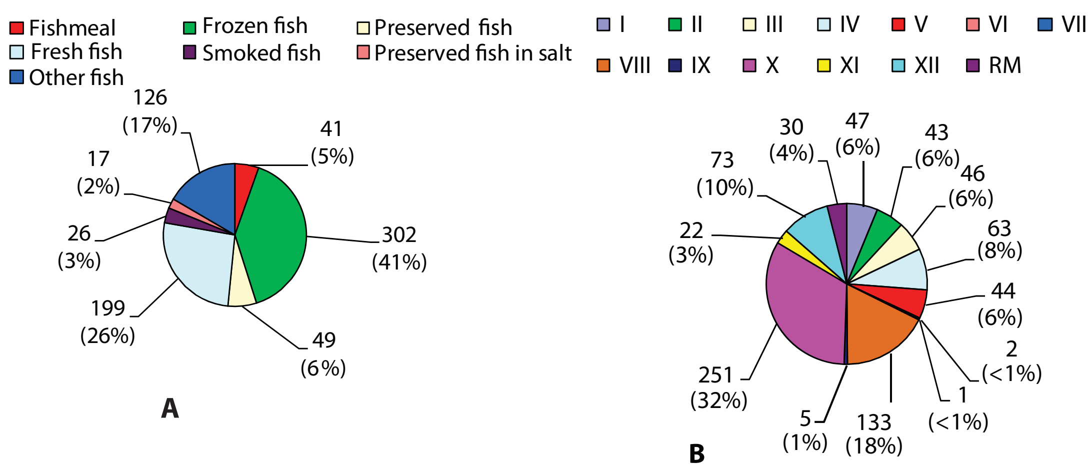
TABLE 9
Monthly variation of fishmeal and fish oil prices, July 2006 - September 2006

Year	Month	Fish oil	Fishmeal
2005	Jul	676	636
	Aug	661	657
	Sep	639	672
	Oct	676	700
	Nov	654	723
	Dec	637	731
Mean		657	687
2006	Jan	671	757
	Feb	700	786
	Mar	701	807
	Apr	716	844
	May	739	886
	Jun	761	980
	Jul	754	1 166
	Aug	803	1 283
	Sep	750	1 340
Mean		733	983

Source: Aqua (2006)

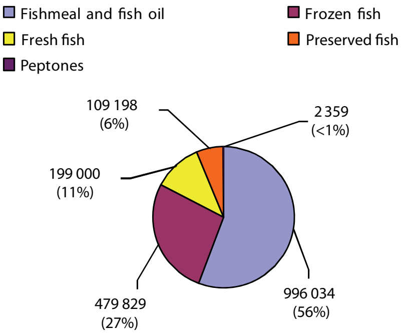
When the production of processed products for human consumption is divided into frozen, canned and fresh chilled, we can observe that the frozen products maintain a significantly greater production than the other products. The frozen and fresh chilled products have maintained a continuous growth during the period 1995–2005,

FIGURE 14
Percent distribution of all the processing plants in Chile by type of product and region



Source: SERNAPESCA (2006)

FIGURE 15
Production (tonnes) and percent distribution of main fishery processed products, 2005



Source: SERNAPESCA (2006)

with an increase of around 176 percent and 411 percent, respectively. The total production of frozen products has increased from 174 to 480 thousand tonnes, whereas that of fresh chilled products grew from 39 to 199 thousand tonnes. Production of canned fish products has stagnated during the same period, the average annual growth being -3.3 percent (Figure 18).

3.2.1 Frozen products

In 2005, the total production of frozen products was 480 thousand tonnes, of which 90 percent correspond to fish (432 thousand tonnes), 8.7 percent to molluscs (42 thousand tonnes), 1 percent to crustaceans (4.6 thousand tonnes) and 0.3 percent to other species (1.5 thousand tonnes). Of the production of frozen fish, 55 percent corresponds to

TABLE 10
Number of processing plants in Chile by product line and region, 2006

	Chilean region													
Product line	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**RM**	**Total**
Fishmeal	5	2	3	4	2	0	0	20	0	4	1	0	0	41
Frozen fish	4	10	6	30	28	2	1	44	1	115	12	36	13	302
Preserved fish	1	0	1	6	0	0	0	14	0	22	0	5	0	49
Fresh fish	14	17	12	14	11	0	0	15	2	70	8	27	9	199
Smoked fish	0	0	0	1	0	0	0	2	2	20	0	0	1	26
Fish preserved in salt	10	3	0	0	0	0	0	0	0	3	0	1	0	17
Other fish	13	11	24	8	3	0	0	38	0	17	1	4	7	126
Total	**47**	**43**	**46**	**63**	**44**	**2**	**1**	**133**	**5**	**251**	**22**	**73**	**30**	**760**

Source: SERNAPESCA (2006)

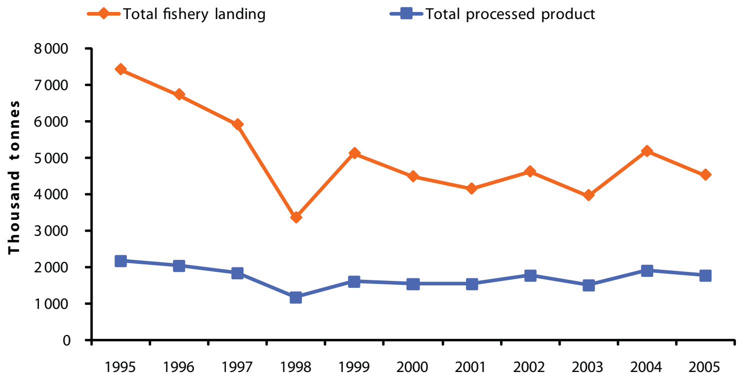
TABLE 11
Production of main processed fish products, 1995–2005 (thousand tonnes)

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Total fishery landing	7 411	6 726	5 905	3 362	5 118	4 486	4 151	4 621	3 971	5 176	4 531
Fishmeal	1 553	1 399	1 225	643	1 000	877	778	843	705	988	827
Fish oil	326	292	206	107	201	180	141	128	130	194	169
Frozen fish	174	179	216	226	223	288	390	380	378	447	480
Fresh fish	39	77	74	78	73	99	135	128	164	164	199
Preserved fish	84	79	118	117	110	110	108	286	115	116	109
Peptones*	0	0	0	0	0	0	0	2	3	2	2
Total processed products	**2 176**	**2 025**	**1 839**	**1 170**	**1 608**	**1 555**	**1 551**	**1 767**	**1 494**	**1 912**	**1 786**

* Peptones are protein hydrolysates that are soluble in water and not heat coagulable. These products may have significant value for the fisheries industries because their market prices are somewhat higher than those of the usual by-products such as fish silage and fishmeal.

Source: SERNAPESCA (2006)

FIGURE 16
Fishery landing trends compared with processed production



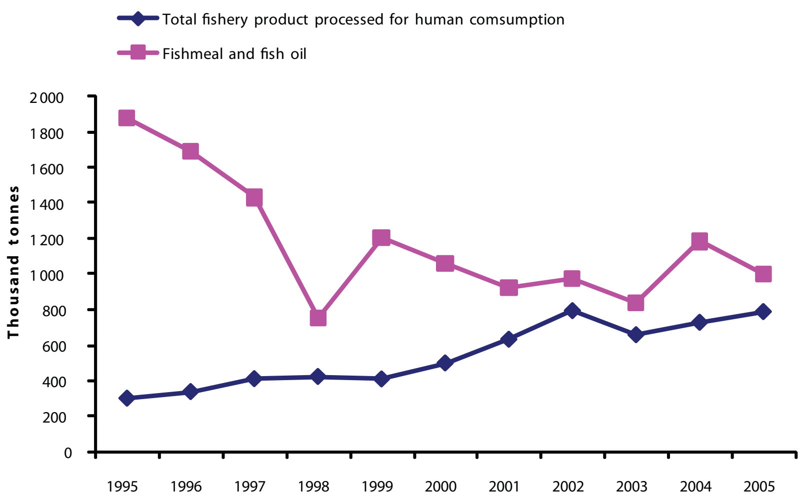
Source: SERNAPESCA (2006)

cultivated fish (mainly Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*)), 35 percent corresponds to pelagic fish (anchoveta, jack mackerel, South Pacific hake and sardine) and the remaining 10 percent is comprised of other fish (Figure 19).

In 2005, 78 percent (116 000 tonnes) of frozen pelagic fish products was made from jack mackerel, 16 percent South Pacific hake (23 000 tonnes) and 5 percent chub mackerel (7.6 thousand tonnes), with anchoveta and sardines together contributing only 1 percent (Table 12 and Figure 20).

Pelagic fish that are traditionally destined to the reduction industry have made a significant contribution to the growth in the production of frozen products. Over the period 1995–2005, their contribution has increased by around 700 percent, rising from a total of 21 thousand tonnes in 1995 to 147 thousand tonnes in 2005. The greatest

FIGURE 17
Fishmeal and fish oil production trends compared only with trends in production of processed fishery products for direct human consumption, 1995–2005



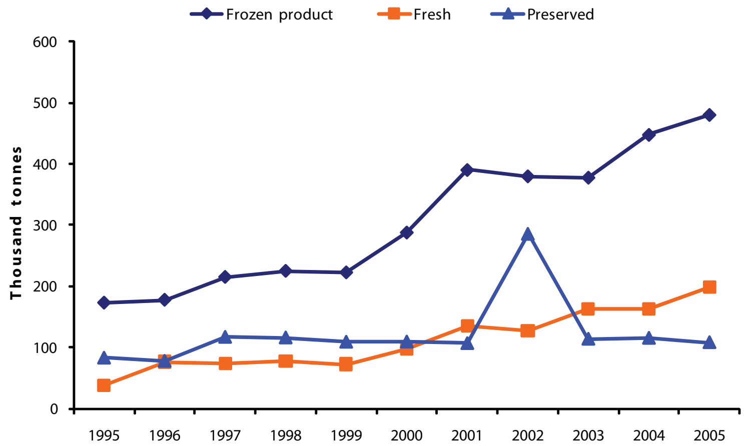
Source: SERNAPESCA (2006)

contribution to growth is provided by jack mackerel, chub mackerel and South Pacific hake, with an average increase during this period of almost 1 157 percent. Nevertheless, the production of frozen product from smaller pelagic fish (anchoveta and sardines) has decreased by an average of around 87 percent (Table 12 and Figure 21).

FIGURE 18

Annual production trends of the main processed fishery products for direct human consumption during the period 1995–2005

Source: SERNAPESCA (2006)



Source: SERNAPESCA (2006)

Figure 22 and Table 13 show the total pelagic fish landings and the production of frozen fish and fishmeal. It can be observed that from the first half of the decade 1995–2005 the production of fishmeal from the pelagic fish landings has stayed more or less constant, with an average of 21 percent; however, the production of frozen fish has shown an increase from 0.7 to 4.1 percent, which means that the growth in frozen fish production has not affected fishmeal production, a fact that could be explained by the reduction of other types of processed products.

3.2.2 *Chilled fresh products*

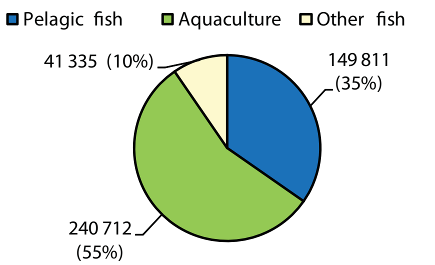
The total chilled fresh fish production is around 199 thousand tonnes, of which 98.5 percent corresponds to fish (196 thousand tonnes), 0.84 percent to molluscs (1.7 thousand tonnes), 0.01 percent to crustaceans (29 tonnes) and 0.7 percent to other species (1.3 thousand tonnes). Of the total production of fresh chilled fish, 93 percent corresponds to cultivated fish, mainly Atlantic salmon, coho salmon (*Oncorhynchus kisutch*), rainbow trout and turbot (*Psetta maxima*), 7 percent to pelagic fish (anchoveta, jack mackerel, South Pacific hake and sardine) and a very small percentage to other fish (Figure 23).

3.2.3 Canned products

The total production of canned fishery products in 2005 was 109 thousand tonnes, of which 91 percent corresponded to fish (99 thousand tonnes), 8.8 percent to molluscs (9.6 thousand tonnes) and 0.2 percent to crustaceans

FIGURE 19

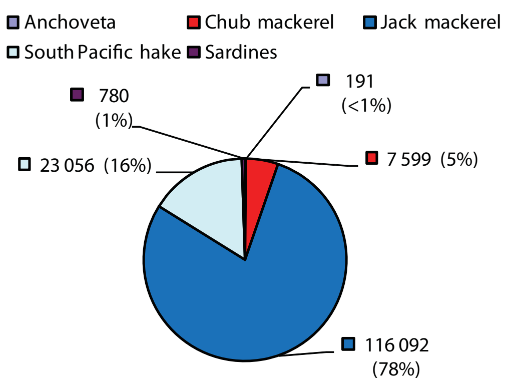
Production (tonnes) and percent distribution of frozen fish, 2005



Source: SERNAPESCA (2006)

FIGURE 20

Production (tonnes) of pelagic fish processed as frozen products, 2005



Source: SERNAPESCA (2006)

TABLE 12

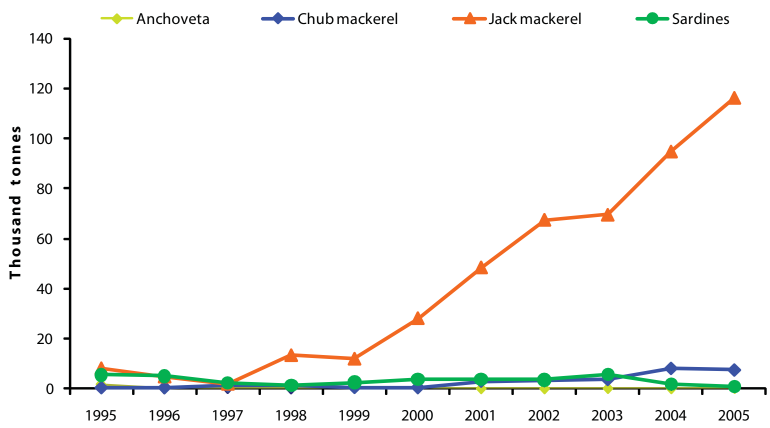
Production of frozen products from small pelagic species, 1995–2005 (thousand tonnes)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Anchoveta	1.66	0.04	0.16	0.02	0.36	0.05	0.09	0.07	0.17	0.09	0.19
Chub mackerel	0.39	0.45	1.14	1.18	0.53	0.50	3.06	3.25	3.74	8.26	7.60
Jack mackerel	8.15	4.83	1.92	13.37	11.97	28.15	48.41	67.42	69.43	94.66	116.09
South Pacific hake	5.64	1.94	4.05	4.98	4.92	3.08	9.96	16.58	22.68	21.34	23.06
Sardines	5.31	4.89	2.15	1.16	2.34	3.75	3.74	3.40	5.47	1.75	0.78
Total	**21.15**	**12.15**	**9.41**	**20.70**	**20.13**	**35.53**	**65.26**	**90.72**	**101.48**	**126.09**	**147.72**

Source: SERNAPESCA (2006)

FIGURE 21

Production of frozen products from the main pelagic species, 1995–2005



Source: SERNAPESCA (2006)

TABLE 13

Production of fishmeal and frozen products from the main pelagic fish species in Chile (thousand tonnes)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total pelagic fish landing	7 096	6 414	5 560	3 041	4 576	4 868	3 516	4 032	3 368	4 477	3 577
Fishmeal	1 553	1 399	1 225	643	1 000	877	778	843	705	988	827
Frozen products	21	12	9	21	20	36	65	91	101	126	148
% fishmeal	22	22	22	21	22	18	22	21	21	22	23
% frozen products	0	0	0	1	0	1	2	2	3	3	4

Source: SERNAPESCA (2006)

TABLE 14

Production of fresh chilled fish from pelagic species, 1995–2005 (thousand tonnes)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Anchoveta	0	0	0	134	5	0	0	3	87	129	5
Chub mackerel	0	0	0	0	0	3	28	44	15	0	0
Jack mackerel	285	8 444	9	79	499	3 272	11 281	3 301	757	321	256
Sardines	10	8 512	0	0	0	256	33	138	94	0	0

Source: SERNAPESCA (2006)

TABLE 15

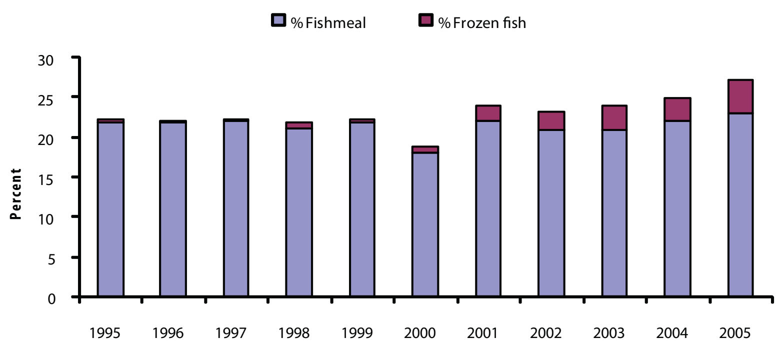
Production of canned fish from pelagic species, 1995–2005 (thousand tonnes)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Anchoveta	0	0	0	0	0	1	0	0	0	0	0
Chub mackerel	1	0	1	1	1	1	5	3	5	12	5
Jack mackerel	60	63	99	103	95	99	92	273	100	94	94
Sardines	11	2	4	1	0	1	0	0	0	0	0
Total	**73**	**66**	**104**	**105**	**97**	**101**	**98**	**276**	**105**	**105**	**99**

Source: SERNAPESCA (2006)

FIGURE 22

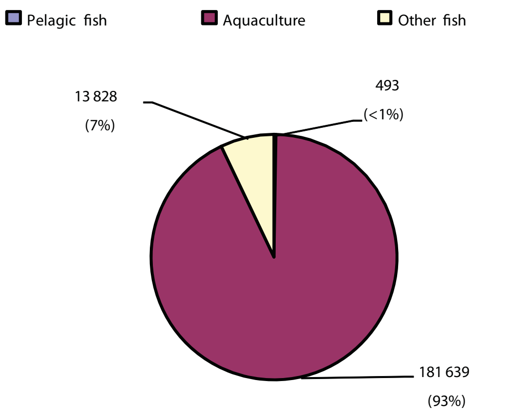
Relative proportion of fishmeal and frozen fish produced from the total landing, 1995–2005



Source: SERNAPESCA (2006)

FIGURE 23

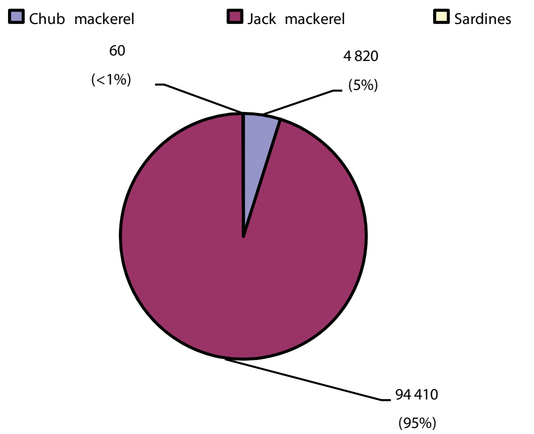
Production (tonnes) of fresh chilled fish, 2005



Source: SERNAPESCA (2006)

FIGURE 24

Production (tonnes) of canned pelagic fish processed from main species, 2005



Source: SERNAPESCA (2006)

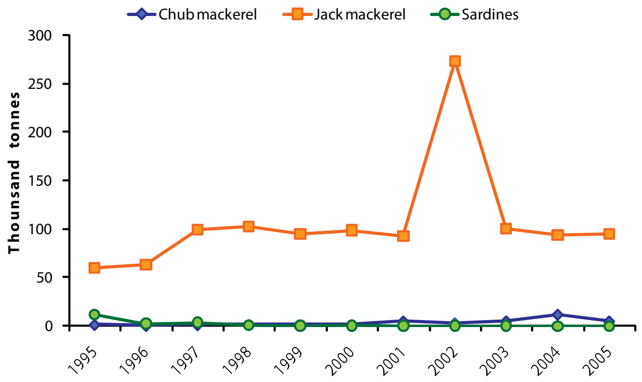
TABLE 16

Production of fishmeal and canned fish from pelagic species in Chile (thousand tonnes)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total pelagic fish landing	7 096	6 414	5 560	3 041	4 576	4 868	3 516	4 032	3 368	4 477	3 577
Fishmeal	1 553	1 399	1 225	643	1 000	877	778	843	705	988	827
Canned fish	73	66	104	105	97	101	98	276	105	105	99
Percent fishmeal	22	22	22	21	22	18	22	21	21	22	23
Percent canned fish	1.0	1.0	1.9	3.4	2.1	2.1	2.8	6.9	3.1	2.4	2.8

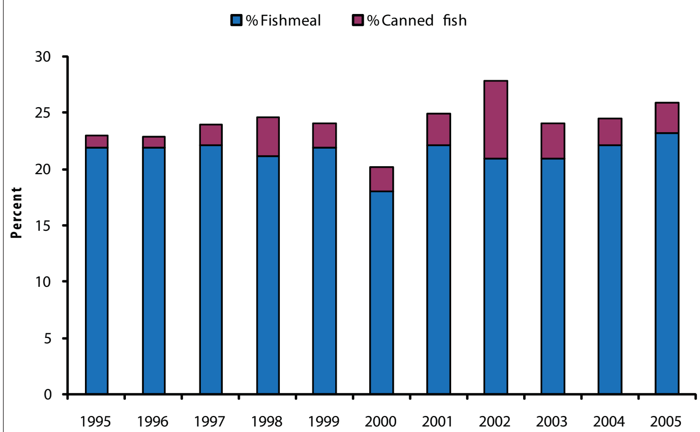
Source: SERNAPESCA (2006)

FIGURE 25
Production of canned products from the main pelagic species, 1995–2005



Source: SERNAPESCA (2006)

FIGURE 26
Fishmeal and canned fish production from pelagic fish species, 1995–2005



Source: SERNAPESCA (2006)

(214 tonnes). The total production of canned fish was entirely derived from pelagic species (anchoveta, jack mackerel and sardines) (Table 15).

In 2005, 95 percent (94 thousand tonnes) of the production of canned pelagic fish was from jack mackerel, 5 percent from chub mackerel (4.8 thousand tonnes) and less than 1 percent from anchoveta and sardines (Table 15 and Figure 24).

During the period 1995–2005, the production of canned products from pelagic fish increased by 36 percent, rising from a total of 73 thousand tonnes in 1995 to 99 thousand tonnes in 2005. This growth was due to the increased use of jack mackerel (whose contribution rose by 58 percent), while the use of other pelagic fish did not have a significant impact on the production of canned products (Table 15 and Figure 25).

Table 16 and Figure 26 and show a comparison of total landings of and fishmeal and canned products produced from the main pelagic species. It can be observed that from the second half of the decade 1995–2005, the production of fishmeal from overall pelagic fish landings was more or less constant, with an average of 21 percent. However, production of canned products from the same species presented a slight increase, rising from 2.1 to 2.8 percent. The increasing production of canned products from pelagic fish did not impact fishmeal production.

3.2.4 Destination of main processed products

From January to March 2007, the Chilean export of fish products showed an increase of 34.6 percent over the same period in 2006 (SERNAPESCA, 2007). Almost 46 percent of exports was frozen products and 33.5 percent was fishmeal, followed by exports of chilled fresh and canned fish products. The majority of these exports were derived from salmonids produced by the aquaculture industry. Besides fishmeal that is produced from pelagic fisheries, the remainders of the processed and preserved products that are derived from non-salmonid aquatic species do not contribute significantly to the total export values. As of February 2006, 88 countries were destinations for fishery exports. Nine countries account for 81.6 percent of the total value exported, the most important being Japan (32.7 percent), the United States of America (23.4 percent), China (6.3 percent) and Spain (5.2 percent).

4. USE OF FISHMEAL AND FISH OIL IN AQUAFEED

The fishmeal that is used in the manufacture of aquafeeds in Chile is all produced domestically. Most of the aquafeed manufacturing companies make use of high-quality fishmeal with low biotoxic residues (minimum toxic biogenic amines content) made from fresh raw ingredients. The average price of fishmeal during 2006 was approximately US$1 200/tonne, which together with the vitamin premix and carotenoids pigments, represents more than 60 percent of the total costs of aquafeed ingredients.

4.1 Chilean aquaculture production

The aquaculture of salmon and trout has a special importance in Chile. The enabling environmental conditions and abundant water resources, together with the availability of advanced scientific and technological know-how, have made Chile to become the second largest producer of salmon after Norway. The Chilean aquaculture industry is now one of the main sources of income and employment in the country. It is also one of the most important export sectors in Chile, contributing 22.2 percent of the total food products exported.

There are around 65 Chilean companies dedicated to fish culture, with 1 400 authorized salmon farming centres. Most of the Chilean salmon producers are members of the Chilean Salmon and Trout Producers Association, which is known as SalmonChile. This association was founded in 1986 by 16 of the main companies and has the main objective of ensuring the quality standards of produced and processed salmon.

During 2005, the total aquaculture production in Chile reached a volume of around 739 thousand tonnes, with salmonids contributing about 83 percent of the total, followed by molluscs (14 percent) and seaweeds (3 percent).

There are also some preliminary projects that aim to enhance the development of new species aquaculture in different regions of the country. These initiatives are promoted by the central government through the Chilean Economic Development Agency (Corporación de Fomento de la Producción, CORFO).

4.2 The aquafeed industry

Nowadays, in Chilean salmon aquaculture, the feed constitutes about 60–70 percent of the costs at the farm level and about 30–35 percent of the total cost of the final product once it is processed and packaged. In the beginning years of the Chilean salmon aquaculture industry, feed production was the exclusive responsibility of the aquaculture farms, and the diet formulation was essentially a mix of cattle entrails (predominantly liver), wheat by-products, fishmeal and occasionally, vitamins or special additives. Entrails were crushed in small mills and manually mixed with the rest of the ingredients. Intensive commercial aquaculture operations and industrial aquafeed companies started up in 1984 when the high demand for aquafeeds made it necessary to produce diets in the form of pellets whose formulation was based almost exclusively on the use of fishmeal and fish oil as main ingredients (Bórquez *et al.*, 1996). Since then, new feed production technologies and feed formulations have been incorporated into aquafeed industry operations, and the quality control of ingredients employed has become more rigorous.

Initially most of the aquafeeds employed in the Chilean aquaculture industry (fundamentally, in salmonid culture) was of a very simple formulation based on a high percentage (around 60 percent) of fishmeal as the main protein source, together with wheat flour, mineral premix and vitamins (Bórquez *et al*., 1996). The average concentrations of fishmeal and fish oil used in aquafeeds by Chilean salmon aquaculture operations during 2006 were around 25–30 percent and 15 percent, respectively. These values represent a significant reduction in the use of these ingredients in salmonid feeds when compared with the levels used during the mid-1980s.

It is important to stress that fishmeal is considered the best protein source for salmonid aquafeeds mainly because of its high protein content and suitable amino acid profile. Salmonids are carnivorous species that are able to make use of this kind of protein source in an efficient manner. However, the limited availability of fishmeal, unstable prices and a principle of economic and environmental sustainability have driven the national aquaculture industry to look for fishmeal substitutes. Consequently, the reduction of fishmeal inclusion levels during the last five years has been both accelerated and substantial. This reduction has been the result of sustained and joint research between aquafeed companies and universities in Chile. The average feed conversion ratio with these innovative low-fishmeal diet formulations in the Chilean aquaculture industry is around 1.35, meaning that the amount of aquafeed required to produce a tonne of fish is around 1 350 kg and that the amount of fishmeal incorporated in these diets is approximately 405 kg.

4.3 Aquafeed-producing factories in Chile and installed production capacity

During the 1990s, in Chile there were around 23 salmon feed factories that produced approximately 100 thousand tones of feed; however, the feed production subsector has consolidated and specialized, generating diverse types of diet that optimize nutritional content and create pellets which are resistant to crumbling (Bórquez and Zuñiga, 1995). Since 2000, there are seven major aquafeed manufacturing plants belong (Skretting Chile, Ewos Chile S.A., BioMar Chile S.A., Alitec S.A., Salmofood S.A., Salmones Antartica S.A. and Cultivos Marinos Chiloé Ltda) that all together produce nearly 700 thousand tonnes of feed per year. The installed production capacity of Chilean salmon feed plants was around 1.2 million tonnes in 2003 (SalmonChile, 2003).

4.4 Innovative use of alternative protein ingredients in Chilean aquafeeds

Most diets for carnivorous fish are heavily dependent on fishmeal as the main protein source. Fishmeal is prepared from dried, ground tissue of whole marine fish, mainly pelagic species such as jack mackerel, anchovy and sardines, or from the waste of processed fish products. Feed is the highest recurrent cost in aquaculture and represents more than 60 percent of the variable operating costs, depending on the intensity of the operation. In general, fishmeal is considered a conventional and important ingredient of aquaculture diets. Fishmeal contains from 55 to 75 percent protein, depending on the species of fish used. Li *et al.* (2000) reported that fishmeal contains from 5 to 10 percent oil, making it rich in energy and essential fatty acids, together with bones and other sources of essential minerals. Currently, an important proportion of the world's supply of fishmeal is used by aquaculture, followed by poultry raising, swine production and other applications. The worldwide production of feed for aquaculture currently consumes around 46 percent of the available fishmeal. According to the projections, the demand in 2010 will double. Traditionally, fishmeal is the most important protein source in formulated diets of carnivorous fishes (Hardy, 1989; Pike, Andorsdottir and Mundheim, 1990; Donaldson, 1997).

Salmonid aquaculture depends on fishmeal, which constitutes a substantial part of the concentrated feeds that are used for these species, because of its essential amino acid content (Cowey, 1994), the high bioavailability of amino acids (IAFMM, 1970) and also its high palatability (Pike, Andorsdottir and Mundheim, 1990). But fishmeal is an expensive ingredient, and global supplies are becoming insufficient to sustain aquaculture production that uses fishmeal-based feeds. In addition, further increases in fishmeal prices are expected due to the anticipated increase in the amount of marine raw materials used by aquaculture (Hardy, 1995), which will result in increased demand for this finite resource (Rumsey, 1993; Hardy, 1996).

Therefore, rational use of fishmeal is a priority if further development of aquaculture is to be sustainable (Bardach, 1997). The need for alternative protein sources to replace fishmeal has been recognized, alternatives are needed also because the rich phosphorus content of fishmeal leads to increased pollution of receiving waters through aquaculture effluents. In response to environmental concerns, fishmeal production sustainability issues and increased costs, efforts are focused on research aiming to reduce or eliminate phosphorus from fish feeds employed in aquaculture. The resultant efforts have led to the development of many plant feedstuffs that have already been tested in the diets of freshwater and marine fish. Total or partial substitutes for fishmeal by the inclusion of alternative protein sources having low phosphorus content has been used in freshwater and marine species with varying success (Pongmaneerat *et al*., 1993; Viyakarn *et al*., 1992; Watanabe *et al*., 1993, 1997, 1998; Ketola and Richmond, 1994; Akiyama *et al*., 1995; Luzier, Summerfelt and Ketola, 1995; Riche and Brown, 1999; Storebakken, Shearer and Roem, 2000; Satoh *et al*., 2003; Hernandez *et al*., 2004). If Chile intends to maintain its international position as a leading salmonid producer, it is imperative that it evaluates the use of new vegetable protein sources produced in the country as alternatives to fishmeal.

The main factors in the selection and use of alternative protein ingredients for commercial aquaculture diets are that the ingredients contain a sufficient amount of essential nutrients for optimal growth of fish and that the nutrients are digestible, bioavailable and commercially available at a reasonable cost, and do not contain antinutritional factors and toxic substances. Enhancement of the nutritional quality of alternative ingredients is one of the main strategies in the sustainable development of national aquaculture. Efficiency of alternative plant raw materials could be maximized by means of biotechnological processes that aim to enhance the abovementioned factors. In this sense, biotechnological innovations aimed at concentrating the protein content, improving the essential amino acids profile (sulfured amino acids), reducing the level of carbohydrates and fiber, and increasing nutrient digestibility and energy availability will make possible the optimal use of plant raw materials. Among the biotechnological processes, bioconversion has emerged as a potential technology for the production and use of agro-industrial products and by-products, and provides an alternative for the improved utilization of alternative protein sources that in another form would be limited or simply would not be available.

In Chile, a great portion of the fishmeal component in aquafeeds has been progressively replaced by plant and animal protein substitutes. Among the main ingredients that have been recently used to replace fishmeal and those that will gain more relevance in the near future are: corn gluten meal, lupine, peas, sunflower, feather meal, canola meal, soybean meal and bio-proteins. Plant protein concentrates with high nutritional value and digestibility, as well as some animal protein meals, will acquire great importance in the coming years.

Use of fishmeal substitutes by the Chilean aquafeed industry was initiated around ten years ago as a direct result of the reduction in capture volumes of small pelagic species. These substitutes have been used considerably and are effective and viable. Nowadays, a greater percentage of the protein fraction in aquafeed is of plant origin, and these plant protein resources are expected to substitute, for around 50 and 50–80 percent of the fishmeal and fish oil respectively, currently being used.

Fishmeal substitution by other protein alternatives is a primary objective for Chilean aquafeed companies. The replacement must be done in a way that does not affect productive performance, health and the sanitary quality of fish. This replacement still requires intensive and advanced research, as well as a great economic effort. The Government of Chile has identified aquaculture research as a priority and one of the most strategic sectors for national development. Considerable resources are invested in this area, and there are numerous projects aimed to increase the inclusion of alternative protein sources in aquafeed through research in nutrition, genomics, proteomics, biotechnology and new feed technology processes.

When considering fish oil replacement, numerous researchers have concluded that this aquafeed ingredient can be exchanged at a level of 50 percent with alternative vegetal oils without affecting the productive performance, normal growth, health or nutritional quality of fish. Nowadays, the Chilean aquafeed industry incorporates in the diets around 30–50 percent of vegetable oils and between 50 and 65 percent of fish oils. Fish oil is very important in salmon diets, mainly because it can supply the essential omega-3 fatty acids (eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)) that are necessary for the normal metabolic functions and well-being of the fish. These essential fatty acids that deposit in salmon muscle can also have important nutritional functions for human health, including reduction of cardiovascular diseases, cancer and diabetes. Additionally, these fatty acids have an important role in the development of the nervous system and in the normal metabolic functions of the body. Some vegetal oils that are rich in omega-3 fatty acids can substitute a portion but not all of the fish oil in the aquafeed formulations.

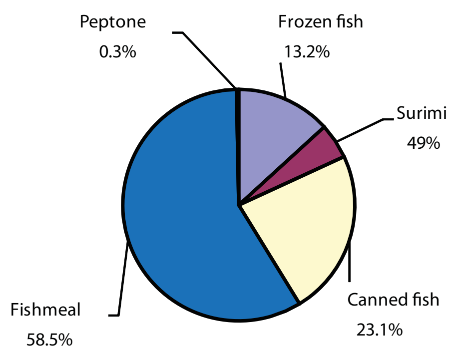
Currently, the main limitation is that there are not enough commercially available sources for these fatty acids except fish oil. However, there have been important scientific advances with promising results for the development of new sources of fatty acids with the capacity to generate or convert into EPA and DHA. These advances will reduce the high dependence of the salmon aquafeed industry on fish oil as the main source of essential fatty acids.

5. CASE STUDY: THE JACK MACKEREL RESOURCE IN REGION VIII, BIO-BIO, CHILE

The national fishery sector has been affected by a strong contraction of the labour force during the last decade. Some of the main causes for this reduction are related to the decline of the industrial fishing fleet and the optimization of production processes in processing plants.

Market demand and the intention to increase productivity require increased specialization and training of the labour force. Increasing the skill levels of the labour force in the Chilean aquaculture industry could compensate for a possible high reduction of employment in fishing fleets and processing plants. However, it is unlikely that the employment levels previously enjoyed by the fishing sector would be achieved, at least over the short- and medium-term. Even though the salmon aquaculture industry is a major and reliable employment generator in many areas of Chile, the skill levels in communities where salmon aquaculture takes place are much lower than the national average. Changing demands for labour

FIGURE 27
Destination of jack mackerel captures in Region VIII, Bio-Bio, Chile



Source: SERNAPESCA (2006)

Coquimbo Port, Coquimbo, northern Chile

in the sector represent both a challenge and an opportunity for the unqualified workers that characterize the poorest groups of the country. Therefore, the employment that is generated by this expanding industry has a positive and direct impact on the poverty indicators of communities where aquaculture is developed.

5.1 Introduction

Question: Could the Region VIII of Bio-Bio obtain more social and economic benefit and improved food security if the jack mackerel resource were used mainly for human consumption instead of for reduction?

Region VIII (Bio-Bio) contains the most important fisheries landing sites in Chile for the main pelagic species, including jack mackerel. The total fisheries landing in Chile during 2005 was 5.5 million tonnes, of which Bio-Bio contributed 1.91 million tonnes or 34.1 percent. Jack mackerel landings in Bio Bio represent around 50.3 percent (960 thousand tonnes) of the total fisheries landings for the Region and 67.1 percent of all the jack mackerel captured (1.43 million tonnes). The artisanal fishery sector contributes only 1.7 percent (16.72 thousand tonnes) of the total jack mackerel landed in Region VIII and has around 2 617 boats, of which 733 are dedicated to the jack mackerel resource (SERNAPESCA, 2006). The industrial fishing sector in Region VIII operates only 102 vessels.

The industrial fishing sector in Bio-Bio employs 14 771 people (63 percent men and 37 percent women); 7 891 workers are employed in processing plants (fishmeal, canning, frozen, etc.), 982 people are employed on vessels (on average, each vessel operates with a crew of 9.6 persons) and 5 580 are employed in aquaculture centers (SERNAPESCA, 2006). The artisanal fishing sector employs 12 434 people (91 percent men and 9 percent women) as follows: shipbuilding – 1 451 people, shellfish collectors – 2 304 people, seaweed harvesters – 1 949 people and artisanal fishermen – 10 139 people (Montoya, 2006).

Region VIII has 133 processing plants, with some of them dedicated to more than one line of production: 20 plants for fishmeal and fish oil, 44 plants for frozen fish, 14 for canned fish, 15 for fresh chilled fish, two for smoked fish and 38 for other fish products (SERNAPESCA, 2006). The total number of plants in the region represents 17.5 percent of the fish processing plants in the country.

5.2 Use of jack mackerel for reduction and human consumption

An analyse the destination of the jack mackerel captures, we can observe that 41.5 percent were destined to human consumption, as can be seen in Figure 27.

In the artisanal fishing sector the landed prices for chub mackerel and jack mackerel were as follows: monthly average price US$809 per tonne (minimum price US$56.9 per tonne and maximum price US$2 365 per tonne). The same resources in the industrial sector registered landing prices with a monthly average of US$110 per tonne (the minimum price was US$53.20 per tonne and the maximum was US$151.40 per tonne). Considering the monthly average price in 2006, the artisanal sector of Region VIII obtained gross revenues for the jack mackerel resource of around US$13 525 935; this value divided by the number of artisanal fishers results in an annual average per capita income of US$1 334. Based on the monthly average price of jack mackerel industrial landings, a gross income of about US$105 370 326 was generated, which represent an annual average income per boat of approximately US$1 033 042 or US$1 982 per crew member.

National fishmeal production is about 829 thousand tonnes, of which 221 thousand tonnes come specifically from the jack mackerel resource (SERNAPESCA, 2006). The fishmeal production in Region VIII is around 435 thousand tonnes (52.6 percent of the national production); of this, 176 thousand tonnes are from jack mackerel, which represents 40.4 percent of the total fishmeal production of the Region. According to the fishing industry, to produce 1 tonne of fishmeal requires around 4.1 tonnes of fresh fish, which means that in Region VIII, 712 thousand tonnes of fresh jack mackerel were used to produce 176 thousand tonnes of fishmeal (SERNAPESCA, 2006). Considering that the average sale price during 2005 was US$643 per tonne, the gross income from fishmeal produced in Region VIII was approximately US$113 200 000.

The export of jack mackerel during 2005 reached values of around US$164.8 million, ranking third in importance among total national exports of fish. During that year, canned jack mackerel represented 52 percent of the total exports for this species, followed by frozen jack mackerel with 35 percent and surimi with 12 percent. If the

TABLE 17

Volumes and FOB values of processed jack mackerel by product line in Region VIII

Product line	Raw material (tonnes)	Processed product (tonnes)	Relation RM/PP*	FOB value (US$/ tonne processed)	Total value (US$ million in 2005)
Fishmeal	712 311	175 985	4	643	113
Canned fish	281 885	93 707	3	1 059	99
Frozen fish	160 716	115 846	1	473	55
Surimi	59 948	17 277	3	1 130	20
Peptones	3 711	916	4	1 052	1
Fresh cooled fish	283	256	1	482	0
Smoked fish	28	17	2	4 000	0
Total	**1 218 882 ** **	**404 004**	**3**		**288**

* RM/PP: relation between raw material and processed product.

** According to the national statistics service SERNAPESCA, the jack mackerel total landing in Region VIII is 969 thousand tonnes; however, the statistics of the SERNAPESCA affiliated institutions responsible for one specific product line give values that are greater than the registered landings for the region. Apparently, the fish processing industry in Region VIII receives raw material from others regions.

Source: SERNAPESCA (2006); BCC (2006)

TABLE 18

Adjusted volumes and FOB values of processed jack mackerel by product line in Region VIII*

Product line	Raw material (tonnes)	Processed product (tonnes)	Relation RM/PP**	FOB value (US$/ tonne processed)	Total value (US$ million in 2005)
Fishmeal	561 226	138 658	4	643	89
Canned fish	222 096	73 831	3	1 059	78
Frozen fish	126 627	91 274	1	473	43
Surimi	47 233	13 612	3	1 130	15
Peptones	2 924	722	4	1 052	1
Fresh chilled fish	223	202	1	482	0
Smoked fish	22	36	1	4 000	0
Total	**960 350**	**318 335**	**3**		**227**

*Adjusted volumes and values in relation to the true jack mackerel landing in Region VIII.

**RM/PP: relation between raw material and processed product.

Source: SERNAPESCA (2006); BCC (2006)

total value of the jack mackerel processed products for export was about US$164.8 million, the contribution from Region VIII was on the order of 78 percent (BCC, 2006).

5.3 Evaluation of alternative-use scenarios

Table 17 shows the volumes of processed jack mackerel by type of processing and the US$ freight on board (FOB) value, Table 18 describes the adjusted values in relation to the real jack mackerel landing in Region VIII and Table 19 presents a simulation that considers three different scenarios:

- the *first scenario* considers that the entire volume of jack mackerel that is currently destined for fishmeal production and be used in equal proportions for the production of frozen and canned products;
- the *second scenario* considers that the whole volume of jack mackerel that is currently used for fishmeal is destined for the production of canned products; and
- the *third scenario* allocates the jack mackerel used for fishmeal production to the preparation of frozen products.

TABLE 19

Simulation of volume and value of jack mackerel for human consumption that are destined for fishmeal production in Region VIII

	Fishmeal	Canned product	Frozen product	Surimi	Peptones, cooled fresh and smoked	Total
Present situation*						
Landing (tonnes)	561 226	222 096	126 627	47 233	3 169	960 350
Destination (%)	58	23	13	5	0	100
Processed product (tonnes)	138 658	73 831	91 274	13 612	0	317 376
Value of processed product (million US$)	89	78	43	15	1	227
Scenario 1						
Landing (tonnes)	0	502 708	407 240	47 233	3 169	960 350
Destination (%)	0	52	42	5	0	100
Processed product (tonnes)	0	167 569	290 886	13 612	0	472 068
Value of processed product (million US$)	0	177	138	15	1	331
Scenario 2						
Landing (tonnes)	0	783 321	126 627	47 233	3 169	960 350
Destination (%)	0	82	13	5	0	100
Processed product (tonnes)	0	261 107	91 274	13 612	0	365 994
Value of processed product (million US$)	0	277	138	15	1	431
Scenario 3						
Landing (tonnes)	0	222 096	687 853	47 233	3 169	960 350
Destination (%)	0	23	72	5	0	100
Processed product (tonnes)	0	74 032	491 324	13 612	0	578 968
Value of processed product (million US$)	0	78	232	15	1	327

**Source*: SERNAPESCA (2006); BCC (2006)

The sale price of jack mackerel that was destined for freezing and canning during 2005 was US$473.00/tonne and US$1 059.90/tonne, respectively (BCC, 2006). If the volume of jack mackerel intended for fishmeal production were used instead for frozen fish (with a yield of 0.71 tonne frozen per 1tonne fresh fish), 491 thousand tonnes of frozen jack mackerel with an approximate value of US$302 760 667 could be produced. Bearing in mind that Region VIII has around 44 processing plants with the capacity to process 161 thousand tonnes of frozen products, it can assumed that at least triple the number of plants would be needed and consequently, the demand for labour could grow in the same proportion (scenario 1).

In the same way, if the volume of jack mackerel destined for reduction were used for canned fish (scenario 2)., with a yield of 0.33 tonne of canned per tonne of fresh jack mackerel, around 235 thousand tonnes of canned products with a value of US$248 930 658 could be produced, and the waste residue (head, tail, entrails) could be used to produce 110 thousand tonnes of "standard fishmeal" with a value of US$87 756 715. At the moment, Region VIII has 14 processing plants producing 94 thousand tonnes of canned jack mackerel. To process all jack mackerel in canned form would require double the number of plants and labour force.

In the first scenario, the total income derived from jack mackerel processed products shows an increase of 46 percent in relation to the income currently derived from fishmeal production. In second scenario, the revenue earned by jack mackerel processed products increased by 89.6 percent, while in the third scenario, the increase is 44 percent. Regarding the volumes of processed products, the first, second and third scenarios show increases of 48.5 percent, 15 percent and 82 percent, respectively. Hence, the highest demand for labour for the production of processed jack mackerel would occur in the first and third scenarios.

Although Chile is a country with a long coastline, there is a limited tradition of seafood consumption. Per capita consumption in the country is not higher than 7 kg/year; therefore, an increase in jack mackerel production aimed for human consumption would have a limited impact on the per capita consumption. Changing the destination of jack mackerel from reduction to processing for human consumption could have a greater impact in the export sector of Chilean fishery products. Chile has a free-market economy that bases its development on the economic diversification of products for export; hence, the benefits from a change in production strategy will mainly accrue to this sector of economic activity. Indirectly, this would result in an increased demand for workers in the canning and frozen fish sectors, assuming that the demand for labour tripled in the processing plants (rising from 7 000 to 21 000 persons) and the level of unemployment declined by 1.9 percent in Region VIII (from 9.6 to 7.7 percent) (INE, 2005).

If jack mackerel landings in Region VIII were reserved exclusively for processed products (frozen and canned products, and surimi, etc.), the result would be a reduction in total Chilean fishmeal production of 176 thousand tonnes (21 percent). The impact on national salmon aquaculture would be limited, as nowadays fishmeal inclusion levels in salmon aquafeeds are around 30 percent, which generates a demand for little more than 30 percent of the national fishmeal production. However, in Chile, all the fish oil produced in the country is used domestically, so a reduction of 21 percent in fishmeal production would result in a reduction in fish oil production of 7.73 thousand tonnes.

At present, the average inclusion of fishmeal in the aquafeeds is around 30 percent, and the average conversion factor of the salmon aquaculture industry is 1.35, meaning that for each tonne of salmon produced, 1 350 kg of feed is consumed and implies that to produce this amount of feed, it is necessary to incorporate 405 kg of fishmeal. To produce 405 kg of fishmeal, 1 687 kg of jack mackerel are required; hence, if only the net weights are considered, only 1.7 kg of jack mackerel are needed to produce 1 kg of salmon.

One tonne of salmon yields approximately 850 kg of headed and gutted (H&G) salmon, while 1 687 kg of jack mackerel yield 843 kg of H&G jack mackerel. As explained in the foregoing paragraph that 1 687 kg of jack mackerel, when reduced to fishmeal, would produce about 1 tonne of salmon and hence, it can be deduced from these values that there is no difference whether salmon or jack mackerel are used for human consumption, because both would eventually yield the same amount of H&G fish. However, the price of salmon H&G is at least four times the price of jack mackerel. From this point of view, the salmon introduces an additional value relative to jack mackerel and benefits the entire country at a macro-economic level. Again, the impacts shown by this analysis relate mainly to the export sector – access to the salmon resource is limited, because it is an expensive product intended for a market with high purchasing power, while jack mackerel is accessible to populations with low buying power.

In summary, diverting jack mackerel from fishmeal production to food production for human consumption might have a positive impact. However, from the point of view of the role of jack mackerel in food security and poverty alleviation, using this resource for human consumption might not have a very significant impact, given that demand for it is not very high and it would be destined mainly for export. Reducing the production of fishmeal will not have a negative impact on national salmon aquaculture, given the present levels of inclusion in salmonid aquafeeds and the surplus of fishmeal, which is generally destined to export. However, there is a socio-economic impact when the production of fishmeal is reduced to increase the production of human food products, as this conversion is only translated into an increase in employment for Region VIII, basically as a result of an increase in the number of processing plants. If there is a high demand for new processing plants, this could result in a need for new investment for construction or if the present plants have unused processing capacity, it could lead to only a small increase in the demand for labour.

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Status of and trends in the use of small pelagic fish species for reduction fisheries and for human consumption in Peru

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SUMMARY

This paper examines the current status of the Peruvian small pelagic fisheries, including the stocks, landings, fishing areas and seasons, infrastructure, fish utilization, nutritional value of resources (particularly of anchoveta, *Engraulis ringens*) and the position of the national fisheries within the international context. The fishing fleet – small– and large–scale – and the processing activities for food and feedfish products are also reviewed.

Besides a brief description of the current fishery policies and a profile of the main institutions that form part of the fisheries sector, several aspects of the national fish product consumption and the main product exports are examined. The study highlights the importance of Peruvian production of fishmeal in world trade, as well as the potential for using the current resource of small pelagic fish for food fish products for internal and external markets. Proposals for newly developed products made from anchoveta are also described.

The economic and social implications of using a small proportion of the Peruvian anchovy catch as foodfish are assessed, including the impact that it would have on food security, value addition, manual labour supply and general poverty alleviation.

The review then describes the characteristics of the fishery in Chimbote City – the main fishing port in Peru, located on the northwestern coast – where the largest anchoveta landings occur and are used for the reduction and direct human consumption.

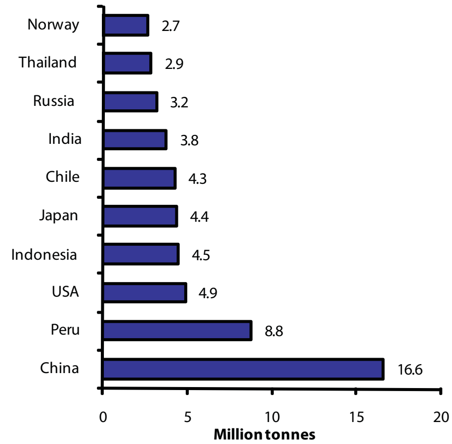
The history of the fishmeal industry, its peak years, and the problems in and limitations of catching and utilizing anchovy for different purposes, including direct human consumption, are described. The results of a series of interviews with artisanal fishers, processors and other professionals of the sector are presented in a case study in an attempt to gain a real understanding of the problems facing the pelagic fishery in the port of Chimbote, as well as the development potential of the fishery in the short and medium terms.

It concludes that the abundant anchoveta resource could contribute to easing some of the nutritional problems of Peru and the immediate region. However, achieving this goal will require improvements in landing infrastructure, renovation of processing plants and the development of a market that is able to repay the value of such a commercially and nutritionally valuable resource.

1. CURRENT STATUS OF THE PERUVIAN FISHERIES

Peru is one of the major fishing countries in the world. Its 3 100 km coastline is characterized by intensive oceanic upwelling, which, combined with various environmental and biological factors, makes its waters highly productive. According to IMARPE (2004–2005), the Peruvian sea hosts over 730 fish species. The fish fauna of the relatively narrow continental shelf includes pelagic fish stocks, and although the abundance of these stocks are subject to abrupt fluctuations, the Peruvian continental shelf area is a very large, extremely productive system with a great recovery capacity.

FIGURE 1
Marine and inland capture fisheries: top ten producer countries, 2004



Source: FAO (2007)

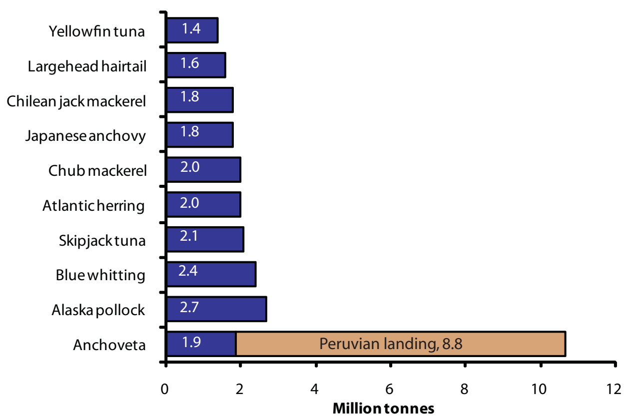
1.1 Ranking of global fisheries

Preliminary estimates for 2005 based on reporting by some major fishing countries indicate that the total landing of the world capture fisheries reached almost 93.8 million tonnes (FAO, 2007). Peru is the second largest country, after China, in terms of capture volumes and provided nearly 10 percent of the total world catch (Figure 1). Global capture production in 2004 reached 95 million tonnes, an increase of 5 percent in comparison with 2003, when total catch was 90.5 million tonnes.

The highest and lowest total catches in the past ten years (1995–2004), for which complete statistics were available at the end of 2006, coincided with the fluctuating catches of anchoveta (*Engraulis ringens*) (Figure 2), a species notoriously influenced by the El Niño effect on the oceanographic conditions of the southeast Pacific Ocean. Catches of this small pelagic species ranged from a minimum of 1.7 million tonnes in 1998 to a maximum of 11.3 million tonnes in 2000, whereas global total catches excluding anchoveta remained relatively stable, ranging from 83.6 to 86.5 million tonnes. With production totalling about 10.7 million tonnes in 2004, the anchoveta ranks first among the ten most-caught marine species by a considerable margin (Figure 3).

FIGURE 2
Anchoveta (*Engraulis ringens*)

FIGURE 3
Marine capture fisheries production: top ten species, 2004



Source: ITP (2004), FAO (2007)

1.2 Peruvian fisheries resources

Peru's marine resources are among the richest in the world. The country's coastline is dominated by a cold current known as the Peruvian or Humboldt Current that flows from south to north, with waters that are extremely rich in oxygen and nutrients as a result of the intense upwelling.

The most important pelagic fish stocks inhabiting Peru's relatively narrow continental shelf are anchoveta, chub mackerel (*Trachurus murphyi*) and Chilean jack mackerel (*Scomber japonicus*) (Table 1), which together represented 95 percent of the catch volume in 2006. Although historically the standing stocks have been subjected to sharp variations, apparently due more to environmental conditions than to fishing pressure, it is clear that these stocks are potentially large and generally able to recover from periodic declines.

Of these the anchoveta is the main species, comprising 92.5 percent stocks of the total catch, according to 2005 records, and is mainly destined for the production of fishmeal. Nevertheless, the utilization of this raw material in the processing of other products with a higher added value (anchovies and other value-added products like canned, dry and minced fish paste) has also proven to be viable.

TABLE 1
Some characteristics of the main fish species in Peru, 2004

Species	Average spawning size	Average spawning age
Anchoveta	12 cm	12 months
Chilean jack mackerel	31 cm	3 years
Chub mackerel	32 cm	4 years

Source: ITP (undated)

1.3 Fishing activity in Peru

In general terms, the Peruvian fishery industry consists of two completely different sectors: the pelagic or industrial fishery and the demersal fishery (which includes the small-scale or artisanal fishery). The pelagic fishery, a large-scale and relatively modern operation, provides the raw material to the fishmeal and fish oil processing industries and accounts for almost 92 percent of the catch by volume (Figure 4) and approximately 91 percent of the value of fish products exports.

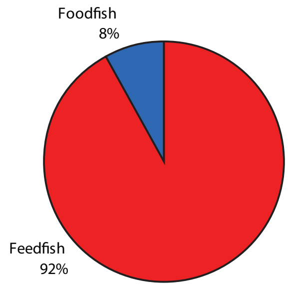
According to the Ministry of Production (PRODUCE, 2006b), the industrial fleet is made up of 1 302 licensed vessels, representing a hold capacity of 222 264 m^3. The artisanal fishery is comprised of 5 950 vessels with a hold capacity of 45 570 m^3 and with 24 150 registered fishers. The landings are dedicated mainly to the fishmeal and fish oil industries, which represented 91 percent of the industrial fishing activity in 2005 (Table 2). In 2005, the Peruvian fishery sector depended on the currently installed fish processing capacity as shown in Table 3.

TABLE 2
Summary of fish landings, processing and use in Peru, 2005 (thousand tonnes)

	Landings*	Processing**	Domestic consumption	Export
Total	**9 400**	**2 444**	**565**	**2 492**
Reduction fisheries	8 629	2 221	127	2 280
Fishmeal		1 931	66	2 001
Fish oil		290	60	279
Human consumption	772	223	438	212
Fresh fish	312		323	
Frozen fish	322	146	55	180
Canned fish	89	55	46	12
Cured fish	48	22	14	20

*Fish landings are measured in wet weight, while domestic consumption and export are measured in product weight.
**Volume of processed product does not equal the totals of domestic consumption and export, as part of the export volume in 2005 consisted of 2004 production.
Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

FIGURE 4
Landings by use, 2005



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

TABLE 3
Industrial-scale fish processing capacity in Peru

Activity	No. of plants	Installed capacity
Fishmeal		
Special meal	48	3 277 tonnes/hour
Standard meal	78	5 661 tonnes/hour
Residual meal	24	155 tonnes/hour
Processed products		
Canned	87	191 840 boxes/shift
Frozen	95	3 557 tonnes/day
Cured	17	1 592 tonnes/month

Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

2. STATUS OF AND TRENDS IN SMALL PELAGIC FISH LANDINGS

The Peruvian marine ecosystem is characteristically a system of intense and highly productive coastal upwelling with water rich in nutrients. This allows the development of a large fish biomass, especially in the pelagic neritic environment, as is the case for anchoveta (*Engraulis ringens*), which sustains 90 percent of the national fisheries. Other important species are Chilean jack mackerel (*Trachurus murphyi*), chub mackerel (*Scomber japonicus*), sardine or South American pilchard (*Sardinops sagax*), South Pacific hake (*Merluccius gayi gayi*), jumbo flying squid (*Dosidicus gigas*), common dolphinfish (*Coryphaena hippurus*) and Peruvian scallop (*Argopecten purpuratus*). The oceanographic conditions off the Peruvian coast show seasonal cyclic variations and high variability associated with the El Niño Southern Oscillation (ENSO) in the Pacific Ocean. These characteristics of the Peruvian waters mainly affect the pelagic resources, altering their biological behaviour and their populations, the anchoveta being one of the most sensitive species.

2.1 Stocks

Recruitment has shown to be an important factor affecting anchoveta biomass variability in Peruvian waters. In general, strong recruitment is associated with cold oceanographic conditions. The higher recruitment months in the north-central stock occur from November to January and May to July, while recruitment in the south Peru–north Chile stock is observed from November to March (Pauly and Tsukayama, 1987).

Recruitment levels for the anchoveta stock showed a general upward trend until 1993, registering two peaks in 1987 and 1993, with levels that exceeded 4.5 million tonnes. These strong annual classes facilitated the recovery of the stock, reinforcing the spawning stock structure. However, recruitment during the period from 1994 to 1997 showed a downward trend, with lower peaks than the average of the analysed series. In 1998, the recruitment estimates were optimistic and represented approximately 60 percent of the total biomass, which would have guaranteed a quick turnover of the stock during the biological year 1998/1999. The appearance of recruitment at the time came from the March 1998 spawning at the beginnings of the post-El Niño stage.

Evaluation of the anchoveta population in Peru is made by the Instituto del Mar del Perú (IMARPE), which determines and evaluates the changes of abundance, distribution and accessibility in relation to the environment in which they live. The results of these investigations support fisheries management and are based mainly on direct and indirect evaluation methods.

The results of the acoustic evaluations carried out during the period 1985–2005 showed an important growth in biomass after the 1982/1983 El Niño event, with high values in 1994, followed by a decrease during the El Niño period of 1997/1998, then at the beginning of 2000, a quick recovery occurred, reaching a maximum value in 2001.

The main management measures include a reduction in fishing effort via closed seasons in February–March and August–September to protect the spawning stock and a short closed season (three or five days) at any time of the year to protect juveniles (fish smaller than 12 cm in length). The annual fishing season is set according to the biological year, wich occurrs from 1 October up to 30 September of the following year.

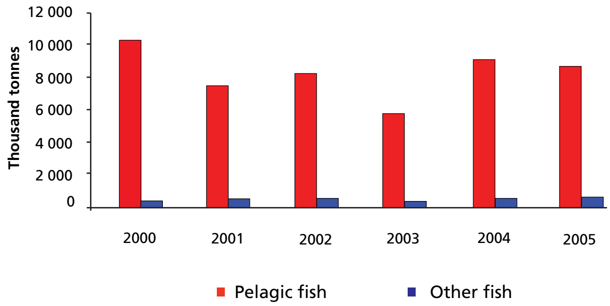
2.2 Nutritional value

Fish, especially pelagic species, are an excellent source of high-quality animal protein. The high content of lysine and other essential amino acids makes these species a suitable complement to carbohydrate-rich diets that are consumed in places where protein sources are limited, such as in most developing countries. These resources are a valuable source of energy and are very rich in micronutrients not usually found in basic foods. In addition to being high in potassium, iron, phosphorus and calcium, the fatty component of fish contains significant amounts of vitamins A and D. Fish also constitute a valuable source of fatty acids, which are very important for proper development of the brain and body. Pelagic fish, in particular, are high in the polyunsaturated fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), whose consumption yields many benefits in terms of human physiology, including a significant decrease in blood cholesterol levels and prevention of cardiovascular disease. The consumption of small quantities of these species of fish associated with basic foods can significantly improve the nutritional value of the food and the biological value of the diet, particularly in the case of children who have difficulty in digesting carbohydrates. Market research clearly indicates that people are increasingly aware of the nutritional value of fish, especially in developed countries and in some developing countries such as Peru. In many of these countries, the current trend is to consume natural and nutritional products. This ultimately promotes greater consumption of seafood, which might include small pelagic fish.

2.3 Landings

Over the period 1997 to 2005, landings showed a peak in 2000, when the captures of pelagic fish reached 10 million tonnes (Figure 5). As previously noted, the most important pelagic species are anchoveta, jack mackerel, chub mackerel, common dolphinfish and sardine, which together contribute 95 percent of the total volume landed (Table 4). The main demersal species is the South Pacific hake, which is considered fully exploited and whose capture is currently prohibited. Among the invertebrates, the most important species is the jumbo flying squid, which has an increasingly important presence in Peruvian coastal waters.

FIGURE 5
Landings in Peru, 2000–2005 (thousand tonnes)



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

TABLE 4
Main landings, 1997–2005 (thousand tonnes)

Species	1997	1998	1999	2000	2001	2002	2003	2004	2005
Marine fish	7 838	4 310	8 392	10 626	7 956	8 741	6 061	9 574	9 353
Anchoveta	5 952	1 912	6 751	9 580	6 495	8 111	5 349	8 813	8 656
Sardine	625	908	188	226	60	7	9	2	1
Chilean jack mackerel	650	387	185	297	724	154	218	187	81
Chub mackerel	206	402	528	73	176	33	94	62	53
Common dolphinfish	5	21	2	11	28	30	36	31	37
South Pacific hake	178	82	37	83	125	46	8	39	31
Jumbo flying squid	16	1	55	54	72	146	154	270	291
Other fish	206	597	647	302	275	214	194	170	204
Continental	33	34	39	34	39	33	37	44	47
Total	**7 871**	**4 344**	**8 431**	**10 661**	**7 995**	**8 775**	**6 098**	**9 618**	**9 400**

Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

2.4 Behaviour of the main fisheries

The main resource of anchoveta, with 92.5 percent of the total 2005 landings, was almost entirely dedicated to the production of fishmeal, even though its potential to be used as foodfish had been demonstrated. Another important species, South American pilchard/sardine, had been dedicated mainly to the production of fishmeal and as raw material for the fish canning and freezing industry. However, capture levels suffered a serious decline that is expected to reverse in the near future.

The Chilean jack mackerel and the chub mackerel are increasingly being used in fishmeal production, despite the higher profit that can be realized when these species are processed for direct consumption. The Resolucion Suprema Nª 001-2002-PE mandates that sardine, jack mackerel and chub mackerel should only be dedicated to direct human consumption.

In 2005, the jumbo flying squid was a very important resource. Its availability 1995-2005 remained constant, and during 2006 it was one of the main frozen fish commodities exported.

As of 2006, the South Pacific hake was the main domestic commercial species and the landing was mostly frozen. Catches declined thereafter and the fishery closed subsequently.

Landing ports are located along the entire coast of Peru, the main ports being Chimbote in the Department of Ancash, Pisco in the Department of Ica and Chancay in Lima. The landings of anchoveta by fishing port for 2004 and 2005 are given in Table 5, while the distribution of ports along the coast is shown in Figure 6

TABLE 5
Anchoveta landings by port (thousand tonnes)

	2004	2005
Total	**8 797**	**8 628**
Paita	370	193
Parachique	266	199
Bayovar	441	293
Chicama	1 226	575
Coishco	538	427
Chimbote	1 597	1 292
Samanco	176	173
Casma	238	147
Huarmey	307	330
Supe	506	629
Vegueta	402	439
Huacho	185	228
Chancay	753	786
Callao	625	606
Tambo de Mora	179	312
Pisco	262	940
Atico	62	233
La Planchada	40	197
Matarani	50	112
Mollendo	29	73
Ilo	546	443

2.4.1 Fishing areas

The raw materials, the bases of Peruvian fisheries, are resources subject to continuous changes due to climatic and ecological conditions in their natural habitat. Due to the system of currents and upwelling in the Peruvian sea, a broad biological diversity with its own population dynamics can be found.

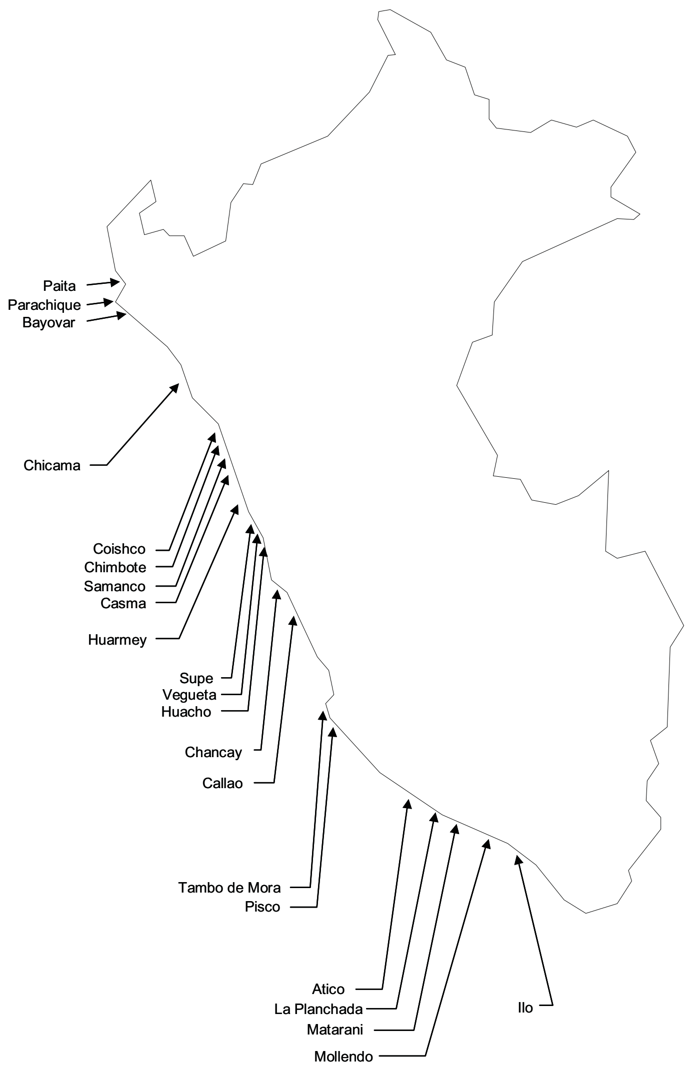
The regions of the Peruvian sea where this marine diversity is found are classified as coastal, neritic and oceanic. The neritic region can be subdivided into pelagic, demersal and benthic regions. The pelagic-neritic region is the most productive, with species like anchoveta supporting over 90 percent of the national fisheries, in addition to Chilean jack mackerel and chub mackerel, which are still underexploited. In the demersal-neritic region, species like South Pacific hake are the main species landed in this region.

In Peru, however, the pelagic fishery is the most important. The areas and seasons change depending on the target species. Anchoveta, for example, is fished throughout its entire distribution, from 4° S to the southern borderline. In general, in the north and central areas, this species is caught within a coastal strip from 30 to 50 miles and while in the southern area, this species is caught within a coastal strip of 20 miles. It is located in three large areas:

- 7º to 10º30' S latitude between Pimentel and Supe, Chimbote being the main landing port;
- 11º to 14º S latitude between Huacho and Pisco, the latter being the main landing port; and
- 15º to 18º S latitude between San Juan and Ilo, the latter being the main landing port.

Anchoveta are generally found in waters with temperatures ranging between 14 and 22 °C, with an average temperature of 19.5 °C, salinity between 34.9 and 35 ppt and depths ranging from the surface down to 70 m. In the spring and summer, anchoveta are concentrated in shoals located within 30 miles of the coast. In autumn and winter, they are dispersed along a broader coastal strip, which can be as distant as 100 miles from the coast if the water is particularly cold.

FIGURE 6
Map of anchoveta landing ports



Chilean jack mackerel occur along the coasts of Peru and Chile up to 52ºS latitude, although, for example, during the El Niño event of 1983, their distribution extended to the north of the Guayaquil Gulf and the Galapagos Islands. The longitudinal distribution of this resource is wider and more dispersed, extending even 200 miles from the coast. This species has been caught in international waters between 200 and 500 miles from the coast. In general, the distribution of this species is characterized by its high dispersion.

- In the north, between Tumbes and Paita, Chilean jack mackerel are found in dense concentrations between Punta Picos and Lobitos, within the 15-mile coastal strip.
- Between Paita and Chimbote, this species shows a wider distribution, reaching 84 miles off the coast, the main concentrations being found between Paita – Sechura, Punta La Negra – Islas Lobos de Tierra, Islas Lobos de Afuera – Pacasmayo and between Chicama and Punta del Brujo.
- From Chimbote to Callao, chilean jack mackerel are found off the coast of Samanco and Casma, at a distance of 20 to 42 nautical miles.

- Between Callao and San Juan, the distribution of the Chilean jack mackerel is very limited; they are mainly found off the coasts of Pucusana, Cerro Azul, Tambo de Mora, Punta Paracas, Punta Caballas and San Nicolás, at a distance of between 3 and 60 nautical miles.
- Between San Juan and Tacna, their distribution is very limited, Chilean jack mackerel being mainly found in Lomas – Punta Chala, Quilca, Matarani – Punta Bombón and Punta Coles between 2 and 6 nautical miles.

South American pilchard or sardine, which were previously an important commercial species, are mostly found in the north from Sechura Bay and the Galapagos Islands to Valparaiso, Chile, in the south, and up to 200 nautical miles off the coast. The areas of higher concentration are located south of Paita, from 60 to 70 nautical miles off the coast; in Pimentel, Eten, Salaverry and Huarmey between 6° and 10°S latitude; and in Punta Caballas and San Juan between 15° and 16°S latitude. They are found in waters with temperatures ranging between 14 and 25°C and salinity between 34.8 and 35.3 ppt, ranges that are wider than those of the anchoveta. Juveniles of this species can have a maximum total average length of 21 cm. This species tends to dwell in areas similar to those inhabited by the anchoveta.

Another species is the chub mackerel, for which there is limited fishing information in relation to its biological behaviour. This species is mainly used for direct human consumption and is distributed from Manta, Ecuador and the Galapagos Islands to Valparaiso, Chile.

2.4.2 Fishing seasons

October is the month of final spawning for anchoveta and is when the fishing season normally starts. Although the spawning season of the anchoveta runs from August through March, the peak months are August–September and February–March; therefore, these months are normally declared as a closed season. A similar annual cycle occurs in the case of sardine. Their capture is restricted during the same months as those of the anchoveta. The other small pelagics – Chilean jack mackerel and chub mackerel – generally have no fishing restrictions, as these fisheries are regarded as underexploited.

The largest catches of these resources (except the anchoveta) are made in the months of January through March, unless there are favourable oceanographic conditions in other months of the year. However, in general the fishing season is quite consistent from year to year.

The distribution of anchoveta biomass is coastal between depths of 0 and 60 m (Ñiquen and Bouchon 1991). In spring and summer, anchoveta occur mostly within the 30 mile limit, while in autumn and winter they are widely dispersed, reaching up to 100–120 miles from the coast when the cold waters prevail and homothermic and homohaline conditions exist. The main fishing areas are located between 7–8°S and 11–12°S latitude and are associated with temperatures of 16–20°C and salinities of 34.9–35.1 ppt. Anchoveta are highly gregarious, forming large and extensive shoals that facilitate their capture. The El Niño drastically affects stock distribution, with stocks moving closer to the coast, into deeper waters and finally southward to 10°S latitude (Ñiquen and Bouchon, 2004).

Anchoveta live to 3 to 4 years of age, but are usually captured when they are 1 to 2 years old. The size structure of individuals in the north-central stock fluctuates between 10 and 18 cm. Sexual maturity is reached at a length of 11–12 cm and an age of one year. The main spawning areas are located between Chicama and Chimbote and between Callao and Pisco. Spawning occurs throughout the entire year, with peaks in August–September and February–March. The largest spawning stock is observed from December to April.

2.4.3 Measures regulating the exploitation of pelagic fish

Measures regulating the exploitation of anchoveta are applied in two large areas:

- between the north and the latitude 16°S (northern-central stock); and
- between latitude 16°S and the south (southern stock).

The main regulatory measures are specific and include:

- quotas of permissible capture for periods and certain areas, based on information on the biological/fishery characteristics of the species;
- a short prohibited fishing season (three or five days) to protect juveniles (fish smaller than 12 cm);
- prohibited seasons during the periods of maximum spawning to protect recruitment, generally applied in February–March (secondary summer spawning) and August–September (main winter spawning); and
- regulation of fishing effort by limiting the number of vessels, the days of fishing and the processing capacity of the factories.

3. THE FISHING FLEET IN PERU

The national fishing fleet includes: (a) the industrial fleet, comprised of fishing vessels with more than 32.6 m^3 of hold capacity (larger-scale steel vessels and smaller-scale wooden vessels); and (b) the artisanal fleet consisting of vessels with hold capacities of up to 32.6 m^3.

3.1 Industrial fleet

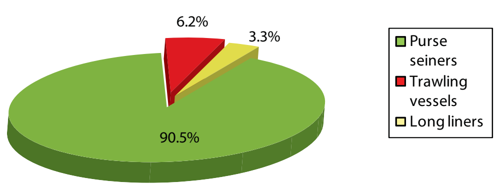
The development of fishing activities in Peru is strongly associated with the development of the anchoveta fishery and the growth and evolution of the purse-seiner fleet. As noted previously, approximately 90 percent of the fishery catches in the Peruvian sea are anchoveta, which is almost exclusively directed to the fishmeal and fish oil industry.

According to the Vice-ministry of Production of Peru (PRODUCE, 2006a), during 2005 the fishing fleet consisted of 1 345 vessels with fishing licenses, representing a capacity of 227 448 m^3. Of the total, 1 217 units (91 percent) were purse seiners; 84 (6 percent) were trawling vessels and 44 (3 percent) were long liners (Figure 7).

The purse-seiner fleet (Figure 8) is comprised of vessels with fishing licenses for the following purposes:

- for foodfish, 25 vessels, with a holding capacity of 4 011 m^3;
- for feedfish, 559 vessels, with a holding capacity of 143 667 m^3; and
- for both foodish and feedfish, 633 vessels, with a holding capacity of 63 251 m^3.

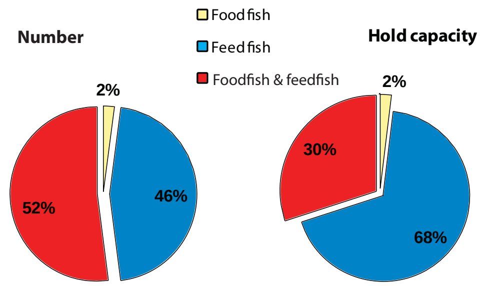
FIGURE 7
Distribution of main fishing fleets in Peru



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

If a comparison is made between the type and number of vessels and catching capacity, it can be observed that, on the average, the vessels authorized to supply foodfish are much smaller than those dedicated to feedfish. Furthermore, the vessels in the purse-seiner fleet licensed for anchoveta as foodfish have 100 m^3 of hold capacity group (Table 6). In terms of vessel hold capacity range, 245 vessels (80 percent of these units) register capacities between 32.6 and 50 m^3 and 117 vessels have capacities between >50 and 100 m^3. Likewise, it can be observed that the fleet with larger holding capacity (> than 350 m^3) comprises 48 vessels, which are made of steel and have modern preservation systems such as Refrigerated Sea Water (RSW) and Chilled Sea Water (CSW) systems.

FIGURE 8
Purse-seiner fleet



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

The majority of vessels used for foodfish anchoveta are wooden vessels (475) (Table 7), which represent 89 percent of the total number. These vessels do not have appropriate preservation systems on board, generally using boxes and ice. Steel vessels (58) represent 11 percent of the total number and have RSW or CSW systems.

TABLE 6
Distribution of purse-seiner hold capacity by fishery, 2005

Species	Holding capacity range (m^3)				
	32.6–50	50–100	100–270	270–350	270–350
Anchoveta	3		1		
Anchoveta, jack makarel and chub mackerel	2				
Anchoveta, sardine, chub mackerel	2				
Anchoveta, sardine, other fish	73	26	10	3	11
Anchoveta, sardine, jack mackerel and chub mackerel	157	135	39	6	37
Anchoveta, sardine, jack mackerel and chub mackerel, other fish	8	15	4		
Anchoveta, sardine, other fish		1			
Total	**245**	**177**	**54**	**9**	**48**

Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

TABLE 7
Type of construction material of purse-seiner vessels by fish species/species-groups, 2005

Species	Steel	Wood
Anchoveta		4
Anchoveta, jack mackerel and chub mackerel		2
Anchoveta, sardine	15	107
Anchoveta, sardine, chub mackerel		2
Anchoveta, sardine, jack mackerel and chub mackerel	43	331
Anchoveta, sardine, jack mackerel and chub mackerel, other fish		27
Anchoveta, sardine, others		2
Total	**58**	**475**

Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

In 1999, the Ministry of Fishery of Peru established the maximum size of purse-seiner nets for anchoveta and sardines in relation to vessel hold capacities (Table 8). To guarantee the implementation of this measure, a net-size adaptation process was stablished whereby users require an Adaptation Certificate for purse-seiner nets.

TABLE 8
Purse seine net length for licensed vessels

Holding capacity (m³)	Net length (m)	
	Anchoveta	Sardine
32–90	220	260
100–199	280	330
200–299	330	390
300–399	385	450
400–499	400	500
500–599	495	520
600–more	550	550

Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

3.2 Artisanal fleet

According to the results of the Second Structural Survey of the Artisanal Fishery in Peru, the artisanal fleet (small scale) consists of 9 667 vessels with a hold capacity ranging between 0.5 and 30 gross registered tonnes (GRT). In terms of regional distribution, the regions of Piura, Lima and Ancash register 66 percent of the total number of small-scale vessels (Table 9).

TABLE 9
Distribution of small-scale vessels by region

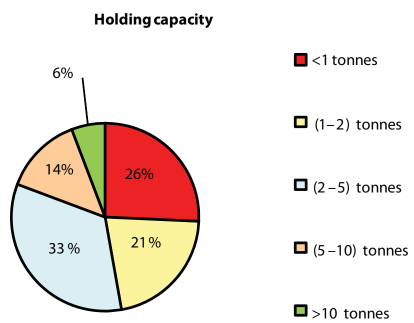
Region	Number of vessels
Tumbes	667
Piura	2 898
Lambayeque	222
La Libertad	333
Ancash	1 294
Lima	2 178
Ica	784
Arequipa	816
Moquegua	347
Tacna	128

Source: IMARPE (2004–2005)

Artisanal vessels are made mostly from wood (99 percent). Eighty-one percent of the hold capacity of this fleet consists of vessels smaller than 5 tonnes, while only 6 percent of the total hold capacity consists of vessels larger than 10 tonnes (Figure 9). Gillnets and longlines are the most frequently used fishing gear in this sector.

According to the Second Structural Survey of the Artisanal Fishery in Peru, the artisanal fisher population comprises about 37 727 persons, 35 percent of whom are in the region of Piura, followed by 15 percent in Lima. Of the total, 55 percent of the fishers have completed high school and 7.1 percent did university studies. Ten percent of the fishers are owners of their fishing vessel.

FIGURE 9
Artisanal fleet – holding capacity distribution



Source: IMARPE (2004–2005)

3.3 Fish-landing infrastructure

Along the Peruvian coast, there exist 36 artisanal landing facilities. In addition, there are six piers for fish landing, of which three are public and three are private. Most of the facilities have structural deficiencies that impact the quality of landings. The last official inspection by the sanitation authority showed that these facilities often do not fulfill the requirements set down in the Sanitary Norm for fishery and aquaculture activities (Decreto Supremo Nº 040-2001-PE).

4. PROCESSING ACTIVITIES IN PERU

4.1 Fishmeal industry

Peru is the most important producer of fishmeal in the world, and fish processing is the second main contributor, after mining, of foreign currency to the national economy. The landings for the fishmeal industry represent more than 90 percent of the total landings in Peru and consist of small pelagic species, formerly sardine and now mainly anchoveta (Table 10).

TABLE 10

Landings destined for fishmeal production (thousand tonnes)

Species	Year									
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total	**8 772**	**6 999**	**3 696**	**7 788**	**9 913**	**7 208**	**8 157**	**5 165**	**8 811**	**8 629**
Anchoveta	7 460	5 923	1 206	6 732	9 556	6 348	8 083	5 336	8 797	8 628
Other fish	1 311	1 076	2 491	1 056	357	860	74	12	13	–

Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

It is important to note that Resolucion Suprema Nª 001-2002-PE sets down that catches of sardine, jack mackerel and chub mackerel must only be dedicated to direct human consumption.

4.1.1 Fishmeal production

The landing of 8 628 704 tonnes of anchoveta for the fishmeal industry in 2005 generated a production of 1 930 727 tonnes of fishmeal and 290 422 tonnes of fish oil (Table 11). The production, however, was severely impacted by the 1998 El Niño event, with production levels declining to 832 043 tonnes of fishmeal and 122 956 tonnes of fish oil.

TABLE 11

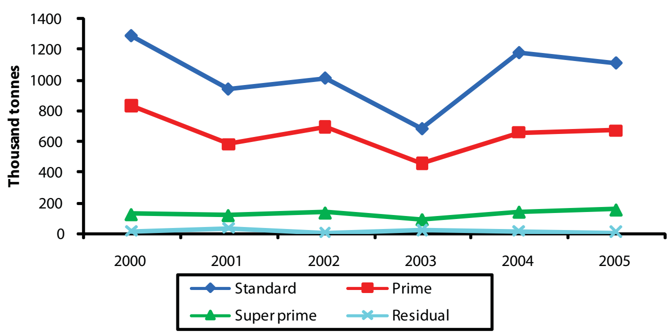
Fishmeal and fish oil production, 1997–2005 (tonnes)

Product	Year								
	1997	1998	1999	2000	2001	2002	2003	2004	2005
Fishmeal	1 597 134	832 043	1 769 532	2 241 529	1 635 427	1 839 209	1 224 484	1 971 449	1 930 727
Fish oil	330 042	122 956	514 818	587 312	302 875	188 949	206 154	349 821	290 422

Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

FIGURE 10

Fishmeal production by grade, 2000–2005



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

4.1.2 Processing plants

One hundred and three processing plants (69 percent of the total) engaged in the manufacture of fishmeal and fish oil are located along the central coast of Peru. There are also 35 plants (23 percent of the total) located in the northern area and 12 (8 percent of the total) in the southern area. In Peru, there are presently around 150 industrial plants engaged in the manufacture of fishmeal, with a processing capacity exceeding 9 093 tonnes/hour. These plants produce mainly the traditional fishmeal (57 percent of the total), although with the recent investments made in new machinery and equipment, there is a growing trend to produce prime and super-prime meal (43 percent of the total) (Figure 10).

Over 80 percent of the production is exported. The main markets for Peruvian fishmeal are Asian countries, mainly China, due to its important aquaculture industry. Germany is the main European importer.

4.2 Foodfish production

There is an important industry for frozen and canned fish products and an artisanal industry for cured fish products, which although small, has been growing rapidly in the past few years.

4.2.1 Fish freezing industry

The South Pacific hake is the main species used by the freezing industry, yet landings have been declining. In order to ensure the sustainability of this resource, the fishery has been regulated through closed seasons and capture quotas. The other main species landed for this industry is the jumbo flying squid, with the most important landing ports being located in the northern area of Peru, mainly in Paita.

Frozen fish production is concentrated mainly in Piura, where most of the plants are located due to the proximity of the main resources of South Pacific hake and jumbo flying squid. Traditionally, the main species destined for frozen production is hake; however, with the recent decrease in landings of this species, jumbo flying squid, squid and scallops now constitute the basis of this industry. Due to the variability in landings of South Pacific hake, it has been necessary to implement measures to promote the use of other species such as red prawn and spider crab, as well as highly migratory species such as tuna and jumbo flying squid.

Production is directed mainly to the export markets, which results in greater numbers of plants adopting hazard analysis and critical control point (HACCP) systems to ensure satisfactory quality for export. The small pelagics used in the freezing industry represent only 5 percent of the total landings for frozen seafood production in Peru.

There are 95 industrial plants along the Peruvian coast that are engaged in the manufacture of frozen products, with a total processing capacity of 3 557 tonnes per day. The production of frozen fish and invertebrates in 2005 reached 144 831 tonnes, following an upward trend that began in 1999 with the increasing presence of jumbo flying squid in the landings.

4.2.2 Fish canning industry

The industrial canning activity in Peru began during the Second World War and grew during the 1950s such that by 1956 there were 69 plants with daily production capacities ranging from 50 to 1 500 boxes and using mainly eastern Pacific bonito (*Sarda chiliensis lineolata*) and Pacific menhaden (*Ethmidium maculatum*). Increasing costs and the rise of the fishmeal industry marked a decline in the canning industry. The appearance of new markets and new technological advances provided important new growth, transforming Peru in 1981 into the main global producer of canned fish. New crises have affected this industry, including the reduction of fishing levels caused by El Niño, inflationary problems, market requirements, etc.

At present, the canning industry in Peru is in a state of change. With the drastic reduction of landings of sardine (the main species used by this industry in recent years), it has become important to look for other species like the anchoveta that have large prospective markets and a socio-economic environment favouring investments. It is necessary, therefore, to diversify the products as well as modernize the production lines to make them efficient and profitable.

The main species landed for the canning industry in 2005 were jack mackerel, chub mackerel and anchoveta. The Peruvian Government has been carrying out several product development projects with anchoveta, traditionally directed to the production of fishmeal, and jumbo flying squid, species that can be used in the processing of products with a higher value added and wide acceptance in different markets.

The main fish landing ports for canned processing are concentrated in the northern area of Peru. Paita, Coishco and Chimbote are where almost 80 percent of the landings for this industry occur. There are 87 canning plants, mainly located in Chimbote, Paita and Lima, with a total installed capacity of 191 840 boxes per shift. In 2005, small pelagics like anchoveta, chub mackerel and jack mackerel represented 68 percent of the landings for this purpose. Anchoveta, with 14 887 tonnes, constituted 16 percent of the landings. It is important to note that the anchoveta landings for this industry are mainly artisanal, and that the use of vessels fitted with boxes of ice is necessary to guarantee the quality of this species for direct human consumption.

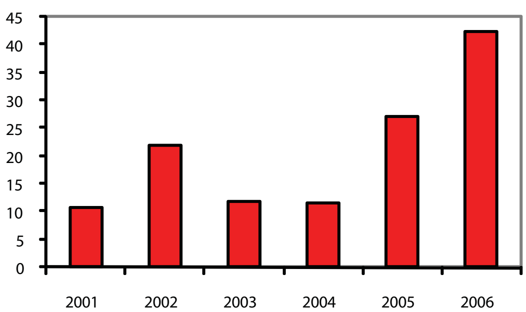
TABLE 12
Anchoveta landings by production category (thousand tonnes)

Year	2001	2002	2003	2004	2005	2006**
Fishmeal	6 348	8 083	5 336	8 797	8 628	5 884
DHC*	10.56	21.83	11.68	11.35	27.07	42.38
Fresh fish	0.40	0.01	0.39	0.32	0.35	0.01
Canned fish	3.29	13.36	4.82	2.63	14.89	30.95
Frozen fish	1.14	4.33	0.66	0.21	1.41	0.75
Cured fish	5.73	4.13	5.81	8.19	10.43	10.67

*Direct human consumption.
** Preliminary estimated data.
Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a, 2006b)

The volume of anchoveta used for canning has grown since 2001 (Table 12, Figure 11). The Instituto Tecnológico Pesquero del Perú (ITP), the state organization in charge of research and development of new products for human consumption, has adapted technologies making possible the use of anchoveta to manufacture products with a higher value added, including canned and cured products. These technologies have been transferred to the private industry.

FIGURE 11
Anchoveta landings for direct human consumption, 2001–2006*



* Preliminary estimated data
Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a, 2006b)

4.2.3 Fish curing industry

The main species used for curing are pelagics like anchoveta, jack mackerel and chub mackerel. In 2005, these species represented 76 percent of the 28 075 tonnes landed for this purpose.

In the north, Pisco has become the main landing port for the curing industry, due to the availability of anchoveta for use in the production of anchovies that are directed to export markets. In the northern area of the country, landings are also destined for the artisanal production of salted chub mackerel, mainly used for household consumption.

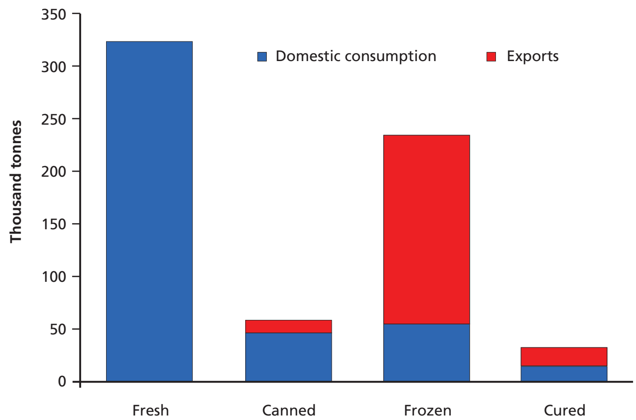
Taking into account that the traditional cured products (salted, dry and dry-salted) are widely accepted in the north, the main plants are located in this part of the country. The processing plants for "anchoas", which are mainly exported, are located in the south from Chimbote to Tacna, particularly in Pisco. It is important to note that there has been a substantial increase in the number of small-scale artisanal companies engaged in the production of salt-cured fish, known as “la saladita”. Most of these plants are located in the north and their products are directed to social programmes.

5. DOMESTIC CONSUMPTION AND EXPORT PATTERNS

In Peru, 8.2 percent of the landings (771 600 tonnes in 2005) sustain the processing industry dedicated to direct human consumption. In 2006, the freezing industry was the most active, using 41.8 percent of the landings for direct consumption, most of the production being dedicated to the export markets (Figure 12).

Fresh/chilled fish is mainly used for domestic (household) consumption, representing 66 percent of the landings for foodfish, followed by the canned industry with 18.7 percent and the freezing industry with 9.3 percent, which are directed to both household and export markets.

FIGURE 12
Domestic consumption and exports of pelagic fish in Peru



Source: PRODUCE (2006a)

5.1 Per capita consumption in Peru

According to the State of World Fisheries and Aquaculture (SOFIA) published by the Food and Agriculture Organization of the United Nations (FAO, 2007), the per capita worldwide supply reached 16.5 kg per year. In Peru, the average consumption of the last few years is nearly 20 kg per year (Table 13). Fresh fish is the main component of the per capita fish supply in Peru, representing 63 percent. Canned and frozen fish represent approximately 15 percent, while cured fish represent just 6 percent.

TABLE 13
Per capita consumption of fish products in Peru, 2000–2005

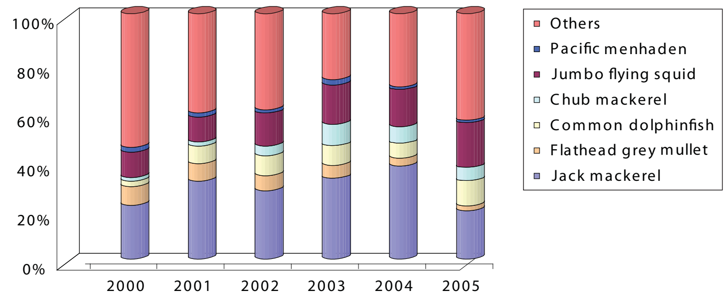
Year	Consumption (kg/person/year)				
	Canned fish	Frozen fish	Cured fish	Fresh fish	Total
2000	4.0	1.2	1.9	14.1	21.2
2001	3.4	2.2	1.7	15.1	22.4
2002	1.7	2.7	1.5	13.1	19.0
2003	3.8	1.9	1.3	13.6	20.6
2004	2.6	2.7	1.1	13.9	20.3
2005	3.1	2.8	1.1	11.9	18.9

Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

5.1.1 Fresh fish

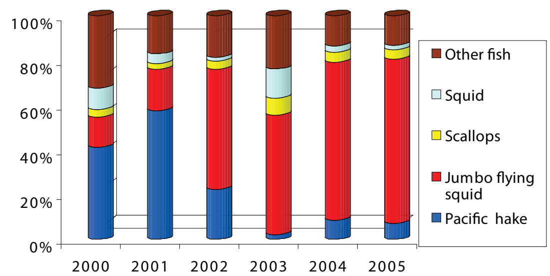
Fresh fish are mainly used for household consumption. In 2005, 285 947 tonnes of fish were consumed in fresh form, the main species being jack mackerel, jumbo flying squid, common dolphinfish and chub mackerel (Figure 13) and accounted for 53.5 percent of total landings. Demand for fresh fish, which is mainly supplied along the coast, has shown a regular and sustained trend over the last few years. Most of the fish consumed fresh are pelagic and of low cost. This factor is critical in determining the preference of consumers. There is also a small market for white-flesh fish, characterized by its shortage and high price, which make it inaccessible to the low-income group.

FIGURE 13
Proportion of landed fish of different species/species groups used for direct human consumption as fresh fish, 2000–2005



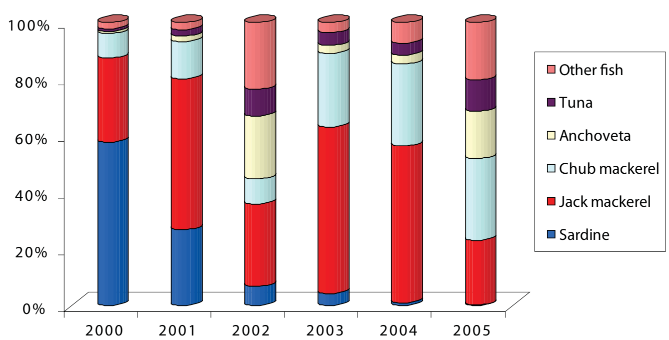
Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

FIGURE 14
Proportion of landings used for frozen fish production, 2000–2005



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

FIGURE 15
Proportion of landings used for canned fish production, 2000–2005



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

5.1.2 Frozen fish

The landing of 321 221 tonnes of seafood for freezing in 2005 generated a production of 145 575 tonnes of processed products. Fifty-three percent of the frozen products was used for household consumption, and the balance was sent to export markets. This, in terms of internal consumption, represented a contribution to the annual per capita consumption of 2.8 kg, the highest average of the last few years.

The jumbo flying squid is currently the main species landed for the freezing industry, replacing the Pacific hake (Figure 14). In 2005, jumbo flying squid represented 73 percent of the landing for freezing. In Peru, frozen products (mainly whole fish) are mostly consumed in coastal areas or in areas of close proximity that are equipped with cold storage and supermarket chains that enable the products to be distributed under satisfactory quality conditions. Frozen whole fish is sometimes stored and thawed before it is sold for direct consumption.

5.1.3 Canned fish

The production of canned products is based on the use of pelagic species such as jack mackerel, chub mackerel and, more recently, anchoveta (Figure 15). In 2005, the landing of 89 359 tonnes of fish for canning resulted in a production of 55 502 tonnes of canned fish, of which approximately 22 percent was exported. It is important to note, however, that the canned fish industry has been very sensitive to the drastic decrease of the sardine in Peruvian coastal waters. Before 2000, the landings of this species did not exceed 100 000 tonnes and were directed to fishmeal and canning production.

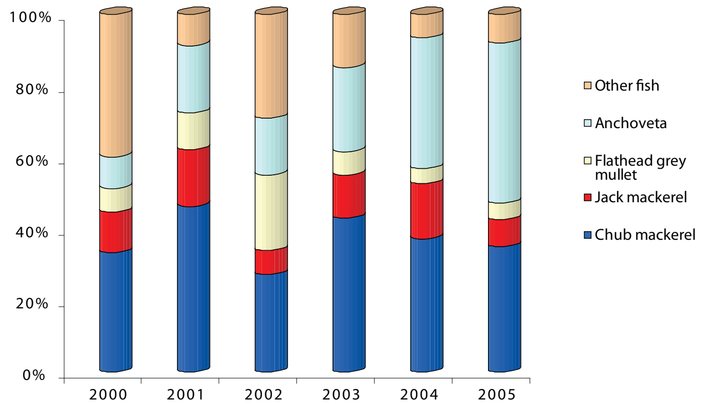
Of the total production, 46 000 tonnes were directed to domestic consumption, resulting in an annual per capita consumption above 3.1 kg. Canned products, because of their easy storage, are easily distributed throughout the country. It should be emphasized that in 2005 small pelagics represented 60 percent of the total landing destined to the canning process.

5.1.4 Cured fish

In 2005, 48 105 tonnes of fish were landed for the curing industry. This production was for domestic consumption and for export. The domestic sale of 14 500 tonnes of product (which includes that of continental origin), mainly salt-cured, resulted in an average annual per-capita consumption of 1.1 kg.

The main species used for curing are chub mackerel, Chilean jack mackerel and flathead mullet (*Mugil cephalus*) (Figure 16). However, in recent years, the anchoveta has been used in the production of "anchoas" (anchovies), in 2005 representing almost 45 percent of the total landings used for curing. It is important to recognize the training and technological transfer in the landing ports conducted by the ITP within the framework of the National Training Programs.

FIGURE 16
Proportion of landing used for cured fish production, 2000–2005



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

5.2 Characteristics of fish consumption

5.2.1 Metropolitan consumption

Lima, the capital of Peru, harbours a third of Peru's population. The low-income earners consider price to be one of the main factors in their purchase decision-making. Pelagic species such as jack mackerel, sardine and chub mackerel are mainly consumed usually as fresh fish. The medium- and high-income population show preference for white fish such as the palm ruff (*Seriolella violacea*), Pacific bonito and humpback smooth-hound (*Mustelus whitneyi*).

Marketing research studies indicate that fish is the Lima resident's favorite meat, and that it is considered the most nutritious. All income strata show a predisposition toward the consumption of novel fish product forms such as frozen products, new types of canned fish, pastes, etc. They also show a preference for anchoveta, a good tasting species that they consider of high nutritional value. This has been taken into account by the ITP for the development of new small-pelagic products and packaging that are adapted to the necessities and customs of the medium- and low-income population.

5.2.2 National consumption

Peru has 27 million inhabitants, 72 percent of whom live in urban areas and 28 percent in rural areas. Annual per capita consumption of fish is 20 kg. There is greater consumption of these resources in areas near the coast and minimal consumption in the interior regions of the mountains and jungles of Peru.

Consumption of fresh fish occurs primarily in the coastal region of the country (Table 14), with a per capita consumption of about 13 kg. Likewise, frozen fish is consumed mainly along the coast and in adjacent areas where cold chain facilities are available for distributing frozen products under satisfactory quality conditions.

Canned and cured fish products, due to their preservation characteristics, are distributed throughout the different regions of the country, although the contribution of these two products to per capita consumption is very low.

A quick examination of the rural populations of Peru indicates that there is a high percentage of residents that experience problems in accessing the basic foods needed

TABLE 14

Patterns of fish consumption in Peru

Product	Per capita consumption (kg/person/year)	Site of consumption	Species
Fresh fish	13.0	Coastal areas	Jack mackerel, jumbo flying squid.
Canned fish	3.1	Nationally	Jack mackerel, anchoveta
Frozen fish	2.8	Major cities	South Pacific hake, jumbo flying squid
Cured fish	1.1	Interior provinces	Chub mackerel and jack mackerel, anchoveta

Source: ITP (2004)

to meet their minimum nutritional requirements. This situation becomes worse in the highland regions and rural forests of the country, where people invest almost the entirety of their incomes in the purchase of food, highlighting the need for nutritious low-cost products. Likewise, rural populations present a high proportion of children who have difficulty in digesting carbohydrates and proteins, mainly resulting from micronutrient deficiencies, which implies the need to supply foods of high nutritional value.

Another characteristic of the rural populations is a lack of chilling equipment and adequate essential infrastructure, which hinders the distribution of fresh and frozen foods. Consequently, the products destined for these areas must have a long shelf life at room temperatures (e.g. canned products).

5.3 Exports

5.3.1 Fishmeal and fish oil

Fish products represented about 13 percent of total Peruvian exports in terms of value, and Peru is the major supplier of fishmeal in the world. In 2005, Peru exported 2 million tonnes of fishmeal and 278 thousand tonnes of fish oil, generating revenues of US$1 295 million (Table 15).

Fishmeal exports, although reduced in volume due mainly to the regulatory measures to conserve anchoveta stocks, have increased in terms of value due to higher prices in the international markets (Figure 17). This is because of the growing demand mainly from the Asian countries for aquaculture feeds. For the first time, in 2005 the price of fishmeal was over US$1 000/tonne.

The main markets for Peruvian fishmeal are Asian countries, mainly China, importing approximately 52 percent of the domestic exportable production (Table 16).

TABLE 15

Exports of fish by value, 2000–2005 (million US$)

	2000	2001	2002	2003	2004	2005
IHC *	954.60	926.50	891.10	822.50	1 103.60	1 295.20
Fishmeal	874.00	835.40	821.70	742.40	955.80	1 148.10
Fish oil	80.60	91.10	69.40	80.10	147.80	147.10
DHC **	177.10	197.50	164.60	204.60	277.70	331.20
Canned fish	44.20	43.20	25.40	36.00	35.80	31.50
Frozen fish	114.30	129.30	116.70	148.30	217.00	267.00
Cured fish	7.40	6.70	5.30	6.80	6.30	9.30
Other fish	11.20	18.30	17.20	13.50	18.60	23.40
Total	**1 131.70**	**1 124.00**	**1 055.70**	**1 027.10**	**1 381.30**	**1 626.40**

* Indirect human consumption.

**Direct human consumption.

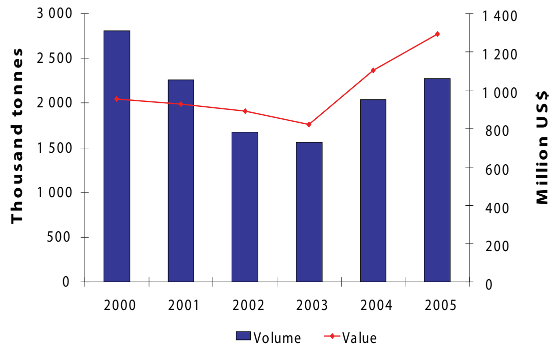
Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

Germany is the main European importer (12 percent). The main importers for fish oil are Belgium, Denmark and Chile (Table 17).

5.3.2 Direct human consumption

A significant growth in non-traditional exports has occurred over recent years, mainly in the form of frozen products (e.g. 179 662 tonnes in 2005). These include jumbo flying squid, South Pacific hake and scallops that are exported to European countries such as Spain and France, with hake fillets mainly going to the United States of America (Figures 18 and 19; Table 18).

FIGURE 17
Fishmeal exports, 2000–2005



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

TABLE 16
Fishmeal export value (FOB, thousand US$)

Country	2004	2005
China	425 962	505 561
Germany	76 602	134 757
Japan	114 314	103 032
Taiwan POC	84 026	52 020
Spain	20 602	25 841
Viet Nam	16 322	25 107
Indonesia	19 582	23 812
Turkey	27 136	21 023
Canada	28 770	20 246

Source: PROMPEX (2005, 2006)

TABLE 17
Fish oil export value (thousand US$)

Country	2004	2005
Belgium	26 230	48 197
Denmark	12 909	24 639
Chile	40 487	22 923
Canada	14 038	13 495
Japan	3 154	6 727
Italy	39	5 412
Australia	3 713	4 391

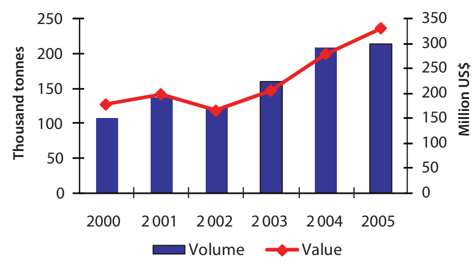
Source: PROMPEX (2005, 2006)

TABLE 18
Frozen seafood export value (thousand US$)

Product	2004	2005
Squids, dry frozen	82 541	94 712
Dry frozen scallop shells	24 415	32 759
Other frozen fillets	24 887	28 591
Non-conserved prepared molluscs	26 711	27 356
Lines of prawns with shell	15 253	26 594
South Pacific hake fillets	13 606	16 268
Other frozen fish meat	9 316	10 931
Frozen whole prawns	5 603	9 015
Other fish	14 668	13 514

Source: PROMPEX (2005, 2006)

FIGURE 18
Exports for human consumption, 2000–2005



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

TABLE 19
Export values of canned products (thousand US$)

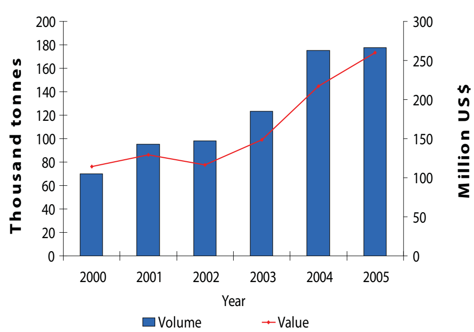
Products	2004	2005
Other canned fish	11 277	6 403
Tuna, bonito	5 154	6 145
Clams, false abalone	4 352	5 991
Whole anchovies	3 755	2 855
Other conserves of whole fish	2 897	2 694
Sardine	2 299	2 021
Whole mackerel	3 961	1 642
Other conserves	2 105	4 259
Total	**35 800**	**32 010**

Source: PROMPEX (2005, 2006)

In comparison to previous years, the export of 13.1 thousand tonnes of canned products generating the revenues of US$32.01 million reflected a relative decline in global consumption of canned product (Table 19, Figure 20). According to FAO (2007), canning represented 24 percent of the fish processed for food use in 2004, while this percentage was 27 percent in 2002 (FAO, 2005). However, it is important to note the canned exports of whole anchovies and sardines to the European and Latin American markets.

It is clear that the production of high value-added seafood products for direct human consumption (DHC) would significantly increase the fishery sector's contribution to the Peruvian economy, increasing the value of exports and employing more labour, while making more rational use of fishery resources.

FIGURE 19
Export volumes and values of frozen products, 2000-2005 (thousand tonnes and million US$)



Source: PROMPEX (2005, 2006)

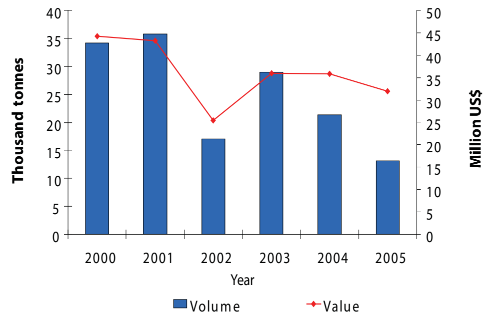
6. NATIONAL FISHERIES DEVELOPMENT ADMINISTRATION

6.1 Political framework

Fishing management actions are in accordance with the Reformulated Sectoral Strategic Multi-annual Plans 2004–2006, Program 044: Promotion of the Fishery Production. These include:

- promotion of farming and breeding of fish resources through the application of fishery regulation plans;
- responsible administration of the fishing effort on the main species that sustain the national fishery, assuring their sustainability and optimizing economic and social benefits;

FIGURE 20
Export volumes and values of canned products, 2000–2005 (thousand tonnes and millon US$)



Source: PROMPEX (2005, 2006)

- promotion of fish consumption in order to increase the per capita consumption of aquatic resources, with the participation of the state and private sector and highlighting the nutritious qualities of these resources and their different presentation forms;
- technological transfer of and training on the production technologies developed by ITP, particularly to the national fishing industry, as well as to the agents involved in the fishery sector;
- implementation of measures and actions oriented towards establishing an effective regulatory framework to guarantee the sustainability of fishery resources, as well as for the development of fishing activities and aquaculture;
- monitoring, control and surveillance of fishing effort in order to guarantee the responsible use of fishery resources, in the areas of capture, landings and processing, including aquaculture and the execution of sanitation and environmental guidelines; and
- environmental control in order to preserve biological diversity and care for the ecosystems and the quality of the environment.

6.2 Legal framework

Following the crisis of the national fishery sector that occurred at the beginning of the 1990s, Law No. 750 was promulgated for promoting private investment in the sector. In 1992, the General Fishery Law (DL 25977) established that the state must promote the sustainable development of the sector, harmonizing the economic and social benefits with the preservation of the environment and the sustainable use of the resources. Under this framework, catch quotas, seasons and fishing areas, extraction methods, minimum sizes of the fish, etc., were defined. Four modalities for field operation were also established for the sector through:

- the concession of the state infrastructure;
- research activities, commercialization, growth of the fleet or installation of industrial fishery establishments;
- permission to operate vessels with Peruvian or foreign flags; and
- licenses to operate processing plants.

This law sets down that licenses, concessions or authorizations are granted according to the commercial value of the species to be exploited. In the case of species that are fully exploited, such as the anchoveta, the grant of authorizations for fleet increases, new permissions and fishing licenses is restricted. For those species that are under-exploited, access for exploitation is allowed, permitting orderly growth. When the species are not being exploited, research and development programmes are developed to ensure their rational use.

In the case of the anchoveta, the law establishes control measures for catch levels as well as gear utilization. For example, fishing bans are normally imposed to allow the species to reproduce. Due to the El Niño phenomenon of 1998, a provisional ban system guided by constant monitoring by the Instituto del Mar del Perú (IMARPE) was established. According to this system, fishing bans depend exclusively on the behaviour in real time of the biomass, for which the periods of capture cannot be previously specified. In spite of the limitations that this system has had on the planning of fishing activities, it has been extremely successful in promoting the quick recovery of the anchoveta after El Niño events. However, the problem of the common property persists and, therefore, fleet overcapacity is still seen in the sector.

Some investment measures have also been established for anchoveta utilization. For example, the expansion of the fishing fleet is not allowed, and only the replacement of vessels of the same hold capacity is authorized. Even so, in the year 2000 it was already considered that fleet capacity was in excess given the available biomass. To solve this problem, the National Society of Fishery proposed the creation of a Fund for the Protection of the Biomass (FOPROBI), whose objective would be to reduce the fleet capacity by around 30 percent (50 000 m^3) in terms of hold capacity. This would be archived through the purchase and withdrawal of excess vessels. The cancellation of fishing licenses and the retirement of the vessels would be compensated with grants. This proposal outlined that a grant fund of up to US$200 million would be made available over a period of 10 years, during which time private companies would contribute to financing of the plan. However, this initiative remains unimplemented due to disagreement over the type and age of the vessels to be retired and because the fishing managers want the participation of the banking and state sectors in providing funds. Although the fishing companies recognize that it is necessary to reduce the fleet size, they apparently prefer to maintain the "status quo" for the time being.

Proposals for changing the resource management system, especially for anchoveta, to a quota-based system have met with a similar response. Distribution of quota would favour the most efficient companies, although in the initial distribution other considerations could prevail (e.g. the social impact), because in the end, rights would be negotiable.

In the last few years, following threats of a reduction in the anchoveta biomass and the biomass of other species like Chilean jack mackerel, there has been a move towards establishing an access system to fishery resources by means of individual quotas. The utilization of non-transferable quotas for South Pacific hake served as a pilot test. A total capture quota of 10 000 tonnes was established and distributed among the trawl vessel owners. The quotas have validity for one year, and they were assigned in relation to the historical capture of the applicant vessels.

The state authority is aware that a quota-based system requires much more careful monitoring than has previously been the case. An inspection organization is needed to control fish landings, and the crews of the entire fishing fleet need training; the implementation of satellite-based vessel monitoring systems (VMSs) is also necessary. The port authorities also have to be strengthened to ensure their capacity to determine infringements and take necessary actions.

Another important aspect of the fishery legislation is the conservation of the environment. The high concentration of fish processing factories in various ports along the Peruvian coast has caused some damage, mainly due to unregulated emissions. For this reason, if any new plant is to be installed, it is necessary to conduct an Environmental Impact Assessment (EIA). For those plants already operating, an Adaptation Program for Environmental Management (PAMA) is required. Increased environmental regulation has been a great step towards improvement of the conditions of the fishing ports, as well as an increase in the efficiency of the productive units. Although the legislation has resulted in the reduction of large quantities of toxic effluents, especially organic loads, it has not regulated the release of vaporous emissions.

6.3 Institutional framework

6.3.1 Key institutions

Fisheries regulation is the responsibility of the Ministry of Production (PRODUCE), which combines the former Ministries of Industry and Fisheries. The Vice-ministry of Fisheries (VMP) formulates, executes and directs sector policies, and its objective is the rational administration of the fishery resources and the preservation of the environment. For this purpose, the ministry has specialized directorates and public decentralized organizations within its structure that assume, among others, the following specific functions:

- **The Aquaculture National Directorate** is in charge of implementing and supervising the relative sector policies for farming resources from marine and inland waters. It supervises the legal frame of this activity and grants the corresponding rights.
- **The Artisanal Fisheries National Directorate** proposes and executes policies for the development of the artisanal fishery. It programs, executes and evaluates training for the fishers and artisanal fishing processors and proposes regulatory norms for artisanal fishing.
- **The Fishery Extraction and Processing National Directorate** administers the extractive activities and proposes and implements sector policies with regard to the processing scales of the fishery resources. It evaluates applications to develop catching activities and fish processing; grants the corresponding authorizations, permits and licenses; supervises the granted rights; and promotes the research required for the sector.
- **The Control and Surveillance National Directorate** proposes, implements and supervises policies for the sector relative to the monitoring, control and surveillance of fishing activities and aquaculture, in agreement with the effective guidelines, and evaluates and applies the corresponding sanctions. It administers the vessel monitoring system (VMS), Sistema de Seguimiento Satelital (SISESAT) and imposes sanctions for proven infringements.
- **The Environment National Directorate** formulates and proposes policies and strategies for allowing harmony between the development of fishing activity and the environment. It supervises the execution of the norms and environmental control measures and registers the public and private institutions destined to the implementation and certification of environmental studies of the sector.

The fishery sector is also responsible for the following five public organizations that provide technical support to the sector:

- **El Instituto del Mar del Perú (IMARPE)** conducts scientific research at sea, in continental waters and on their living resources and is dedicated to their rational development. This institute studies the atmosphere and marine biodiversity, evaluates the fishery resources and provides information and advice to support decisions on fishing, aquaculture and the protection of the marine environment. IMARPE has laboratories and offices for data processing at its central headquarters in Callao, as well as a series of laboratories along the coast at all the main fish landing points. It also has a scientific research vessel and three smaller vessels for coastal work.
- **El Instituto Tecnológico Pesquero del Perú (ITP)** promotes and conducts scientific and technological research in order to achieve the optimal use of fish resources and to disseminate results. Its mission includes the transfer of technical knowledge on the handling, preservation and processing of fishery resources. It also promotes fish consumption through the development of new products based on traditional and non-traditional species. As the competent authority of the Servicio Nacional de Sanidad Pesquera (SANIPES), ITP is responsible for the inspection, surveillance and sanitary quality control of the capture, landing, processing and commercialization of fish and aquaculture products in the wholesale markets. At present, ITP is carrying out an intensive programme for transfer and promotion of high value-added product based on anchoveta.

- **El Fondo de Desarrollo Pesquero (FONDEPES)** promotes, executes and supports technically, economically and financially the development of marine and continental artisanal fishing activity and aquaculture, mainly with regard to aspects of basic infrastructure. It manages the Fund for Aquaculture Research (FIA). This organization is currently under organizational restructuring and is being amalgamated with the Centro de Entrenamiento Pesquero (CEP-Paita).
- **El Centro de Entrenamiento Pesquero (CEP-Paita)** designs and executes actions to improve the training and personal development of fishery sector workers, especially the artisanal fishers. CEP-Paita contributes to the improvement of the socio-economic status of the artisanal fishers in the country.
- **The Peruvian Amazon Research Institute (IIAP)** evaluates the natural resources of the Peruvian Amazonia and its productive potential. It promotes the application of the results of the scientific and technological research and proposes procedures and norms to the relevant institutions for the sustainable use of natural resources. This institution advises public-sector organizations on policy development and informs them of their research plans.

The interaction between the Vice-ministry of Fishery and the decentralized institutions is close. For instance, IMARPE coordinates with the VMP so that it can regulate the closed season periods based on its investigations of available biomass, while ITP advises the VMP in matters of surveillance and sanitary control of the seafood production chain and in promoting fish consumption at the national level. IMARPE and ITP also combine their work, because the information on the marine species obtained by IMARPE is used by ITP in developing new alternatives for human consumption.

6.3.2 Coordination among government levels

Since 2003, Peru has been executing institutional decentralization, transferring national government functions to the regional governments. The functions to be assumed by the regional governments include:

- developing plans for fishery and aquaculture policies in their jurisdictions;
- administering and supervising the activities and fishery services under their jurisdictions;
- executing control actions and surveillance;
- administering the use of the landing services infrastructure and fishing processing within their jurisdictions; and
- supervising the execution of norms related to the artisanal fishery and its exclusivity within the five-mile coastal waters zone.

At present, PRODUCE is delegating the implementation of some of the national recurrent fisheries management tasks to its Regional Directions.

Coordination also exists among local governmental authorities charged with the execution of the tasks related to the sanitary control of fish products in local markets, the National Society of Fisheries (SNP) and trawling owners' associations. SNP is a private organization that includes members from most of the fish companies of Peru. SNP associates are fishmeal and canning company representatives, as well as the cold store operators, trawlers, shrimp farming company representatives and some capital goods and services suppliers. SNP maintains a close relationship with the VMP in formulating fisheries development policies. The trawling owners' associations were created mainly to negotiate landing prices with the fishmeal industry or with the crew, who are strongly supported by the labour unions.

7. POTENTIAL ALTERNATIVE USES OF PELAGICS FOR DIRECT CONSUMPTION AND VALUE-ADDED PRODUCTS

The majority of anchoveta landings is directed to the production of fishmeal to be used as feed – this use is controversial as the capacity to use this species for direct human consumption has been well demonstrated. Numerous studies present technological alternatives and their economic feasibility that allow the processing of the anchoveta into commercially attractive products for human consumption that might contribute to the alleviation of the food security problem in Peru.

Although a number of barriers (e.g. market, provision of necessary investments and installed capacity of processing plants) prevent a significant part of this resource from being used for direct human consumption, appropriate processing technologies for this species are not one of the barriers. The institution conducting research and development of new products in Peru, ITP, has implemented and adapted various technologies for the handling and processing of the anchoveta with different presentations and market possibilities.

The fishery statistics over recent years in Peru show a sustained increase in anchoveta landings destined for direct human consumption, especially for canned and cured products.

7.1 Pelagic fish used for direct consumption

In Peru, the main species used for direct human consumption are small pelagics. In 2005, 724 602 tonnes of aquatic species were landed, of which 362 995 tonnes were fish and 353 558 tonnes were invertebrates, mainly jumbo flying squid. Of the total fish landings, 222 325 tonnes (61.3 percent) were pelagics, including Chilean jack mackerel, mackerel and common dolphinfish.

The use of anchoveta as a foodfish has increased over the years, and in 2005 anchoveta was the most commonly used species after Chilean jack mackerel, chub mackerel and common dolphinfish, especially as canned and cured product. However, being a small and fatty species, anchovy catches that are subjected to mechanical pressure can quickly deteriorate due to breakage of the belly area and/or enzymatic action. They, therefore, need special attention on board during their capture and preservation.

Experience elsewhere suggests that it is possible to obtain raw material of appropriate quality for human consumption by using small- and medium-sized vessels. However, in order to ensure good quality fish, some practical requirements must be met. Thus, it is necessary to:

- minimize the time between capture and the start of processing;
- use exclusive vessels to catch fish for human consumption that are equipped with preservation systems for small pelagics;
- maintain the cold chain for the raw material from its storage on board the vessels to the hoppers and storage rooms on land;
- use appropriate landing systems that do not impact upon the quality and physical integrity of the catch; and
- use ice in the processing chain and avoid bacterial contamination through the application of sanitary measures.

The artisanal fishery is a productive sector that constitutes a traditional source of fish for direct human consumption. The sector provides thousands of direct and indirect jobs and contributes to the coastal economies. However, the sector is in a permanent crisis, with its main constituents immersed in a subsistence economy, due to their vulnerability to sea conditions, seasonal and inter-annual resource variability, and a lack of modern vessels and fishing technologies, which translates into lower economic returns due to the low quality of the landed products.

It is important to promote a change of attitude in the artisanal fishers to finally break the vicious circle in which this sector is immersed by encouraging integration into the managerial sector and the abandonment of low productivity processes, and establishing strategic alliances with the processing and marketing organizations in order to produce and receive increased added value. In this way, the artisanal fishery might serve as a key tool for increasing the per capita fish consumption and/or providing raw materials to other companies or for export through diversification of the fishery. It is necessary to offer high-quality products through the adoption of modern handling and preservation methods on board that allow the quality of the fish to be maintained after it is captured.

The artisanal fishery sector could assume the responsibility for supplying the anchoveta required by the large and small processing companies. To this end, a training programme has been started that includes training of national fishers in the techniques of manipulation of anchoveta on-board small fishing vessels (i.e. vessels smaller than 10 tonnes).

7.2 Impacts of the utilization of anchoveta

In contrast to other countries where the fisheries have reached the limits of sustainable production, in Peru supplies can be increased if part of the catch used by the fishmeal industry is used for to human consumption. According to the Projection of the Peruvian Population published by the National Institute of Statistics of Peru (INEI), it is estimated that by 2020 Peru will have a population of 31.5 million inhabitants, and to maintain the current annual per capita fish consumption, 654.6 thousand tonnes of fish would be required. This would mean an increase of around 89.3 thousand tonnes (Table 20).

TABLE 20
Projected growth in population and seafood consumption in Peru

Year	Population (millions)	Consumption (thousand tonnes)
2005	27.2	565
2010	28.9	600
2015	30.3	630
2020	31.5	655

Source: INEI (undated)

The Peruvian Government has designed plans for the establishment of a Food Security System using fish, particularly anchoveta, to achieve the required increase in production, and is aware that this would require a series of incentives that include the transfer of technologies and the development of a restructured internal market. A significant increase in the volume and types of fish products offered based on the anchoveta would be essential to cover food supply deficiencies of a significant part of the projected Peruvian population. These products would bring many additional benefits related to achieving food security and economic and social well-being.

7.2.1 Food security

Fishing could contribute to the improved food security of the country by providing the residents of depressed areas with a source of low-cost protein that substitutes for traditionally consumed foods. In order to increase the annual per capita fish consumption from 20.8 to 25 kg by 2010, an additional 157 300 tonnes would be required, corresponding to 1.8 percent of the anchoveta catch in 2005 (Table 21).

TABLE 21

Potential increase in fish consumption in Peru

Year	Population (millions)	Per capita consumption (kg/year)	Total consumption (thousand tonnes)	Increase in consumption (thousand tonnes)
2005	27.2	20.8	565.2	
2011	28.9	25.0	722.5	157.3

Source: ITP (undated)

7.2.2 Added value

During 2005, Peru's fishmeal exports were valued at US$1 295 million and used 8.6 million tonnes of raw material. The use of these catches in the production of food for direct human consumption would add significant value to the resulting products and would increase the overall productivity. Assuming that the production of 1 tonne of fishmeal requires 4.5 tonnes of anchoveta costing US$80/tonne, the sale value of the final product would be US$800/tonne, giving an added value of US$440 (Table 22). Alternatively, 4.5 tonnes of raw material at a cost of US$150/tonne that is converted to canned product would have a sale value of US$8 100, generating an added value of US$7 425. This is an added-value relationship of 17:1, even though the price of the raw material used for human consumption is higher, as to maintain its quality requires the use of ice on-board, additional labour for handling, etc. (Table 22).

TABLE 22

Examples of added value through product development

Product	Raw material (tonnes)	Price of raw material (US$)	Estimated quantity of product	Sale price (US$)	Sale value (US$)	Added value (US$)	Increase added value (ratio)
Fishmeal	4.5	80	1 tonne	800/tonnes	800	440	1.0
Canned fish	4.5	150	405 boxes	20/boxes*	8 100	7 425	16.9

* Each box contains 50 cans of ¼ club (a can of 1/4 club contains a net weight of 120 g and a liquid medium of 35 g. Each can contains from 6 to 9 pieces of anchovy).

Source: ITP (undated)

From these calculations, it can be projected that the current value of US$1 300 million generated by using 8.6 million tonnes of anchoveta for reduction could be generated by using only 11 percent of the anchoveta landed during 2005 if it were directed to food production. This would not significantly affect the reduction industry.

7.2.3 Labour

The term "food security" refers not only to assuring an adequate and affordable production of food but also to establishing of mechanisms for labour and employment opportunities. A greater use of small pelagic resources, like the anchoveta, for the production of food would generate employment that would increase the socio-economic level of the population participating in such activity.

According to the last analysis of employment in the fishery subsector, 6 631 workers, both full- and part-time, were employed for the processing of feed-fish products. If we consider the same level of employment and the landing volumes and production corresponding to the year 2005, the utilization ratio would be 0.77 (number of workers required per 1 000 tonnes of landing) (Table 23).

By contrast, a production study of canned anchoveta at the industrial level indicates that the production of 7 160 boxes, corresponding to 2 880 tonnes of raw material, required 189 workers. If 1 percent of the fishmeal landings were assigned to anchoveta ¼ club production, then 86 287 tonnes of material would generate work for 5 662 people, as compared with the 66 positions that are provided by the fishmeal industry.

The study highlighted the sale value of canned products at US$8 100/tonne against that of US$440/tonne for fishmeal and also considered that assigning 1 percent of the

TABLE 23
Comparison of labour utilization for fishmeal versus canned products

Product	Landing (tonnes)	Production	Labour (workers)	Utilization ratio (workers/1 000 tonnes)
Fishmeal	8 628 704	2 221 149 tonnes	6 631	0.77
Canned fish	86 287	2 14 520 boxes	5 662	65.62

Source: Ministerio de la Producción, personal communication

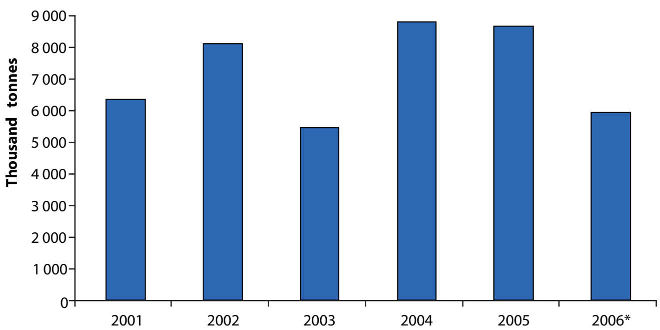
fish currently destined to fishmeal to direct human consumption would generate work for 5 662 people, compared with the 6 631 positions that are provided by the fishmeal industry.

7.3 Technological applications for anchoveta

The industrial production of fishmeal using anchoveta will continue to be an important social and economic activity in the country. It is a resource that, despite being fully exploited and threatened by recurrent El Niño events, still maintains a constant biomass and landings.

With average annual catches exceeding 7 million tonnes over the years 2001-2006, it will require considerable effort to change from traditional fishmeal production to the production of products for human consumption, both in terms of technical processing and in market development. However, a number of socio-economic and technical factors advocate using a part of the anchoveta catch in the processing of added-value products, the technical feasibility of which has been studied and promoted by ITP. So, within this context, the question would be "Why use anchovy as foodfish?" The answers are because:

FIGURE 21
Anchoveta landings, 2001–2006

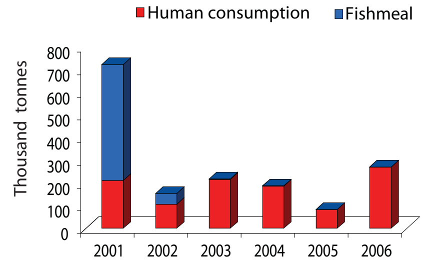


* Preliminary estimated data
Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

- Anchoveta is the main Peruvian fish resource and the most important reserve of animal protein for Peruvians. Anchoveta grows fast and catches remain constant (see Figure 21).
- Anchoveta is a resource of great nutritional value that provides a good quality protein with a high lysine content and other essential amino acids. Having a high content of minerals (K, Fe, P, Ca, I) and vitamins (A and D), it presents a valuable source of omega-3 fatty acids (EPA and DHA) that are essential, especially for pregnant and nursing women (Table 24).
- Alternative fish resources for popular consumption such as Chilean jack mackerel and chub mackerel present irregular landings (Figures 22 and 23) and are more expensive due to the added effort involved in their capture.
- The use of anchoveta for human consumption would contribute to solving food security problems in Peru. In addition to fresh fish products, it is possible to process products of high nutritional value, low cost and long shelf life under room temperature, whose use would be fundamental in combating malnutrition.
- The inclusion of anchoveta in the market could make an important contribution to increased national annual per capita fish consumption, now at 20 kg (Figure 24). By using 7 or 8 percent of the regular captures of this resource (some

540 000 tonnes), national fish consumption could be doubled.
- The technical, economic and commercial feasibility of anchovy-based products has already been proven. These products include canned and prepared frozen fish, dried anchovies, surimi and surimi-based products and a great number of "delicacies", such as anchoas for both domestic and international markets (Figure 25).
- The use of anchoveta in the foodfish industry offers higher benefit/cost when compared in terms of added value with the traditional fishmeal industry. The foodfish industry generates greater demand in terms of labour, supplies and inputs due to the great number of industries associated with the sector.
- The use of this resource and its processing to higher value-added products provide great opportunities for the growth of Peruvian fisheries, elevating Peru's level of international competitiveness.
- Direct consumption of anchoveta would benefit the artisanal fishing sector, provided suitable handling and preservation techniques were developed to ensure the quality and the physical integrity of the landed product (Figures 26 and 27).

FIGURE 22
Production and use of jack mackerel, 2001–2006*



*2006 data are preliminary and estimated
Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

In general terms, it is believed that the benefits derived from this proposal would be multiple and would favour the vessel owners and artisanal fishers, as well as the processors and consumers. ITP has carried out systematic work dedicated to introducing the concept of using this resource as foodfish for direct human consumption through the use of traditional and modern technologies. These products based on anchoveta are described below.

7.3.1 Canned products

The experience of ITP in the development of non-traditional fish products has been used in the design and adaptation of technologies for canned products based on anchoveta. These include:

- headed and gutted anchoveta (tube type) packed in flat cans type ¼ club (125 g) (Figures 28 and 29) or oval cans (½ lb and 1 lb); tinapa (180 g); tuna (175 g), using different sauces and presentations (e.g. tomato sauce, oil, smoky sauce, mustard, red wine, onions, garlic, etc.);
- minced skinless anchovy loins in vegetable oil, packed ½ lb tuna can or 1 lb tall containers; similar to traditional grated fish in Peru;
- anchovy skinless fillets in vegetable oil, packed in tuna cans, ¼ club or other containers;
- concentrated soups based on anchovy pieces; they consist of canned preparations of various styles, blended with anchovy broth and pieces to make a concentrated product that must be reconstituted before

TABLE 24
Nutrient composition analysis of anchoveta

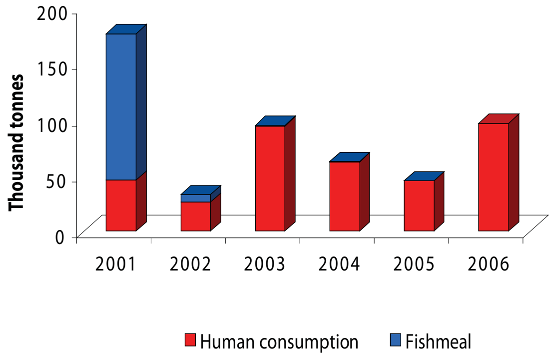
Component	Mean value
Proximate composition (%)	
Moisture	70.8
Crude lipid	8.2
Crude protein	19.1
Mineral salts	1.2
Energy (kcal/100 g)	185
Fatty acids (% of lipid)	
20:5n-3 Eicosapentaenoic acid (EPA)	18.7
22:6n-3 Docosahexaenoic acid (DHA)	9.2
Minerals (mg/100 g)	
Sodium	78
Potassium	241.4
Calcium	77.1
Magnesium	31.3
Iron	30.4

Source: ITP-IMARPE (1996)

consumption; several presentations are already on the market;

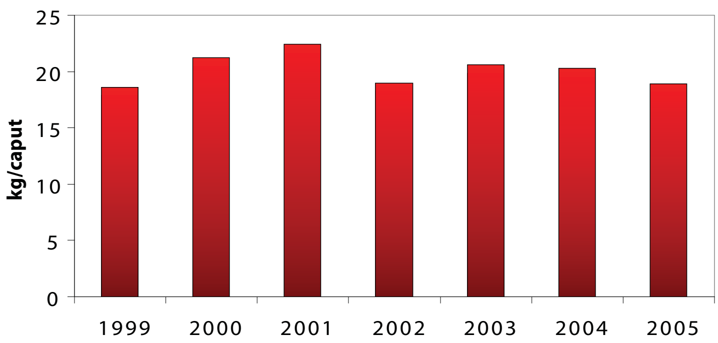
- heavy salted and maturated anchovy fillets that are presented in vegetable or olive oil and packed in tin or glass containers; the product is traditional in some European countries and is made by means of a process of controlled maturation in a strong saline medium.

FIGURE 23
Production and use of chub mackerel, 2001–2006*



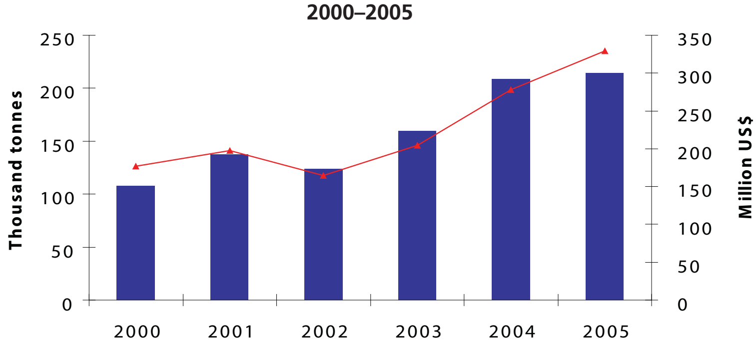
**2006 data are preliminary and estimated*
Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

FIGURE 24
Fish consumption in Peru, 1999–2005



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

FIGURE 25
Production and value of nontraditional fish products, 2000–2005



Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

7.3.2 Frozen products

Frozen products include:

- surimi made from anchovy flesh that is subjected to successive washing cycles, refined and partially dehydrated. This product is an intermediate raw material used for manufacturing pasty products.
- anchovy burger, which consists of a cooked and frozen product that is manufactured from minced meat obtained from fresh anchovy;
- anchoricas, a product consisting of deep-fried boneless anchovy double fillets that are covered with corn flour, frozen, packed in polyethylene bags and stored at temperatures below -18 °C;
- anchovy block: whole or headed and gutted (HG) frozen anchovy in 5 kg blocks, to be used as raw material for product applications; and
- anchovy sausages (Figure 30), which are a sterilized product of long shelf life under room temperature that is based on anchovy surimi, has a high protein content and is similar to other traditional stuffed products.

7.3.3 Cured products

Cured products (Figures 31 and 32) include:

- wet salted anchovies, a product consisting of heavily salted anchovies that are vacuum packed, allowing a long shelf life under room temperature if stored under fresh and ventilated storage conditions; and
- boiled and dried anchovies, consisting of small-sized anchovies that are subjected

FIGURE 26
Anchoveta for fishmeal production in Peru

FIGURE 27
Anchoveta landing in Peru

to a boiling and drying process which allows for a long shelf life at room temperature.

7.3.4 Other products

These include:

- fish protein concentrate (FPC) made from anchovy flesh that is subjected to a quick-cooking, decanting and drying process; FPC is generally used in the manufacture of cookies (Figure 33).
- fish oil for human consumption, obtained by processing high-quality fresh fish to obtain raw oil that is subjected to refining, deodorizing and stabilizing processes. The product contains high concentrations (around 30 percent) of EPA and DHA and is being tested as an ingredient in prepared fish products (Figure 34).

FIGURE 28
Anchoveta can filling

FIGURE 29
Anchoveta packed in flat cans ¼ club (125 g)

FIGURE 30
Anchovy sausages

FIGURE 31
Heading and gutting operation

FIGURE 32
Boiling and drying process of anchoveta

FIGURE 33
Anchovy cookies

FIGURE 34
Fish oil produced from anchoveta

7.4 Exports of anchovy-based products

7.4.1 Canned anchovy

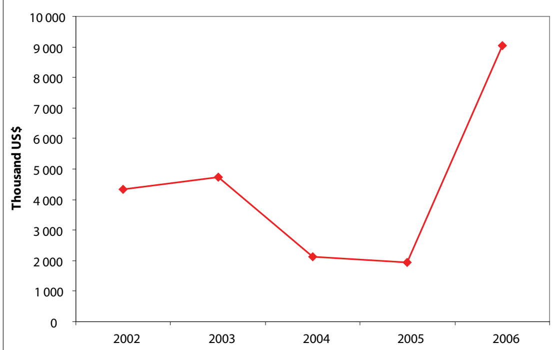
According to the report of the Office for Export Promotion of Peru (PROMPEX), exports of canned anchovies have experienced remarkable growth in 2006 (Figure 35), highlighting whole products presented mainly in tomato sauce and oil. The most important markets for these products are Colombia, the Dominican Republic and Haiti, followed by Bolivia, Panama and Spain, along with 17 other destinations. The placement of products in other developed countries as a substitute for similar types of products is expected in the future.

7.4.2 Anchoas (salted and maturated anchovy fillets)

The production of anchoas (a product based on anchoveta) is an industry that deserves to be highlighted because of its recent spectacular growth (Figure 36). According to statistics published by PROMPEX, the exports of salted and maturated anchovy fillets (vacuum packed and in metal containers) grew by 146 percent in 2006 compared with the previous year, mainly due to the lack of traditional raw materials in the markets of some of the European countries. For example, the landing of European anchovy

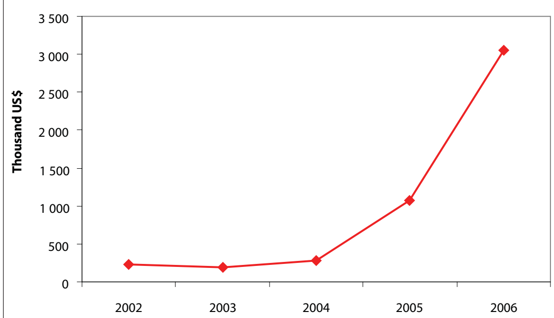
(*Engraulis encrasicolus*) in the Cantabric Sea has decreased, and this has resulted in the increased importation of anchoas by countries like Spain, Italy and France. The most important markets for this product are Spain, Italy, Brazil and France. Other markets that have been important destinations for anchovy exports include Portugal, Germany and Chile.

FIGURE 35
Canned anchovy exports, 2002–2006



Source: PROMPEX (2005, 2006)

FIGURE 36
Anchoas exports, 2002–2006



Source: PROMPEX (2005, 2006)

8. CASE STUDY – CHIMBOTE FISHING PORT

Chimbote is the main fishing port of Peru and is located on the northwestern coast. This district is the capital of the province of Santa, Department of Ancash and is mainly important for its great fisheries wealth, where pelagic species like anchoveta are the basis for the most important fishing industry in the country.

Chimbote has an important source of electrical energy: the Hydroelectric Power Station of Del Pato Canyon and a steel plant that provided material for the builtding of a port in the 1950s which enabled the plant to market its products. This promoted the rapid growth of Chimbote, which grew from a fishing village of 4 342 inhabitants in 1940 to a town of 30 000 in 1956 and to a city of more than 300 000 people by 2000.

8.1 Landings

Other ports located in Santa province and under the influence of Chimbote are: Puerto de Santa, Coishco, El Dorado, Besique, Samanco, Los Chimus and Tortuga. Basic water, electrical and sewer services are found only in Coishco, with limited services or infrastructure also present in Los Chimus, Tortuga and Samanco (Table 25).

Chimbote, although a main port, has some limitations. For example, the ice plants have insufficient capacity to meet demand, impacting the quality of the raw material, especially for direct human consumption. This port has two shipbuilders whose main activity is to repair the vessels of Chimbote and bordering districts. It also has factories

TABLE 25
Service and infrastructure in the area of Chimbote

	Basic services	Infrastructure
Puerto de Santa	–	–
Coishco	Water, electricity, sewer system	Handling room
Chimbote	Water, electricity, sewer system	Dock, storage room, ice producer, power generator, handling room
C. Atahualpa	–	–
El Dorado	–	–
Besique	–	–
Samanco	–	Dock
Los Chimus	Electricity	Dock, power generator, handling room
Tortuga	Water, electricity	Handling room

Source: PRODUCE (2001, 2002, 2003a, 2004, 2005, 2006a)

that manufacture spare parts for vessels. The mechanical workers do not have technical or university training, although the larger factories have better equipment and more qualified personnel. The input suppliers have specialized stores that sell nets and other fishing and security equipment for fishers. Some small suppliers offer basic supplies, while others operate as department stores.

Recent legislation is forcing vessel crews to have some level of qualification. There is a branch of the CEP-Paita and the Private University of San Pedro that offers training courses.

In 2005, this port accounted for around 14 percent of the national fish landings (1 326 799 tonnes) and provided 97.4 percent of landings (1 292 300 tonnes) to the production of fishmeal and 2.18 percent of landings (28 868 tonnes) to the production of canned fish.

Chimbote has an important industrial fishing fleet. In 2005, there were 302 registered vessels with a total hold capacity of 75 055 m^3. As the fishmeal companies produce mainly standard-grade fishmeal, buyers of new vessels do not encourage the shipyards to equip the vessels with chilling equipment.

Another strategy that has been adopted by several of the big fishing companies is that of diversification. Having their own fleet allows them to fish in the open sea and to access various species that can be processed in their plants. In this way, when the catch diminishes in a fishing area or the area is declared a prohibited fishing area, the companies can get fish from other ports and/or other species can be caught. This global management of the fishing companies has encouraged the establishment of their main offices in Lima. For that reason, the strategic decisions relating to the industry and even the operational decisions take place in the capital.

The prevalence of use of fishery resources for processing into standard fishmeal does not encourage the shipbuilders to improve their vessels by incorporating refrigeration systems that would improve the quality of the protein contained in the fishmeal. However, the growing demand for “prime” fishmeal and its greater price stability have encouraged the conversion of some companies for prime fishmeal production. Currently, 42 percent of the fishmeal produced in Peru is prime fishmeal, yet in Chimbote only 15 percent of production is prime fishmeal. Prime production in the plants in Chimbote is low because the plants are older and require more investment so fishing groups have preferred to modernize their plants in ports other than Chimbote. Another reason is that the production of this type of fishmeal requires conversion of the fishing fleet to incorporate refrigeration systems, since the fish have to arrive at the plant with high indices of freshness and quality.

The fishmeal companies in Chimbote compete for the resource and for the international markets. The lack of property rights on the resource and the over-sized fishing fleet make competition for the resource very strong.

According to the Decreto Supremo Nº 024-2006-PE, the payment for fishing rights for tonnes of extracted resource is equivalent to 0.25 percent of the freight on board (FOB) value of fishmeal, considering the average US$ price for FOB/tonnes corresponding to the previous month. However, this valuation does not consider the environmental and social costs. Considering the current prices of fishmeal and fish oil and future projections for the markets for fishery products, an approach might be considered that takes into account the real cost of the resource.

The artisanal fleet consists of vessels weighing from 0.5 to 2 tonnes, from 2 to 5 tonnes and from 5 to 30 tonnes (Table 26). This fleet includes vessels that, with appropriate equipment (e.g. boxes with ice), can be used to supply anchoveta for direct human consumption.

An estimate of the maximum and minimum landings of anchoveta for human consumption can be obtained for the artisanal fleet located in Chimbote (Table 27).

TABLE 26
Characteristic of artisanal vessels

	Artisanal vessels			Artisanal fishers		
	Less than 2 tonnes	2 to 5 tonnes	More than 5 tonnes	Shipped	Non-shipped	Processors
Puerto de Santa	32	1	1	100	100	0
Coishco	50	15	0	130	4	20
Chimbote	445	50	50	1 300	0	260
El Dorado	320	0	0	300	100	0
Besique	7	0	10	25	25	0
Samanco	35	7	8	240	5	10
Los Chimus	30	2	0	75	20	2
Tortuga	200	20	0	200	600	12
Total	**1 119**	**95**	**69**	**2 370**	**854**	**304**

Source: PRODUCE (2001, 2002, 2003a, 2003b, 2004, 2005, 2006a)

TABLE 27
Projections for the capture of anchoveta for direct human consumption

	Artisanal vessels			Capacity		x 100 days		Landing	Potential landing		With ice	
	< 2 tonnes	2 to 5 tonnes	> 5 tonnes	Min	Max	Min	Max	Actual	Min	Max	Min	Max
Puerto de Santa	32	1	1	23	99	2 300	9 900	31	2 269	9 869	1 134	4 934
Coishco	50	15	0	55	175	5 500	17 500	4 956	544	12 544	272	6 272
Chimbote	445	50	50	573	2 640	57 250	264 000	2 826	54 424	261 174	27 212	130 587
El Dorado	320	0	0	160	640	16 000	64 000	866	15 134	63 134	7 567	31 567
Besique	7	0	10	54	314	5 350	31 400	42	5 308	31 358	2 654	15 679
Samanco	35	7	8	72	345	7 150	34 500	66	7 085	34 435	3 542	17 217
Los Chimus	30	2	0	19	70	1 900	7 000	140	1 760	6 860	880	3 430
Tortuga	200	20	0	140	500	14 000	50 000	1 055	12 945	48 945	6 473	24 473
Total	**1 119**	**95**	**69**	**1 095**	**4 783**	**109 450**	**478 300**	**9 982**	**99 468**	**468 318**	**49 734**	**234 159**

According to the capacity of the artisanal vessels, the annual landings could range from 100 000 to 400 000 tonnes generated by 100 days of labour per year. At the current levels of landing, they only capture around 10 000 tonnes of fish, including Peruvian banded croaker (*Paralonchurus peruanus*), doublelined tounguesole (*Paraplagusia bilineata*), sand grunt (*Pomadasys branickii*), silverside (*Odontotesthes regia*), humpback smooth-hound (*Mustelus whitneyi*), etc. To add a similar or larger quantity (>10 000 tonnes) of anchoveta for direct human consumption would require an additional hold capacity of between 40 000 and 200 000 m^3 due to the reduction of the capacity caused by the installation of preservation systems on board. Over the short term, in terms of the capacity of the artisanal fleet in the port of Chimbote, a supply of up to 200 000 tonnes of anchovy for human consumption would be assured.

Chimbote had landings of anchovy for direct human consumption on the order of 8 777 tonnes during the months of January, February and March of 2007. The average selling price to the processing plants ranges from US$80 to $200 per tonne. Ice that is used to preserve the anchovies on board the vessel is obtained in Chimbote at US$19.23 per tonne, although it is sometimes difficult to obtain.

8.2 Processing

Initially, canning companies in Chimbote produced fishmeal as a by-product. When world demand for fishmeal began to grow, dedicated fishmeal companies were installed, and now this industry is the most important fishing activity in the region.

The production of fishmeal is a continuous process that involves the separation of three components of the fish: solids, oil and liquids. Separation is achieved through various operations that involve cooking stages, pressing, drying and milling of fish. For this purpose, the anchovy is usually pumped together with water from the vessels through pipes into tanks or ponds. The pumped water is used as a means of transporting the fish and is treated by passing through a system that recovers the solids and fats and adds them to the production lines. Then the fish are transported to the cookers where, after a period of cooking, they are brought to the presses where the liquids are eliminated. One of the substances resulting is a pressed solid called "queque", which is sent to a dryer that reduces the humidity to around 10 percent. The dry material is powdered and transformed into meal that is packed in polypropylene sacks ready for dispatch.

The liquid resulting from the process goes to a centrifuge that separates the solid residuals, which in turn are sent to be part of the queque from the press. The liquid continues on to another centrifuge where the oil is separated from the watery fraction that contains soluble solids with a high protein content. The raw oil can be sold directly or passed on to a plant to be semi-refined or refined. Alternatively the line water might go through an evaporation process to reduce the water and to recover the solids, which are recycled into the fishmeal circuit.

This constitutes the typical process. However, in the last 20 years technological changes have been made that allow the production of a type of meal (prime or special meal) with greater protein content. Prime meal is made by replacing the vapor cookers with direct cooking, allowing the fish to be cooked at a lower temperature so that the protein is not degraded. If the fish are landed fresh, the protein content is even higher. Fishmeal with higher protein content command higher prices, so there is an incentive for the production of this type of meal. Countries like Norway and Chile have specialized in the production of these product types.

A source of contamination in the fishmeal reduction process is the water pumping system. As previously mentioned, the fish are transported by pumping them together with water from the vessels to the storage tanks. Centrifugal pumps that require from 2 to 3 tonnes of water for 1 tonne of fish are currently used, although new technology has been incorporated by some companies whereby vacuum pneumatic pumps are used with smaller volume of water to fish ratios. Until recently, the excess water was pumped into the sea and contaminated the bay. Now it is recovered and incorporated into the production circuit.

Vapor emissions are a source of contamination that is still not efficiently combated by environmental regulations. The drying of solids produces vapor containing fine particles that are emitted out the chimneys. The traditional technology is to collect the fine particles through filtration. A technological alternative is to use dryers that are different from those used for direct drying (i.e. dryers of vapor or of overheated air) and allow the resulting vapor to be recovered and to generate energy.

Ancash is the location of the largest number of fishmeal plants (i.e. 47 of the nation's 126 plants), as well as the greatest installed production capacity (i.e. 2 937 of the 8 938 tonnes/hour of total capacity). Most of these plants are old, dating back to the 1960s and 1970s. Only 12 of these plants produce special meals.

The plants in Chimbote belong to two types of companies: (i) local companies and (ii) companies composed of fishing groups and having operations in different ports. The managers of the local companies operate the smallest and oldest plants, and their knowledge of the business is rather empiric. These plants operate with relatively obsolete technology and, as a consequence, they exert a negative impact on the environment. They depend mainly on private operators to supply the raw materials they need, the reason why the fish supply can be very irregular or onerous.

The plants operated by fishing groups are larger due to the investment in modernization that has been carried out in the last decade. These plants operate with more modern technology, although in comparison with the plants operated by these groups in other ports, the plants in Chimbote are the oldest. In 2005, Áncash accounted for 41 percent of the standard installed production capacity and only 19 percent of the capacity for prime meal production. In contrast, another important province, Ica, accounted for 10 percent of the production capacity for standard fishmeal and 21 percent of the production capacity for prime meal. In Chimbote, the plants of the fishing groups work with the most modern technologies, which minimizes harmful effects on the environment.

Whether fishmeal manufacturers belong to big fishing groups or are locally managed, collaborative mechanisms have not been developed to solve shared problems (such as the improvement of port infrastructure), as during the fishing season competition is ferocious in securing landings for their plants.

The advanced technology used to produce fishmeal highlights the importance of the suppliers of technology in the modernization of this industry. Most of the suppliers of capital goods for fishmeal plants are from Norway and Denmark, and more recently, Chile. However, these technologies have been adapted to the particular needs of Peru.

The suppliers of capital goods are usually located in Lima and can assist with the orders of the fishmeal plants located in different ports. The technical personnel of the supplier install the equipment in the plants. Although generic equipment is sold, it usually has to be adapted to the specific characteristics of the fish species utilized and the condition in which it is supplied. The fishmeal manufacturers are very conservative about the equipment that they use and usually do not adopt new technologies unless they have been tested in other plants. This reduces the uptake speed for technological development in fish processing.

There are not many equipment suppliers in Chimbote; however, extensive repair workshops for maintenance have been established. These shops are quite heterogeneous and they compete on the basis of speed and price. The biggest shops are the best equipped, and they are also subcontracted by the companies selling capital goods to work on the installation of new equipment. Due to the large number of old plants in Chimbote, the fishing companies have opted to modernize and enlarge the plants rather than build new ones.

The diversity and improvisation of many of the workshop employees has inhibited the demand for qualified personnel. The manpower becomes qualified through "on the job" experience. However, several small training centers have opened, and about seven years ago a branch of the Servicio Nacional de Adiestramiento en Trabajo Industrial (SENATI) opened up a center of industrial training of high prestige. There are three universities in Chimbote; of these, the University of the Santa offers careers in fishery engineering, while the Private University of San Pedro offers a technical degree for workers involved in fishing activities (crew and machinists). According to equipment suppliers, the engineers in charge of the fish processing plants are very good at handling the equipment and standard technology but lack knowledge of recent advances.

Chimbote is also the main port where the industry producing canned products for direct human consumption is located. More than 50 percent of the landings for the canned fish industry are in Chimbote, and in the Department of Ancash there are 37 plants with an installed capacity of 113 432 boxes per shift, which is 59 percent of the national capacity. Two of the country's main fish processing companies, Southern Group and Hayduk, produce cans of anchoveta, among other products.

The manufacture of canned anchoveta starts with fresh anchoveta that is headed and gutted (HG), in type tube cut, and then packed in tin containers with different covering liquids that are selected according to the product line (oils, sauce, tomato cream, onion, smoky, etc.) being prepared. More specifically, the process involves the heading and gutting of the fish and then washing them in cold water or 3 percent brine for a short bleeding period. The fish are then brined in a saturated solution for 25 to 30 minutes. Following immersion, the fish are then rinsed in cold water and placed in containers, which are then pre-cooked in a continuous or static cooker in order to reduce the moisture content of the fish and to give them an appropriate texture. The fish are dosed with the covering liquid (e.g. an oil or sauce), the air is evacuated from the can and the can is closed and sterilized. The cooled cans are appropriately coded and then packed for storage in dry and ventilated atmospheres.

8.3 Marketing

Most fishmeal (around 94 percent) is sold to international markets, and only a small part is directed to the local market to satisfy the demands of the poultry, livestock and aquaculture industries. The broker is the agent that serves as intermediary between the Peruvian company's fishmeal producers and the big traders that sell to Europe (mainly German) and Asia (mainly Chinese traders). This type of trade is typically controlled by the buyers.

In recent years, the production of special fishmeal has favoured direct sales. In the trading of this type of meal, the product is shipped directly in containers to the end users. In the case of prime meal produced in Chimbote, due to transportation difficulties, it usually has to be carried to Lima for its dispatch to Callao, making the process more expensive. However, the biggest fishmeal companies are taking advantage of their large production volumes to market their products directly. For example, some of them have established representation offices in the destination markets.

Another important actor in the fishmeal trade is the customs agency, which is in charge of the logistics and procedures for dispatch. The customs agencies have offices in Chimbote. Because they also assist other economic sectors, the main offices are in Lima. In the case of the big fishing groups, the contracts are made directly in Lima.

The certification companies play an important role in the trade process, because they certify the quality and quantity of the product that is going abroad. A recent achievement of the Peruvian producers is that the weights and quality of fishmeal reported at the departure point are respected. The certification companies have their main offices in Lima but maintain offices in Chimbote.

An important aspect of the fishmeal trade is the use of warrants offered by the warehouses that provide the fish processing companies with access to short-term bank credit to assist with working capital. The warehouses generally belong to or are affiliated with the main commercial banks, and they have facilities in Chimbote and other fishing ports where the fishmeal is stored until its dispatch. For the larger companies, the storage contracts are generally made directly in Lima.

The limited infrastructure in the port of Chimbote has become an obstacle to the modernization of the entire Peruvian fishing industry. The facilities are too small for the volume of fishmeal dispatched. In the months of higher productivity, it takes the ships one week from time of arrival to load and weigh anchor. These delays and their consequent costs are generally assumed by the buyer who hires the marine transport.

Other sectors in the country have shown a greater increase in exports than the fisheries sector, the sector's growth having occurred due to the higher current product prices. The sustained demand from aquaculture has pushed up the prices of fishmeal and fish oil. For years, the price of a tonne of fishmeal was above US$500. In 2005, the price reached US$600/tonne, and in 2006 it reached US$1 000. For the same reason, the price of fish oil has more than doubled in the last 10 years. Peru once exported around 50 percent of its production; today almost all fish oil is exported.

The fishmeal is used as animal feed. It doesn't contain carbohydrates, but contains proteins with essential amino acids, minerals and fats having a high content of polyunsaturated fatty acids, especially EPA and DHA. Fishmeal is critical for development and growth during the early ages of fish, birds, pigs and sheep. The main competitor to fishmeal (in particular that of standard quality meal) is soy meal, which has 44 percent protein compared to the 64 percent protein content of standard fishmeal and the 72 percent content of super prime.

Two dynamic markets are recognized, that of Asia, with a growing demand mainly in China, Thailand and Japan; and Europe, whose market has been affected by the restriction of the European Union (EU) on the use of fishmeal for ruminants.

In 1993, aquaculture used 16 percent of the fishmeal produced and 29 percent of the fish oil produced. In 2004, it used nearly 34 percent of the fishmeal (and was the most important user) and 56 percent of the fish oil, showing a greater increase in use than the traditional users of fishmeal (for livestock, pigs and birds).

8.3.1 Perspectives on the commercialization of fishery products

Approximately 5 percent of the market of animal feeds is fishmeal, 21 percent is soy meal and the remainder is meals derived from other sources. Increasing numbers of Asian countries are members of the World Trade Organization (WTO), a situation which will facilitate trade on the international markets for fishery products. There are also important changes which promote commerce, such as the labelling and traceability of products, which reflect the growing importance to consumers of the environmental and social impacts of fishing and farming. Since 25 November 2005, the labels on animal feeds sold in the EU must specify all the ingredients.

The price of fish oil has shown an even more dramatic change than that of fishmeal, due to its use in aquaculture, and very minor use in products for human health as a source of omega-3 fatty acids. The demand has doubled the price of fish oil since the early 1990s. Peru currently exports all its fish oil.

8.3.2 The Chinese market

Fish has been an important food source in China for more than 3 000 years. In 2002, China displaced Thailand as the primary producer of fishery products in the world, with an average industry growth rate of 10 percent since the 1990s. It is also the main buyer of fishmeal. In a little more than one decade, fishmeal imports have multiplied 4.5 times. Chinese aquaculture production is expected to reach 30 million tonnes in 2010, constituting 65 percent of China's total fish production (FAO, 2007).

The International Food Policy Research Institute (IFPRI) projected an annual growth of 2.6 percent for foodfish production coming from the aquaculture sector from 1997 to 2020 (FAO, 2007), although this may be an underestimate. The average rate of growth of the aquaculture sector in China has been high; 17.1 percent from 1980 to 1990 and 33.8 percent from 1990 to 2000 (FAO, 2005). In China in 1992, aquaculture contributed 55.5 percent of the total fish production and in 2002, its contribution rose to 79.8 percent. In 1992 the annual per capita consumption of aquaculture products was 7.1 kg and in 2002, increased to 21.8 kg, an average yearly growth of 11.9 percent.

Peru is the major fishmeal suppler for China. In 2005, Peru exported 1 049 000 tonnes of fishmeal to China, while in 2004, the volume of fishmeal exported was 810 638 tonnes. It is estimated that most of the fishmeal imported by China is used for aquaculture.

8.3.3 The European market

In Europe, fish and molluscs are also traditionally farmed. At the moment, population growth in Europe is slower than in Asia, and the consumption of fish is already high and unlikely to increase drastically, except in the countries of the former Soviet Union. In recent years, the volume of fishmeal used in Europe has decreased. The restriction on the use of fishmeal in foods for ruminants has not been fully compensated by the increased use by aquaculture.

Contrary to Asia where carp is the main species farmed, in Europe the main species farmed are the salmon and the trout. Together they represent 80 percent of the volume of European aquaculture production. During the 1980s and 1990s, the rate of growth of European aquaculture was below the world average, with the exception of Norway. Salmon aquaculture will only grow in the United Kingdom, Ireland and Norway, countries where there is a plan to expand the aquaculture sector that includes species other than salmon (FAO, 2005). The plan recognizes environmental restrictions as the main limitation.

In November 2000, France and Germany prohibited the importation of fishmeal in response to the bovine spongiform encephalopathy (BSE) epidemic. Due to the death of more than a hundred cows caused by this illness and concerns about possible human health impacts, the EU's restriction on the inclusion of fishmeal in ruminant diets remains in force.

During the last decades, the increase in food consumption in developing countries has been characterized by an increase in the protein and vegetable content of diets and a reduction in the basic cereals. These changes have been due mainly to the effects of rapid urbanization, as well as changes in the distribution of foods. In several developing countries, such as some countries in Latin America, the rapid expansion of supermarkets has increasingly catered to the needs of all classes.

Dietary habits are also changing in the developed countries, where the basic dietary necessities are available and consumers desire a wider variety of foods in their diets. The average consumer also increasingly worries about his health and diet, and fish is often considered beneficial. Fish, as with other foods, is being transformed into value-added products through novel processing technology. In addition to traditional preparations, advances in food science, together with the improvement of refrigeration and the use of microwave ovens, have lead to the production of many "ready to eat" products that have boosted the overall growth of the fishery sector.

The reasons for the quick expansion of ready to eat products include changes occurring in social patterns such as greater participation of women in the work force, less frequent meals at home, the general decrease in the average size of families and an increase in the number of single-person homes. This has led to the need for simple, easy to cook foods ready to eat. Another trend is the increased importance of fresh, chilled fish. Improvements in packaging, reduced cost of air freight and increased transportation efficiency have created new opportunities for the sale of fresh fish.

These trends are expected to continue in the foreseeable future. The United Nations considers that the rate of world population growth will slow, but that fertility rates will be higher in the developing countries, whose combined populations will increase to approximately 83 percent of the world population by 2030 (from 79 percent in 2005) (FAO, 2007).

By 2030, 57 percent of the population of the developing countries will likely live in urban areas, compared with 43 percent in 2005. Population growth, increased per capita income, and the urbanization and diversification of diets will create an additional demand that will perpetuate the trend towards greater use of animal products in the diet.

In terms of supply, it is expected that capture fisheries will not increase significantly in overall volume and that aquaculture will continue to expand. FAO (2005) conducted studies on the future of capture fisheries and aquaculture with projections to 2015 and to 2020 and a comparison of both projections with the projections made in The State of World Fisheries and Aquaculture 2002 (SOFIA) (FAO, 2003). FAO's comparative study in one scenario matches demand and supply with the relative prices of the substitutes and constant real price, and then in another scenario modifies prices to adjust the demand to the supply. The study concludes that:

- With regard to demand, it is expected that growth will be more limited than that of the last two decades. By 2015, 50 million tonnes of fish and additional products will be required.
- Human consumption will increase due to population growth, as well as increased incomes.
- Fishmeal demand will show a net annual increase of 1.1 percent until 2010 and a 0.5 percent annual increase from 2010 to 2015.
- It is anticipated that there will be reduced demand in developed countries, while demand will increase in developing countries. Also, the amount of pelagic and demersal fish will decrease and that of freshwater fish will increase.
- The difference between supply and high demand will result in an increase in prices. In conclusion, this study foresees a supply deficit.

Similarly in 2002, it was considered that by 2010, 50 percent of fishmeal production and 75 percent of fish oil production would be used by aquaculture. In all the scenarios, the price of fishmeal and oil will increase. This will increase even further if catches from capture fisheries do not increase and the demands of the aquaculture sector increase above projected rates.

8.4 Anchoveta and its contribution to world food supply

Annual global fish production during the decade 1996–2005 fluctuated between 118 and 142 million tonnes (capture fisheries, 88–95 million tonnes and aquaculture (excluding aquatic plants), 27–48 million tonnes), of which 21–27 percent was used for non-food purposes and the remaining 73–79 percent was consumed mainly as fresh, frozen and canned products. Over the last ten years, annual per capita foodfish supply remained more or less static, ranging between 15.3 and 16.6 kg (FAO, 2003, 2005, 2007).

Calculations made on future fish requirements to 2015 estimate a world demand of between 100 and 120 million tonnes. The difference between existing supply and future demand will have to be covered by aquaculture and the use of underutilized resources that can be adapted for direct human consumption.

Globally, of the four most important pelagic species used in reduction processes for fishmeal, the anchoveta could find acceptance in those parts of the world that consume a great variety of pelagic fish and that have established markets for similar species. Nevertheless, an important condition for acceptance would be that the anchoveta products should be low priced within the framework of regional and worldwide policies that include commercial development and the elimination of barriers related mainly to tariff rates.

Prices of fish for human consumption are expected to increase during 2005 20015 because current supplies will not meet the projected demand. Any significant increase in the acceptance of small pelagics for human consumption in countries with nutritionally deficient populations or low fish consumption might possibly be offset by a decrease in buying power as the forecast is for slight economic development. Consumption of small pelagic fish such as anchoveta could be promoted in developed countries based on knowledge of the physiological benefits derived from the consumption of this type of fish. In addition, if the price of demersal fish increases considerably due to limited supplies, consumers of white fish may change to cheaper alternatives, as is presently the case.

With the development of appropriate technologies for the conversion of the anchoveta and other small pelagics to processed foods, the challenge to fight hunger and malnutrition of millions of people worldwide can be met. Considering that most of the world's fish stocks are fully exploited or overexploited, any increase in the fish supply will have to come from increased aquaculture production and the more rational use of capture fisheries resources. This means that a part of the landings of small pelagics that are used in fishmeal production will need to be redirected to direct human consumption.

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The use of wild fish as aquaculture feed and its effects on income and food for the poor and the undernourished

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SUMMARY

This report concerns the effects that the use of wild fish as feed for fish and crustaceans have on the poor and the undernourished worldwide. However, little information is available about the social and economic impacts of the use of fish as feed. Therefore, the analysis focuses on the direct effects on employment/income for the poor and the supply of fish as food for the food insecure. No attempt has been made to assess the long-term effects of changes in income or consumption of fish.

Most of today's shrimp culture and much of finfish culture make use of wild fish as feed in one form or another. Wild fish is obtained from feed fisheries, from bycatch and from artisanal feed fisheries. Most of it is supplied by feed fisheries in South America and northwestern Europe. While bycatch is a worldwide phenomenon, it is only in East Asia that bycatch provides significant quantities of fish for aquaculture. Artisanal feed fisheries (supplying fish to fishers's fish farms) occur in Asia and the Pacific region.

The poor in Europe, North America and sub-Saharan Africa do not obtain more or less cheap fish or more or less work because wild fish is used as aquaculture feed. In Africa, the reason is that feed fisheries are an exception and aquaculture is nascent and not much dependent on fish as feed. In Europe and North America, the practice has no direct consequences because of the low number of poor and undernourished in these two regions.

In Asia, the situation is different; the use of fish as feed benefits some of the poor and undernourished while the practice harms others. On the one hand, Asian shrimp and fish farmers, whose farms provide employment and income to large numbers of poor inhabitants, need more fishmeal (and fish oil) than local producers can supply. The difference is imported from producers mainly in South America and northwestern Europe. On the other hand, the practice of using Asian bycatch as raw material for fishmeal reduces local employment in fish processing and the amount of cheap fish available, particularly in China, Indonesia and Viet Nam.

Feed Fisheries

Wild fish, processed into fishmeal and fish oil and then incorporated into shrimp and fish feed, contributes substantially to employment. The high-quality fishmeal produced in South America and Europe is frequently used in Asian and South American shrimp culture. Employment in marine shrimp culture worldwide is probably equal to between 2.5 and 3 million man-years, and most of this employment is within reach of the poor, and not only for those from coastal areas. Fishmeal is an essential ingredient in shrimp feeds, and in the absence of high-quality fishmeal, the industry would be much reduced, with negative consequences also for the poor and undernourished.

Wild fish, in the form of fishmeal and fish oil, is present – albeit sometimes in very small amounts – in most manufactured fish feeds. For some species, like salmon and trout, fish protein is a prerequisite, while for others, such as carps and tilapias, it is a positive factor but not irreplaceable. Employment is substantial in the farming of finfish, worldwide probably of the order of 4 to 5 million man-years equivalent. Most of these workers earn an income on farms where fish as feed is not absolutely essential. However, on some farms – e.g. those raising salmonids or *Pangasius* – fish protein is essential, and employment for the poor and undernourished is provided on such farms in Chile (salmon) and Viet Nam (*Pangasius*) and on various marine finfish farms in China and other parts of Asia and the world.

By definition, feed fisheries do not contribute cheap fish used directly as human food. However, this does not imply that feed fisheries pre-empt the access of the poor to cheap fish. This does not occur, as feed fisheries obtain a price for their products that even the poor can afford. It is technically and economically feasible to treat species constituting feedfish as foodfish and market them to the poor, but this is seldom done at a significant scale. The obstacles that confront whoever attempts to do this on a large

scale in any of the major feed fisheries are economic; the need to preserve the fish and transport it sometimes long distances (e.g. from northern Europe or South America to Africa or Asia) make the resulting food too costly for the poor. It seems *a priori* that any large-scale attempt to provide feedfish as food to the poor and malnourished would need an international agreement that would make the required subsidies compatible with various international agreements concluded in the World Trade Organization (WTO).

However, for many feed-fish species that are acceptable also as food (herring, sardines, anchoveta) there has been a noticeable, albeit often slow, increase in the quantities used as food. This has come about as the food markets have been able to pay more than the fishmeal/oil manufacturers. Fisheries supplying feed to the capture-based culture of bluefin tuna may be the exception to this rule, given the very high prices paid by the Japanese market for the end product.

While most feed fisheries in South America and northern Europe have existed for several decades, some – particularly in northern Europe – by the early twenty-first century have been exploited beyond what the exploited feed-fish stocks can sustain in the long run. If continued mismanagement were to permanently reduce the level of production in these feed fisheries, it cannot be excluded that the poor in developing countries, particularly in Asia, would also suffer in terms of reduced employment possibilities in shrimp and fish farming.

The onshore employment generated by the fishmeal and fish oil industry is minimal. A modern fishmeal and fish oil plant is capital intensive. In comparison, a modern fish canning plant or shrimp processing facility is labour intensive. The work provided per tonne of fish handled in a fishmeal plant may generate only 1 to 2 percent of the work the same tonne of fish generates in modern food processing. This means that countries that have feed fisheries and the associated shore-based industries, but do not have shrimp or fish farming that consumes the fishmeal, have an interest in promoting local food industries and using part of the feedfish to do so. In poor regions, reducing/abolishing feed fisheries and associated shore-based facilities and replacing them with food fisheries (but maintaining the fishing level on the same species) and associated land-based industries could result in a real boost to local well-being.

Bycatch

In East Asia, there are clear indications that the use of bycatch as aquaculture feed has reduced the access of the poor to cheap fish. This report estimates (Huntington and Hasan, 2009) that the quantities of bycatch involved are of the order of 4 to 5 million tonnes per year. A large part of these quantities is landed in the coastal regions of China, Thailand and Viet Nam. Although it is unlikely that the entire quantity of bycatch used as fish feed would have been available as food for the poor, in the absence of its use in aquaculture, the local supplies of fish within economic reach of the local poor would have been substantially higher.

Shore-based handling of bycatch is labour intensive in East Asia, and this is so irrespective of whether the bycatch is used for food or for feed. However, the same groups of individuals may not be employed when the bycatch is used as food as when it is used as feed. In addition, the care needed to transform and maintain the fish as food is more than that needed to supply the bycatch as feed, and it seems likely that this is reflected in much higher levels of employment if bycatch is used as food.

Fisheries that generate bycatch are harmful to commercial fisheries. Most bycatch contains large amounts of immature commercial fish, and observers agree that fisheries for commercial species are impacted negatively. As this impact also occurs if the bycatch is discarded – and not brought to shore – trying to deal with this issue by prohibiting/limiting the use of bycatch once it is landed will be ineffective. The issue is best tackled as a fishery management problem, i.e. by modifying gear/fishing methods and/or by imposing time or area limitations on fishing.

There are several drawbacks associated with the use of wild fish as direct feed (e.g. pollution, risks of disease transmission, high feed conversion ratios). Government policy in China is, therefore, to encourage farmers to use pelleted feed instead of wild fish mixed in farm-made feeds. It is likely that this policy will be effective and the practice will subside, and not only in China.

Conclusions

Most feed fisheries do not subtract large amounts of cheap fish for the poor. Although aquaculture, by the use of feedfish, may reduce the supply of foodfish in the world, it creates employment opportunities for the poor and undernourished, particularly in Asia. However, a combination of intense fishing and environmental variability means that the sustainability of some feed fisheries continues to be under threat.

Seen from the perspective of the poor and the undernourished, the use of bycatch as aquaculture feed is a much more dubious practice. In regions adjacent to large fishing harbours, particularly in China, Thailand and Viet Nam, the practice does reduce the supply of cheap fish for the poor, and aquaculture does not compensate for this by generating more employment than what would have been available if the fish had been used for food. In fact, employment and income opportunities for the poor would increase considerably if the bycatch now used as feed could be used as food.

There is a concern that the use of fish as feed leads to less food and at times also to smaller incomes for the poor and undernourished. To date, governments have not effectively limited the practice of using fish as feed in order to safeguard a supply of cheap fish – either by limiting the use of small pelagic fish for the production of fishmeal and fish oil or by restricting the use of bycatch as animal feed and thereby increasing the supply of cheap fish as food.

One explanation for this lack of action may be that public policies aiming to alleviate poverty and improve the nutritional status of the poor give priority to creating employment for the poor. Employment (whether self-employed or salaried) has proven to be the best way to ensure poverty alleviation, which in turn leads to improved nutritional status. Providing cheap food (including fish) to people is more often part of schemes meant to support victims of natural or man-made disasters (including crop failures) than part of long-term strategies aiming to lift the poor out of poverty.

Also attempts to create employment are faced with obstacles. Governments that want to establish food industries based on feed fisheries have very limited possibilities to do so. One reason is international trade law; the international trade in fish and fish products means that economic and fiscal policies directed towards fish processing industries must respect both international agreements on international trade and the parameters guiding national economic and fiscal policies vis-à-vis national food industries.

1. THE ISSUE

During the last three decades, aquaculture has grown rapidly, expanding faster than most other food sectors. However, it was already apparent in the early 1990s that aquaculture faced a number of constraints. In particular, there was a concern and an international debate about the use of fish as feed[1] in aquaculture. There were those who argued that although not all cultured aquatic animals require substantial amounts of animal proteins in their feed, aquaculture growth may be slowed significantly as fish become a limiting resource.

In recent years, the focus of this discussion has widened to include the effects that the use of fish as feed has outside the aquaculture industry. In particular, the worldwide effort to reduce undernutrition and poverty has naturally brought aquaculture and its impacts on poverty and nutrition into focus. As a consequence, there is a widespread concern, both within governments and in civil society, that the use of fish as aquaculture feed has more negative than positive outcomes for the poor.

Also, some of those debating these issues maintain that irrespective of the amount of fish available, it is not ethically correct to use fish as feed for other fish or crustaceans if the fish used as feed can be sold as human food. This is particularly the case if carnivorous fish are exported from developing to developed countries; i.e. when wild fish that could have fed the poor are used as ingredients for "luxury" farmed fish.

Others are primarily concerned that a growing demand for fish as animal feed will lead to an increase in fishing effort on the wild fish stocks that are used as raw material in fishmeal production. In their view, such pressure would lead to an even higher overexploitation of the world's marine fish stocks, which could have far-reaching and negative consequences for the total supply of fish from the oceans and exacerbate a situation in which the marine global resources base seems to be shrinking.

In this paper, the debate is narrowed to reviewing the practice of using fish as aquaculture feed from the point of view of the poor and the undernourished. From that perspective, the principal arguments advanced against the use of wild fish as aquaculture feed are that the practice reduces either the income earning opportunities of the poor or their access to cheap fish now and possibly also in the future. There are four main arguments; three concern the supply of cheap fish and one concerns income earning possibilities:

(i) when fish are obtained through reduction fisheries and then converted into fishmeal, less fish are being provided as human food – and particularly for the poor – than would be the case if fish were not converted into fishmeal and then incorporated into industrially-made fish feeds used to grow fish and/or shrimp;

(ii) when fish are obtained from the bycatch of commercial fisheries or from surplus landings of small pelagic fisheries and then fed to cultured fish either directly or as fishmeal, the quantities of cheap fish normally accessible to the poor in port markets is reduced;

(iii) the growing use of fishmeal in fish feed contributes to unsustainable increases in fishing pressure in reduction fisheries and, in the end, to the demise of some wild fish resources, and, therefore, eventually to less fish being available for human consumption, which will affect the poor in particular;

[1] In this text, the expression "fish as food" refers to all fish that is destined for human consumption in fresh or processed form. "Fish as feed" refers to all fish used as feed for animals. Such fish may be provided to aquatic animals whole, minced, as one of the ingredients of farm-made fish/shrimp feeds (this feeding method is sometimes described as fish being provided as "direct feed") or in the form of fishmeal/fish oil used as an ingredient in industrially made fish/shrimp feeds (sometimes referred to by stating that the fish is used as "indirect feed"). "Industrial fisheries" or "reduction fisheries" are those fisheries that are specialized in providing fish to the fishmeal and fish oil industries.

(iv) when fish are obtained through reduction fisheries and converted into fishmeal, employment onshore is much below what it would be if the fish were destined for human consumption, and this affects the poor in particular, as much of the work to be done in preparing fish as food demands only low-skilled labour.

Three aspects of these arguments should be noted.

First, the focus of three of the four arguments is on the supply of cheap fish, and this is surprising, as it is generally recognized by those involved in public programmes pursuing poverty alleviation – and this will be discussed later in this paper – that poverty alleviation is achieved primarily when the poor obtain the opportunity to earn an income. Provision of cheap food is a less effective strategy, and one that poor societies have difficulties financing in the long run.

The second aspect to be noted is that the arguments do not take issue with the notion that aquaculture is beneficial for those who undertake it (they earn an income, especially important for the poor who need to buy food) and for those who eat fish or shellfish, the nutritional benefits of which are recognized universally. Rather, the argument against the use of fish as feed is that it is harmful for others than those directly involved or that harm appears with delay and then possibly also for those active in aquaculture.

The problem is that the market does not by itself correct the negative impacts experienced by third parties and they, most of the time, do not have the economic power to modify prevailing market forces in their favour. Therefore, they need to call on public authorities to intervene on their behalf. However, frequently, calls for redress are made not by those who suffer the negative outcomes of the market, who are often poor and lacking the know-how and access to media needed to make such calls, but by others.

The third aspect to note is that the first three arguments take as a given that more fish equals a better world, and a better world also for the poor. However, if it is agreed that for the poor a higher steady income is more important than cheap fish, then it is worth finding out if the use of fish as aquaculture feed leads to more and sustained income for the poor than any alternative use of the concerned fish. If this is so, actions that maintain such a source of income can be seen as poverty prevention and must be given due consideration.

2. INTRODUCTION

2.1 Purpose, limitations and method

This paper is intended to assist professionals working with poverty prevention and undernutrition to understand the potential that aquaculture provides for achieving sustainable solutions to poverty and malnutrition, while focusing on the role that aquaculture operations that use fish as feed may have in this context. Its purpose is not to provide standard solutions, but rather to indicate strategies that may be used to undertake the analysis needed to identify and formulate equitable and sustainable solutions to issues created by the use of wild fish as aquaculture feed.

The paper also identifies, and where possible, quantifies the issues involved. Although there are lacunae in the knowledge of the amount of fish used as feed, the order of magnitude is now known (Huntington and Hasan, 2009). Paradoxically, there is less information available about the number of individuals directly affected by the use of fish as feed. In order to develop a quantitative estimate, the paper resorts to extrapolations using available data to provide some initial estimates of the numbers of people involved. These estimates need to be verified by surveys in randomly selected relevant locations.

The paper reviews alternatives for dealing with negative outcomes of using fish and feed. As most economies today rely on some form of market economy, the negative outcomes occur in spite of or because of the way the market economy works. Remedies are thus possible only if it is accepted that some kind of interference with the market forces is necessary. In the text, an attempt is made to be explicit about the nature of such interventions.

Aquaculture that uses fish as feed may cause pollution or transmit illnesses. Such effects will also affect the poor and undernourished. No attempt is made to estimate these consequences in this paper.

Neither does the paper attempt to provide any information on "second round" effects. An example of a positive second round effect would be increased schooling for children of the poor who earn a living in aquaculture and its consequences. Conversely, however, the negative outcomes of second round effects can be dramatic. The long-term consequences of child undernurished are dramatic and tragic at the level of the individual and also affect economic growth. It is recognized that it is unrealistic to decide in principle about how to deal with fish as feed without including second-round effects in the information base for such a decision.

It is important to understand not only the current extent and nature of the problem, but to identify how it is has come about and formulate best possible projections of future trends. What are the forces that maintain today's situation? These forces should preferably be co-opted into any future solution of the problem. They must, therefore, be known and are a required part of the problem description. Although this paper is not intended to identify and prescribe solutions to the "negative outcomes" associated with the use of wild fish as aquaculture feed, most likely it will be useful for later research if the outlines of possible solutions could orient the problem description.

"Negative outcomes" are experienced over time by the poor and food insecure. They either see an already difficult situation degenerate or experience that they have missed an opportunity to improve their situation. In both cases, the "negative outcome" is defined by a comparison of what has actually happened with what is believed could have happened. The study of this kind of problem thus involves comparing actual facts with an expectation of what could have happened – an imagined situation.

The first task is to establish a sequence of facts that documents the use of wild fish as aquaculture feed today and provides salient information on how this practice had developed and spread. To this information should be added information about the situation of those poor and food insecure who might be or might have been affected by the practice of using fish as feed.

Once that is done, the second task in this problem identification is to attempt to establish what most likely would have happened had not the practice of using wild fish as aquaculture feed developed and become common. This involves speculation, preferably drawing on information about locations where wild fish have not been used as aquaculture feed.

This speculation starts by providing a tentative answer to the question "what would have been the situation for the "target group of poor" if aquaculture had not used wild fish as feed?" By comparing this situation with the situation as it actually developed, an idea can be generated about the magnitude and the nature of what would have happened if fish had not been used as feed in aquaculture. In particular, one can then ask "how do the benefits (in terms of more cheap fish) stemming from a "no fish as feed aquaculture" for the poor and undernourished compare with a possible loss of income (and associated effects) for those poor who obtain a living through shrimp or finfish culture?"[2]

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[2] But the analytical problems do not end here. Assuming that yes indeed, there would be benefits for the poor (likely some immediate and some long term) from stopping the use of wild fish as feed, is there a linear relationship between cause and effect? Put simply: does a little use of fish as feed cause a small problem and a large use of fish as feed cause a correspondingly large problem? Or is some level of use of fish as feed without harm? (Does the harm only appear after some level of use?)

Other papers in this fisheries technical paper provide ample information on the nature and extent of the use of wild fish as feed in aquaculture worldwide. Data on culture technologies, on the status of fish stocks and on environmental impacts dominate. However, there is little data available about the human dimensions in the use of wild fish as feed. This makes an analysis of the impact on the poor and food insecure extremely difficult.

Given the shortage of data worldwide – particularly that needed to identify social consequences – this report is limited to attempting to develop global quantitative estimates in two areas; the first concerns the "food impact" and the second, the "income impact".

The paper will develop an idea of the "food impact" by estimating the number of food insecure who might have benefited if fish had been used as food instead of as feed. This will be done simply by considering the potential supply per caput (live-weight equivalent) that fish used as feed could have provided if supplied as food. It will also develop an idea of the "income impact" by estimating the number of poor who earn an income under the present practice and comparing it with what the number could have been had fish not been used as aquaculture feed.

2.2 The report

As the focus of this analysis is on the poor and the food insecure, the report starts with a brief section about them and about the nature of the strategies used to ameliorate their situation. This is followed by a brief and general review of the impacts of aquaculture on food production and poverty. An analysis of the impacts on the poor and undernourished of the use of fish as feed in aquaculture then follows. The analysis is divided into two parts. The first concerns the use of fish obtained in reduction fisheries, while the second looks at the food and income impacts of using fish obtained from bycatches and/or from excess landings of small pelagic species.

The paper ends with a discussion of policies that might be able to address the negative consequences of using wild fish as aquaculture feed while, simultaneously, not harming the poor and undernourished.

3. POVERTY AND FOOD SECURITY

Following the Second World War, the number of sovereign states grew as colonies became independent. The international community soon realized that several of the newly formed nations needed technical and economic aid if their populations were to escape poverty and food insecurity. However, progress was uneven during the following decades and in 1996, the international community, assembled at the FAO headquarters in Rome, agreed to increase and improve these efforts with the aim of halving the number of the world's hungry by 2015[3].

[3] The World Food Summit (WFS) held in Rome in November 1996 at which Heads of State and Government, or their representatives, adopted the Rome Declaration on World Food Security and the WFS Plan of Action and pledged their political will and their common and national commitment to achieving food security for all and to an ongoing effort to eradicate hunger in all countries, with an immediate view to reducing the number of undernourished people to half their level no later than 2015. (Declaration of the World Food Summit: 5 years later).

3.1 The poor and the food insecure

The world's poor[4] outnumber[5] the food insecure[6] and undernourished. In 2004–2005, there were about 1.4 billion poor (World Bank and Collins, 2009) and about 830 million (FAO, 2008a) undernourished. With the exception of a few countries in North Africa and the Near East, most countries report that their poor are more numerous than their undernourished. It seems to be the case generally that the undernourished are also poor.

In sub-Saharan Africa about 50 percent of the total population is poor; in South Asia, this is true for about one-third of the population; in East Asia and the Pacific, the proportion of poor has now fallen to below 20 percent; while in Latin America and the Caribbean, it is about 8 percent for the region as a whole.

During the period from 2003 to 2005, more than 35 percent of the population in 17 countries was undernourished. Sixteen of these countries were in sub-Saharan Africa, Haiti being the only country not from that region. The populations of oil-producing countries in Africa were better fed. In Asia, India reported to have about 21 percent of its population underfed; Pakistan, 23 percent; Bangladesh, 27 percent; and China, about 10 percent.

According to the United Nations Hunger Task Force, about half of the world's hungry are smallholders[7]; a fifth are landless; and a tenth are agropastoralists, fisherfolk and forest users; the remaining fifth live in urban areas (World Bank, 2007). The agropastoralists, fisherfolk and forest users would thus number about 80 to 85 million individuals. Full-time and half-time fishers and aquaculturists were believed to number about 43.5 million in 2006 (FAO, 2009a). Providing that each fisher sustains at least two more individuals (children and old), the number of individuals directly supported by fishing and aquaculture would be in the order of 100 million. These figures indicate that, in fact, not all fisherfolk (including aquaculturists) and their families belong to the category of the poor.

3.2 Combating poverty and food insecurity

Combating poverty means not only helping the poor out of their condition of poverty (poverty reduction), but also preventing poverty from spreading to new population groups or worsening for those who already are poor (poverty prevention). Poverty is reduced when the poor generate income and wealth in the form of capital[8]. Preventing poverty is usually achieved by reducing the risks facing the poor and/or by improving safety net[9] functions.

A large portion of the rural poor are smallholders[10], but all smallholders are not poor. Those people concerned with poverty reduction in rural areas generally agree

[4] There are several definitions of poverty. It is generally accepted that poverty consists not only of low income and little wealth, but also a lack of the material requirements needed to meet essential human needs such as health and education.

[5] The most common measuring rod for poverty seems to the World Bank's estimate that affirms that those who have an income below US$1.25/day (Purchasing Power Parity) live in poverty. That definition is used in this paper.

[6] The commonly accepted definition of food security is: "When all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 2002).

[7] Defined as farms of 2 ha or less.

[8] Those concerned with poverty reduction often distinguish between several different types of capital, all important for those who experience poverty. Among these forms are human, social, natural, physical and financial capital (ADB, 2005).

[9] "Safety net" is an umbrella term for various types of programmes aimed at assisting vulnerable population groups. Safety nets include food distribution programmes, cash transfer schemes, various feeding programmes and employment schemes (FAO, 2008a).

[10] About two-thirds of the 3 billion rural people in the world live off the income generated by farmers managing some 500 million small farms of less than 2 ha each (FAO, 2008a).

that improved production and productivity of smallholders is essential, and studies of poverty reduction have revealed that agricultural growth is up to four times more effective in reducing poverty than is economic growth in other sectors of the economy (FAO, 2008a).

Although this finding is not reported as directly applicable to aquaculture, there is reason to believe that aquaculture growth also is effective in reducing poverty. There are two reasons: on the one hand, and as further described below, rural, small-scale aquaculture operations usually generate cash for their owners, which is indispensable for the poor as they buy food both in rural and urban areas, and on the other hand, the economic similarities between rural aquaculture and agriculture are such that the World Bank, in its analysis of the rural economy, classifies aquaculture as part of agriculture (World Bank, 2007).

Given that most of the food insecure are also poor, the actions meant to deal with the problems of poverty will also, in all likelihood, help deal with the problems of malnutrition and food insecurity. However, malnutrition is debilitating and, therefore, reduces the income earning possibilities of those who are undernourished. Thus, any action that leads to better nutrition in the end also combats poverty.

Most of the food insecure live in rural areas where most of the food is produced, yet they are net food buyers rather than sellers. Poverty constrains their access to food in the marketplace.

Therefore, agriculture's ability to generate income for the poor, particularly women, is more important for food security than its ability to increase local food supplies (World Bank, 2007).

This means that the fight against malnutrition is tightly linked to the fight against poverty: if poverty is reduced – or its spread prevented – this generally leads also to a concurrent improvement in nutrition for the poor.

3.3 Food insecurity, malnutrition and fish

Food insecurity has many different forms. The chronically food insecure never have enough to eat. Those who are seasonally food insecure fall below adequate consumption levels in the lean season, while the transitory food insecure fall below the adequate consumption threshold as a result of an economic or natural shock such as a drought, sometimes with long-lasting consequences (World Bank, 2007).

While fish is a good source of minerals, vitamins, fatty acids and animal proteins, it generally does not provide calories in sufficient quantities for those who regularly carry out heavy manual labour. It has been long recognized that those living in prosperous fishing communities must trade – fish does not provide them with sufficient supplies of all essential nutrients (Kurien, 2005).

Fish, however, are important for the micronutrients they contain. Some essential nutrients are not found or are found in very small quantities in many of the staples consumed in low-income countries. These nutrients – iron, iodine, zinc, calcium, vitamin A and vitamin C – are found in fish or vegetables. Marine fish also contribute fatty acids that are necessary for the development of the brain and the body (Bené, Macfadyen and Allison, 2007). The consumption of small fish is of particular importance, as these are often consumed whole, which means that nutrients available in the eyes, viscera and skeleton are used. Whereas big and small fish of the same species contain the same amount of protein per unit weight, small fish provide relatively higher amounts of minerals in diets because they are consumed whole, including the bones (Bené, Macfadyen and Allison, 2007). Fatty fish, in particular, are an extremely rich source of essential fatty acids, including omega-3 polyunsaturated fatty acids (PUFAs), so important for normal growth and mental development, especially during pregnancy and early childhood (FAO, 2003).

Fish are important as a source of animal protein, especially where other sources of such protein are scarce. Fish protein accounts for about 18 percent of the animal protein intake in developing countries (Laurenti, 2007). However, the differences among countries and among regions within countries are large. In many communities in small island states, in Africa south of the Sahara and in Asia, the contribution of fish to nutrition is essential. Fish proteins can provide up to 50 percent and more of the total supply of animal proteins.

Increasing the availability of fish in the diet increases palatability and leads to increased consumption of a range of foods, thereby improving overall food and nutrient intakes (FAO, 2003).

4. AQUACULTURE: THE CREATION OF INCOME AND FOOD

4.1 Introduction

Is aquaculture good or bad for the poor and the food insecure? Although most fishery and aquaculture professionals would probably answer "good" to this question, there is no one answer. There are too many different forms of aquaculture and too much variation in the situation of the poor and food insecure for a single answer to be possible. In fact, even if the question is narrowed down to a particular industry (e.g. tilapia farming in Central America, shrimp farming in Thailand), observers will differ about effects.

On the one hand, there are several effects of aquaculture that are positive for the poor and the food insecure. The industry generates income and produces nutritious food. On the other hand, the pursuit of aquaculture also creates externalities (usually effective through alterations of the environment) and undesirable market outcomes. In this paper "undesirable outcomes" are those that cause either reduced incomes for the poor or a reduced supply of fish or cheap foods containing animal proteins.

However, there seems to be a consensus among those familiar with the poor and food insecure in Southeast Asia where family operated aquaculture activities are common and well-established that their contribution to household income and food security overshadows the negative outcomes that this type of aquaculture may generate (see Edwards, 1999; Tung, 2000; Prowse and Admos, 2007). This section of the paper will consider those features of aquaculture that are positive for the poor and the food insecure. Negative aspects will be reviewed later.

Worldwide aquaculture production (not including plants) at the producer level was estimated to have had a value of about US$85.9 billion in 2006 (FAO, 2009a). A significant share of this accrued to small-scale producers and their employees in Asian aquaculture. As aquaculture continues to expand, it may become a stronger force for lifting rural households out of poverty than small-scale fisheries[11].

Commercial, large-scale, aquaculture of shrimp, salmon, tilapia, catfish, grouper, carps, etc, also generates employment (in production, processing and marketing) and provides income in rural and urban areas. Tax revenues from commercial aquaculture enterprises and foreign exchange earnings allow governments to invest in sectors that may add to the achievement of food security (FAO, 2003).

Aquaculture is now providing about half of the fish consumed by the human population worldwide (FAO, 2009a). As consumers in developed countries account for only about 30 percent of the total world fish consumption (Laurenti, 2007), it is evident that aquaculture supplies a very important part of the fish consumed in the developing world, but almost exclusively in Asia.

[11] As capture fishery production stagnates, the role of small-scale fisheries in poverty alleviation will probably take the shape of poverty prevention (Bené, Macfadyen and Allison, 2007) rather than poverty reduction, at least as long as substantive numbers of alternative employment opportunities do not develop for capture fishers.

4.2 Aquaculture and income for the poor

In Asia, rural aquaculture – managed as household activities or as enterprises – can contribute significantly to income for the rural poor[12]. Worldwide, fish – whether produced through capture fisheries[13] or aquaculture – are frequently seen as cash crop, even in the poorest of households. Studies in various developing countries (e.g. China and Viet Nam) have shown that 80–100 percent of the aquaculture products from rural farm households are marketed (FAO, 2003). This suggests that aquaculture is an activity that generates not only food for rural households but above all, cash and thus is an important direct and indirect source of food security.

In many countries, the average market prices of fish are lower than those of other animal products such as chicken, pork and red meat. Especially in Asia, the low prices of aquaculture commodities such as carps and tilapias make fish highly accessible to even the poorest segments of the population. Poor people in land-locked countries such as Nepal and Laos largely depend on freshwater aquaculture for their fish (FAO, 2003).

The average annual per capita income of people employed full-time in the fisheries sector (including aquaculture) in China was about US$540 in 1999, which was more than double that of rural terrestrial farmers. In Southeast Asian countries such as Cambodia, Thailand and Indonesia, a similar situation can be found; farmers engaged in aquaculture generally generate higher household incomes than those who are not. In Viet Nam, 50 percent of the farmers involved in aquaculture consider it as their main source of income and derive on average 75 percent of their households' income from it. Catfish and shrimp culture specifically have, in recent years, provided an average annual household income of over US$1 000, which is significantly more than that generated by comparable agricultural practices (FAO, 2003).

Suitable technology, know-how and inputs must be available for rural aquaculture to be a reality. However, aquaculture is able to function as an activity that generates cash only if aquaculturists find ways of marketing their produce. Thus, efficient markets are essential. Unless such markets exist or are developed, fishers and aquaculturists will not be able to rely on sales of fish as a source of livelihood.

4.3 Aquaculture and nutrition for the poor and food insecure

In many countries, fish is an important component of the diet and in some, rural aquaculture is an important source of supply. The main factor behind the high demand for staple foodfish (in particular, inexpensive farmed freshwater fish species feeding low on the aquatic food chain) within most developing countries is their greater affordability to the poorer segments of the community (FAO, 2003).

A consumption survey in Bangladesh confirmed that fish is an important part of the diet for most people in rural areas. Fish were eaten in small amounts and with great frequency in nearly all households. Changes in fish supply available for consumption therefore, affect the diets of most people in the country, including the poor households (Roos, Thilsted and Islam, 2003).

Aquaculture producers have, through various technological interventions, achieved important productivity gains and cost reductions. Over time this has led to a decrease in prices, despite short-term intervals of significant price swings. The prices of fishery products did not increase as a result of the growing international demand, instead they showed a decreasing trend (FAO, 2003). Studies seem to indicate two important

[12] "Small-scale aquaculture is a very positive poverty reduction technology if it can be developed and integrated with participatory planning approaches, institutional and credit supports" (Tung, 2000).

[13] Research in the Lake Chad area has shown that the poorest households around the lake consume a lower proportion of their catch than the better-off households and instead sell most of their fish in order to be able to purchase cheaper foodstuffs – in the region, mainly millets (Bené, Macfadyen and Allison, 2007).

characteristics. First, that indeed aquaculture is usually an effective rural activity as a source of income. As income is such a key factor in elimination of poverty, this seems to be extremely important. The second fact is that rural fish farming, where it is a long established tradition, has been and continues to be a source of food that even the lower income groups can afford to buy.

5. USE OF WILD FISH AS FEED: EFFECTS ON FOOD AND INCOME

Up to this point, the paper has provided a brief review of poverty, food insecurity, the interdependence of these conditions and the extent to which aquaculture alleviates poverty and improves food security. The effects of aquaculture on poverty and food security are sometimes large, like those reported for freshwater fish culture in many parts of Asia, sometimes smaller, as is the case in Africa and the Americas. However, there is little doubt that when undertaken in areas where a large part of the population is poor and food insecure, aquaculture will have positive effects on food security and help individuals exit poverty. In economically well-off regions, aquaculture contributes to economic growth. Nevertheless, climatic and economic conditions are not favourable everywhere, and in some regions the initiation and growth of aquaculture has been dependent on provision of public subsidies.

This section reports on investigations of the effects that might stem from the practice of using wild fish (and other aquatic animals) as feed for cultured fish and crustaceans. When these practices reduce income for the poor or decrease their food supplies, then aquaculture activities that employ wild fish as feed can be said to cause negative or undesirable outcomes.

5.1 Use of bycatch as aquaculture feed: impacts on food and income of the poor

Globally, the use of wild fish as direct feed is not common. It occurs mainly in Asia, but is only infrequently practiced elsewhere[14] and with the exception of fattening of bluefin tuna, it is virtually absent from aquaculture as practiced in Africa, Europe and the Americas.

In Asia, the practice is common mostly in East Asia. It has hardly spread to India, Pakistan, Sri Lanka or the Pacific Islands. For countries in which freshwater fisheries predominate, the picture is mixed. There seems to be relatively little feeding with fish in Bangladesh and Laos, while the practice is widespread in Cambodia (Nam *et al.*, 2005), where aquaculture production reached 34 000 tonnes in 2006 (FAO, 2008b).

In East Asia, virtually all of the fish given as feed to fish and crustaceans originates in bycatch. However, bycatch has many uses. Some of it is sold directly as food, some is cured and some is used as raw material for surimi and other modern, ready-to-eat products. Also, some of the bycatch is used as raw material for fishmeal production.

There are reports (De Silva and Turchini, 2009) that fish farmers in Asia go fishing to provide feeds to their aquaculture activities. However, although in some areas large number of farmers are involved, if measured in terms of volumes of fish caught and supplied as feed, this practice is not significant in the Asian context.

In East and Southeast Asia, most of the fish used directly[15] as aquaculture feed has its origin in bycatch, often from trawl fisheries. In the context of this analysis, this fact raises four questions:

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[14] E.g. small-scale fattening of crabs in Africa.

[15] In this paper, the term “directly as feed”, or “direct feed” when applied to wild fish, refers to all practices, with one exception, that result in the fish being used as feed for cultured aquatic animals. The exception is the practice of converting fish to fishmeal that is then incorporated, in an industrial process, in the manufacture of fish or shrimp feed, a practice referred to as using wild fish as “indirect feed” for aquaculture.

(i) Does the fact that bycatch is used as aquaculture feed cause a decline in the availability of fish and possibly, food security for a section of the population in the region where landings occur?
(ii) Does the practice lead to less work and, therefore, less income for the poor and food insecure?
(iii) Does the practice lead to unsustainable fishing pressures that in the end may threaten fish supplies from wild fisheries?
(iv) Does the practice cause pollution and/or threaten human health?

A priori, it is most unlikely that the answer to any one of these questions will be the same for all of East and Southeast Asia. The situation will vary from region to region.

5.1.1 Employment impact: global aspects

Handling of bycatch generates employment on board vessels. Once landed, the catch will again be sorted, preserved, transported and marketed. At sea, crew sort and store the catch into various categories of catch and bycatch. This must be done irrespective of the final use of the bycatch, so the amount of work involved is not much influenced by whether the bycatch is used as aquaculture feed or not.

On land the situation is different; but almost irrespective of the final destination of the bycatch, much employment is generated. Fishmeal manufacturing is the exception, as it provides little employment[16]. Even if many fishmeal plants in East Asia are not the most modern (and do not separate meal from oil[17]), the labour intensity is comparatively low. But, as mentioned, fishmeal is only one of the uses of bycatch in Asia[18], and aquaculture feed is not the principal use for the low-quality meal produced (often used for livestock and poultry). As a result, relatively few workers find employment in fishmeal plants that produce fishmeal from bycatch that is later incorporated into aquaculture feed.

It is fairly recent that the volume of bycatch and its use has drawn attention in Asia. While some countries have detailed reports, others have close to no data. As comprehensive data are lacking, discussions of the Asian situation rely on estimates[19]. This report affirms that the annual amount of fish used as direct aquaculture feed in the Asia -Pacific region in 2004 was in the range of 2.47 to 3.88 million tonnes (De Silva and Turchini, 2009). This feed was used primarily in the culture of marine finfish, freshwater catfish and for crab fattening. Although not quantified, a small amount of trash fish is used for lobster fattening and some for mollusc culture. The total output was in the order of 1.54 million tonnes[20] of fish, which may have generated an

[16] In Peru, for each man-year of labour about 310 tonnes of fishmeal are produced (Sánchez Durand and Gallo Seminario, 2009). This can also be expressed by saying that each 1 000 tonnes of fish (in the Peruvian case – anchoveta) provide only 0.77 man-years of employment in the reduction industry proper.

[17] Edwards, Le and Allan (2004) reported that in Viet Nam few fishmeal plants separate fish oil from fishmeal. Of the 119 fishmeal plants found in Thailand in 2003, only 13 separated fish oil from fishmeal (Thongrod, 2005).

[18] But there are exceptions. In Thailand, almost all "trash fish" becomes fishmeal and about one-quarter of "low-value foodfish" is used as raw material for fishmeal and one quarter as direct aquaculture feed (Khemakorn *et al.*, 2005).

[19] While the historical information for Thailand is comprehensive (Thongrod, 2005), information about bycatches in India is "a matter of individual opinion rather then a verifiable fact" (Salagrama, 1998). Similarly, information on bycatches in Bangladesh is not detailed, and only global estimates are available (Ahamad, 2005).

[20] Finfish production was 1.02 million tonnes in 2004; 0.4 million tonnes of freshwater catfish and 0.12 million tonnes of crabs were produced (De Silva and Turchini, 2009).

employment of 0.27 million man-years (0.175 man-years/tonne[21]), out of which the low-skilled would be a majority, presumably in the order of 80 percent or more. To this employment should be added that of individuals not employed on fish farms but who are employed in bringing fish to farms, in manufacturing farm-made feeds or in bringing the product to export markets. No information is available on how much labour is used in these activities. A liberal assumption would seem to be that it equals the work on the farm. If so, the total employment generated would be on the order of 0.5 million man-years.

If not used in fish farming, the bycatch could, at best, have been used for production of food. Such activities are labour intensive. The employment generated in post-harvest activities (wet market, cured products and modern surimi type production) averages 1.5 man-years per tonne of fish (landed weight)[22]. This means that hypothetically between 8.1 and 10.2 million individuals, mostly unskilled, could have been employed by the fish processing industry. Even if a large degree of uncertainty surrounds these numbers, it seems clear that in Asia the use of fish as aquaculture feed, although creating substantive employment (above all, in the culture of marine fish), would generate a much larger employment had it been possible to sell the bycatch as food.

5.1.2 Food impacts, global aspects

The potential food impact of 5.4 to 6.8 million tonnes of bycatch used as aquaculture feed would have been large in 2004. It would have been sufficient to provide 540 to 680 million people with an additional 10 kg of fish per person per year or, in the latter case, it would have been sufficient to augment world annual per capita fish consumption by between 6 and 7 percent[23]. Such an increase would have made a

[21] There seem to be few published references to the labour intensity on shrimp farms or in aquaculture generally. It is reported for Madagascar (N. Hishamunda, FAO, personal communication, 2009) that the shrimp culture industry has generated employment for about 4 000 to 5 000 persons. With an output of 6 000 to 8 000 tonnes of shrimp per year, this gives an employment "generation" per tonne produced of between 0.500 and 0.833. Given the low living standards in Madagascar and the modernity of the shrimp culture plants, the mechanization is higher on these farms than in most small shrimp farms in India, for example. Thus using an "employment" multiplier of 0.75 is probably an underestimate of the employment generated in Asian marine shrimp culture. Given the work involved in transporting, handling and distributing feed based on bycatch, it would seem, *a priori,* that the employment generation in marine finfish culture is at least as high, and probably higher, than that reported for shrimp culture. However, global statistics do not support this thesis. In 2006, about 8.1 million aquaculturists in Asia (FAO, 2009a) produced 46.3 million tonnes of aquaculture output, not including algae (Lymer *et al.*, 2008), which gives an "employment multiplier" of 0.175. An Asian Development Bank (ADB) review of aquaculture projects arrived at similar multipliers for tilapia farming in Bangladesh and the Philippines, 0.23 and 0.17 for the pond and cage cultures in the Philippines and 0.23 for pond culture in Bangladesh (ADB, 2005).

[22] Scientific studies of employment in artisanal fish processing and marketing in artisanal communities seem to be lacking (Ward *et al.,* 2004; Kébé, 2008). However, it is common in the fisheries literature to find affirmations to the effect that each fisher provides work for two to four individuals further down the line in post-harvest activities. Are these full-time or part-time activities? In Asia, the average fisher may be producing an average of 2 to 3 tonnes per year. This would imply an employment generation of between 0.66 and 2.0 man-years in these post-harvest activities per tonne of fish landed. In Asia, the productivity of the average fisher is low. FAO (Lymer *et al.*, 2008) reports it to have been on the order of 1.3 tonnes per fisher per year in 2006. *A priori,* it seems unlikely that this amount could provide employment for up to four individuals in post-harvest activities. Given the economic growth that has taken place in South and East Asia during the last decades, productivity also in post-harvest activities is likely to have improved. This analysis is based on the assumption that 1.3 tonnes of fish landed provides 2 man-years of work in post-harvest activities. This means that each tonne of fish will generate on average 1.5 man-years of work.

[23] Such an increase would have been ideal from the nutritional point of view. However, it should be recognized that it would be judged as ideal from an overall perspective. It is mostly the case that bycatch contains a large proportion of juveniles of commercial species (or specimens of endangered species). Therefore, public policies will, probably irrespective of the use of bycatch, continue to aim for a reduction of bycatch. In addition, it should be pointed out that although most bycatch is edible, local preferences may preclude some of it being demanded as food.

dramatic improvement in the nutritional status of the poor if the fish could have been channelled to them. In Asia and the Pacific, the number of undernourished in 2003–2005 was estimated to have been 542 million. If the bycatch could have reached them, they would each have had about 8.3 kg of extra fish annually.

Will aquaculture production, in part through the use of feed produced from the use of 5.4 to 6.8 million tonnes of bycatch, somehow compensate for this loss? The species (groupers, snappers, cobia, etc.) that are fed directly with this bycatch are generally priced at levels that preclude their regular purchase by the poor. Neither does it seem reasonable to argue that the production of these fish – generally sold in overseas markets – will somehow cause other species to become cheaper in the localities where the poor and undernourished in Asia do their food purchases, and that they, therefore, somewhat benefit nutritionally from this form of aquaculture. Thus, it is probably not reasonable to argue that the aquaculture production achieved by using bycatch as feed somehow offsets the food "loss" that use of fish as direct aquaculture feed can be said to cause in Asia.

However, the bycatch that is now used as aquaculture feed is brought to shore only in some regions of Asia. Most of the bycatch used for aquaculture feed is landed in China, Thailand and Viet Nam. Together these countries accounted for at least 90 percent of the bycatch used as direct aquaculture feed in 2002 (Stobutzki *et al*., 2005). Although bycatches in India are substantial, only very small amounts are used for aquaculture feed. In Bangladesh, most bycatch seems to be discarded at sea. In Malaysia, the absolute quantities of bycatch used are relatively small, 43 000 tonnes in 2002, but they are large on a per capita basis. In Indonesia, the Philippines and Thailand, the amounts used are small on a per capita basis.

In the regions where bycatches are landed, they represent an opportunity for the local poor and undernourished to obtain cheap fish when the bycatch is offered for sale in wet fish markets. But as soon as preservation and/or transport is needed to bring the fish to the poor, the price of the fish increases, and soon the very poor will not have the means to purchase it. It does not seem reasonable to argue that alternative food-fish markets for bycatch that is now used as aquaculture feed could realistically be found outside the countries where these bycatches are landed. In fact, landings are not economically available as food outside the regions surrounding landing centres[24]. However, it should be recognized that in those regions the nutritional difference could be very significant. Additionally, some of them could cover quite vast territories in densely populated a coastal regions (e.g. in China, India, Viet Nam), given the use of long-established, low-cost curing methods and means of transport. On the one hand, where the volumes are relatively small in comparison with the market, which is the case in several countries (i.e. Bangladesh, Indonesia, India and the Philippines), local demand probably exists for the quantities of bycatch that could be made available, and the difference in food supplies could be considerable in the coastal regions concerned. On the other hand, in China, Thailand and Viet Nam, the quantities of bycatch used as aquaculture feed are probably too large, in relation to markets, to find a market among the poor within the regions surrounding those landing centres where the bycatches are landed. While a difference would be achieved within the coastal regions of these countries, it is not evident that all the present bycatch could be disposed of as food.

[24] However, it should be recognized that the availability of bycatch as food for the poor is not only threatened by its use in aquaculture. Already in 1998 Salagrama (1998) wrote about the use of bycatch in India, where only a very small part of it is used as aquaculture feed: "The growing market demand for all varieties of fish appears to affect poorer segments of the society – petty fish traders, processors and lower-end consumers – negatively and requires careful and urgent attention".

5.1.3 Bycatches: a source of fisheries decline that will impact the poor?

All reports seem to show[25] that often a very large part of the bycatch – be it quantified as trash fish or as low-value foodfish – contains a large share of juveniles of commercial species. This will negatively impact commercial fisheries, and beyond a certain point, may even threaten the sustainability of the species. However, in respect of the question "does the use of bycatch as aquaculture feed lead to unsustainable fisheries?", the answer is probably "no" in most situations. There are two reasons.

First, although fishers in Asia have come to see more of an economic role for bycatch and have modified their fishing practices accordingly, bycatch is still a secondary motivation. Fishers will add something to their earnings by landing and selling bycatch, but most income comes from the sale of the fish at which the fishery was aimed (e.g. shrimp in trawl fisheries for shrimp). So if fishers were prohibited from landing and selling bycatch (thus being obliged to discard all of it), such a rule would somewhat reduce the fishing effort, but probably not for long. Therefore, in the wider context of sustainable fisheries, the use of bycatch as aquaculture feed seems to be a non-issue, and it is unlikely that fishery managers in the future will be able to count on a "bycatch for aquaculture prohibition" as an effective tool in the struggle against unsustainable fisheries[26].

The second reason is that with the exception of China, Thailand and Viet Nam, aquaculture feed, direct or indirect, is not a dominating use for bycatch. In the rest of Asia and elsewhere, bycatch is mostly used either as human food, as feed for livestock and poultry or discarded.

Again, to be clear, fisheries that are characterized by large volumes of bycatch are also mostly unsustainable; and unless remedied, this may cause a decline of the aquatic resource base, which most likely in the end will impact negatively on society, including the poor and undernourished. But, this scenario is not caused by aquaculture, and, therefore, modifications of aquaculture practices will not contribute to a brighter future for world marine fisheries in the sense that they would result in sustainable management of bycatches.

5.1.4 Country notes

China

China reports that large quantities of low-value/trash fish are used in aquaculture. The practice had been growing in parallel with the growth in aquaculture, and lately some 2.8 to 2.9 million tonnes were reportedly fed annually, mostly to marine finfish. During this period, market prices for low-value fresh fish increased and poor sections of the community had seen a fall in their possibilities to consume fish (De Silva and Turchini, 2009).

The proportion of undernourished in the Chinese population has fallen and was recorded at 9 percent in the period 2003–2005 (FAO, 2008a). This means, however, that there were still about 125 million undernourished in the country. In the same period, per capita supplies of fish[27] reached 25.8 kg, providing some 6 g of animal protein per person per day. However, the Chinese diet is relatively rich in animal proteins (21 percent of energy comes from animal proteins), and the contribution of fish to animal protein supply has fallen and was below 20 percent in 2003 (Laurenti, 2007). If fish used as aquaculture feed in China had been supplied locally as human food, annual

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[25] For examples, see Salagrama (1998) and Ahamad (2005).

[26] Management of bycatch will probably continue to focus on the "supply", i.e. the volume of bycatch caught, accepting that the costs associated with any management of the use of bycatch are prohibitive. Therefore, efforts will continue to develop technological inventions in the design and use of fishing gear, but there will also be increasing use of economic incentives and various command and control strategies.

[27] Live-weight equivalent.

supplies would have increased by about 2.2 to 2.3 kg (about 9 percent increase) for all the inhabitants.

Fishery and aquaculture authorities in China are reported to be supporting increased use of industrially manufactured, pelleted aquaculture feeds. There are several reasons for the shift, but a major reason is apparently the difficulty in coming to grips with the pollution and negative effects on human health that are linked to the widespread use of wild fish as feed (De Silva and Turchini, 2009).

Recently, the production of surimi-based products has expanded in China. These products also use low-value fish as raw material. So, even if the use of low-value fish as fish feed were to decline (as farmers follow the policy of using pelleted feeds instead of raw fish), it is not evident that the availability of low-value/trash fish for human consumption would increase. Also, it seems plausible that at least a portion of the bycatch will be channelled into production of pelleted feeds.

India

It has been estimated (Chandrapal, 2005) that landed bycatches in India are around 1.3 million tonnes yearly[28]. A large part is sold directly for food, in fresh or cured form, and most of the rest is converted into fishmeal[29]. However, the quality is low, generally unsuitable as feed for marine shrimp, and the product is used primarily as poultry and livestock feed. The exception is feed for freshwater shrimp[30].

Thus, in India the use of bycatch for aquaculture feed has been limited (although fluctuating), and at present its use does not seem to interfere noticeably with the food and income situation of the poor and undernourished. However, this situation can change, if it has not already done so. Increases in the world price for fishmeal will increase the incentive to establish modern fishmeal factories in India, factories that can supply meal and oil of a quality essential for shrimp feeds. Such developments would, of course, also encourage fishing vessels to retain, possibly even capture, larger quantities of fish suitable to be sold as raw material for fishmeal.

Viet Nam

In Viet Nam, the rapidly expanding aquaculture industry is dominated by marine shrimp and freshwater fish production. In 2006, *Pangasius* culture provided almost 40 percent of the finfish culture. The industry uses large and growing volumes of fish as feed. It has been estimated that in 2002 the industry used 0.9 million tonnes of trash fish as direct feed (Stobutzki *et al*., 2005). Given the rapid expansion in catfish culture and the practice of feeding with feeds that include fish, this amount has most likely have increased considerably.

There are no data about the employment in the Vietnamese shrimp culture industry. If the productivity is similar to that in Bangladeshi marine shrimp culture in industry[31] (ten individuals per tonne produced), then the employment in Viet Nam's shrimp culture industry ought to be on the order of magnitude of 3.5 million people. However, if the technology used were similar to that of the modern, large-scale farms of Madagascar, then employment[32] would number about 290 000. This figure is probably closer to the correct number, as Viet Nam reports a total aquaculture employment of about 670 000 people.

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[28] Equivalent to about 1.3 kg/inhabitant/year (live-weight equivalent). In absolute terms the figure is low, but it amounts to a potential increase in consumption (if all bycatch can be consumed as food – which is not likely) of about 20 percent.

[29] Twenty-seven fishmeal plants are established in South India (Andhra Pradesh, Tamil Nadu, Kerala and Karnataka).

[30] About 30 000 tonnes of freshwater shrimp produced per year (2002, 2003).

[31] FAO data (N. Hishamunda, FAO, personal communication, 2009).

[32] Expressed as the equivalent of full man-years of employment.

The use of wild fish as direct feed is common in the culture of *Pangasius* as well as in grouper and spiny lobster culture. It has been estimated that some 160 000 individuals are employed in the *Pangasius* industry.

If the 0.9 million tonnes of bycatch were not used as direct aquaculture feed, this quantity of fish might give rise to some 1.35 million man-years of employment (see footnote 21) in processing, storage and trade of food-fish products. This is a significant number in a country whose population was 80 million in 2002, and it is twice the employment generated in the aquaculture industry as a whole.

If the bycatch now used as feed, either because it is made into fishmeal for aquaculture (a small portion) or because it is fed directly (generally as an ingredient in farm-made feeds), could be supplied as food, the volumes available would be considerable. The order of magnitude is 0.9 million tonnes[33]. This is equivalent to a supply of 10 kg per person per year, which at the time of writing would be equal to an increase of more than 50 percent of fish supplies. In a country where one in four children is underweight or stunted (FAO, 2008a) but (food) energy supplies are close to normal, additional nutrients are important. If the fish could be channelled to those most in need, then the difference could be considerable.

5.1.5 Conclusions

In summary, it would seem that the use of bycatch as aquaculture feed is beneficial for those of the poor and undernourished in East Asia who are gainfully employed in aquaculture activities. They gain considerable income from this activity.

However, they are outnumbered by those who (at least in theory) could benefit if the bycatch were not used as aquaculture feed. They would benefit both in terms of access to cheaper fish and in terms of employment and, therefore, income. This group is several times larger than the group within the aquaculture industries that benefit. In terms of gaining paid employment, the group not having such opportunities might be three to five times larger than those who are employed in aquaculture activities where fish are used as feed. These "adverse outcomes" of using fish as aquaculture feed seem particularly pronounced in China, Thailand and Viet Nam. However, as pointed out earlier, the benefits for the poor and undernourished that might flow from a cessation of the use of fish as feed in these three countries will come about only if the bycatch can reach their local markets and be sold at prices they can afford.

It is true, of course, that food is produced by the concerned aquaculture units; but the fish and shrimp produced are generally destined to "up-market" consumers, frequently in other countries or on other continents. Thus, the positive effects on local fish markets in Asia and sub-Saharan Africa – the two regions with most of the poor and undernourished – in the sense of more fish being made available, are an unlikely effect[34] of present aquaculture practices.

5.1.6 Outlook

In several Asian countries, the demand for bycatch has increased. It has become a source for making fishmeal and a starting point for making surimi and other easy-to-eat foods. In East Asian countries, the demand for bycatch as aquaculture feed has increased rapidly during the last decades *pari passu* with the growth in aquaculture. The use of bycatch as fish feed has been particularly conspicuous in China, Thailand and Viet Nam.

[33] The effects associated with imported fishmeals are not included in the calculation.

[34] Globally, it is clear that the supply of fish, crustaceans and molluscs from culture has kept world fish prices at a level below what they would have been in the absence of aquaculture. True, the supply of cheap foodfish originating in bycatch or of small pelagic species would have been higher than currently, and this would have kept average prices down, but it is not certain that fishmeal production would have been much smaller than it is, as the meal would have been used as feed in the livestock industry.

Will these trends continue? It is doubtful – on the one hand, there are several forces that work against an increase in using wild fish obtained as bycatch as aquaculture feed. They include the negative effects on commercial fish stocks of the catch of juveniles, the risk of spreading disease to fish and humans, the loss of employment/income for the poor and less nutritious food being available for the undernourished.

On the other hand, rapid increases in prices of internationally traded commodities such as fishmeal and fish oil will stimulate Asian and African entrepreneurs to convert more of the locally available fish – whether bycatch or target catch – into fishmeal and oil, both for local and export markets.

5.2 The practice of fishing for aquaculture feeds and its impacts on the poor and undernourished

With almost no exceptions[35], the fish that are captured explicitly for the purpose of becoming animal feed – and thus also aquaculture feed – are converted into fishmeal and oil before being converted into shrimp and fish feed. Such dedicated reduction fisheries supply the fishmeal industries in most of the Americas and in Europe, where the fishmeal plants are also obtaining a growing volume of viscera, heads and bones from the fish processing industries. In Africa, there are reduction fisheries in Morocco and South Africa, while in the Asia-Pacific region the main such fishery takes place in Japan.

These reduction fisheries affect people who participate in them, as well as those who subsequently use the fish landed. They include those working in fishmeal and fish-feed factories, fish and shrimp farms and those who provide inputs to these facilities and ensure transport of the various raw materials and products. Given the intercontinental trade of fishmeal, these groups of people will find themselves on different continents. Many of those who catch the fish and turn it into fishmeal work and live in the Americas or Europe, while many of those who produce fish feeds and subsequently grow fish and shrimps are in Asia[36].

5.2.1 Employment impacts: global aspects

Modern factories that each day turn hundreds of tonnes of fish (and offal) into fishmeal and fish oil have relatively few employees. The factories that produced the 1.78 million tonnes[37] of fishmeal needed for marine shrimp culture (3.26 million tonnes) and culture of marine finfish (1.1 million tonnes) in 2004 are likely to have created some 1 370 man-years of employment[38] in fishmeal plants. The associated fisheries could have generated some 78 000 man-years of employment for fishers[39].

[35] However, in remote areas, fishers who keep marine fish in cages may not have access to pelleted feeds and, therefore, bycatch is their only option. This means that at times when bycatches are low, fishers have to embark on fisheries for low-value fish explicitly to feed their cultured stock of fish (De Silva and Turchini, 2009).

[36] This study estimates that the total aquaculture use of fishmeal in Asia was on the order of 2.4 million tonnes in 2004. The Asian production of fishmeal in that year was on the order of 1.7 million tonnes (FAO, 2008b). As in many countries, a large share of this meal was not used for fish feed; it is clear that much of the fishmeal used in Asia is produced outside the region.

[37] A global survey by Tacon and Metian (2008) indicates that the food conversion ratio (FCR) for marine shrimp feeds averages 1.7 and the average fishmeal inclusion in 2006 was 20 percent. Thus 1.11 million tonnes of fishmeal were required. The corresponding figures for marine fish are a FCR of 1.9 and fishmeal inclusion of 32 percent. Thus 0.67 million tonnes of fishmeal were needed.

[38] The Peruvian Case Study (Sánchez Durand and Gallo Seminario, 2009) in this technical paper states that 1 000 tonnes of feedfish generate 0.77 man-years of employment in the fishmeal and fish oil industries (not including seagoing personnel), while 1 000 tonnes of the same fish – but then well preserved on landing – would generate 65.6 man-years of work if the fish were taken to a cannery and preserved as food.

[39] Total capture fishery landings in 2006 in Peru reached 7.0 million tonnes. This was done by about 68 000 fishers, an average productivity of 102 tonnes per fisher per year (FAO, 2009a). While the Peruvian fisheries are exceptionally productive, this productivity may be on the high side for other fisheries. Assuming a 23 percent recovery, the total amount of fish required is about 7.74 million tonnes.

The employment on shrimp and fish farms using the fishmeal will be on the order of 2.64 million people[40], more than 90 percent of whom are in shrimp culture, mainly in Asia. Most of this employment is of unskilled labour and is thus a possible source of income for the poor. To this figure should be added some additional employment in independent feed mills and transport services. Thus, most employment is generated where the fishmeal is used, not where it is manufactured.

Could it be otherwise? Could more employment be generated in the regions where the fish are caught and landed and, if so, would the poor benefit? If fish were not landed, and therefore no fishmeal produced, of course all would be worse off. A large section of the South American fishing fleet would stay in port and the shrimp farming in India, Indonesia and Viet Nam would probably close, as they depend almost entirely on imported high-quality fishmeal. Large unemployment would follow. Some of the farms in China and Thailand would survive on local fishmeal. After some years, fish species that prey on the reduction species might flourish. It is unclear if increased landings of such species would impact positively or negatively on the incomes of the poor.

One conceivable scenario is that the fish are landed and instead of being turned into fishmeal, they are processed, preserved and marketed as food. Such a scenario would have very dramatic employment effects, but they will be analysed only if such a scenario is realistic. This will be done in the next section, where in fact, it will be shown not to be realistic.

5.2.2 Food impacts: global aspects

One of the alleged undesirable outcomes associated with the use of fishmeal and fish oil is a reduced supply of fish, particularly for the poor and food insecure. There are two scenarios for reduction in supplies: (i) the situation in which an existing market for fresh fish has seen supplies of fish reduced because fishmeal factories have bought the fish and turned the fish into fishmeal, and (ii) the situation in which the food processing industry has not managed to use drastically increased supplies of fish as food but instead turned the fish into fishmeal, that is, the increased supplies of fish have been used to make fishmeal instead of supplied as food. The first argument applies more to the bycatch situation, the second situation concerns reduction fisheries. This is the situation that will be analysed now.

Only if fish are cheap is there a reasonable chance that the poor can afford to buy them and improve their nutrition. This paper has already argued that bycatch is of nutritional or food benefit to the poor only if they can access it at, or close to, landing centres and soon after off-loading. Once the fish have to be processed in modern fish processing plants, costs are added and the likelihood that the product will be bought by the poor recedes. Where local landings are far in excess of what the nearby markets can absorb – which is the case for some of the fisheries in South America, northwest Africa and Northern Europe – such processing is the only realistic alternative. Traditional processing, relying on wind and sun, will not do.

The same argument applies to the poor and reduction fisheries. The species supplied to fishmeal plants are all edible and more[41] or less in demand as food where they are caught. Why then have reduction fisheries developed? Essentially because the species exploited under reduction fisheries are usually seasonal fisheries of pelagic species with large quantities of fish landed during relatively brief periods, the quantities far exceeding what local markets reasonably can consume in fresh form or what fish

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[40] Conversion factors: 0.75 man-years of employment per tonne of shrimp produced, 0.175 man-years of employment per tonne of marine fish produced. See footnote 21 for explanations.

[41] But not all. While there are other uses for menhaden, the species is hardly consumed as food. The same applies to a group of feedfish known as sand eels that are caught in the North Sea.

processing plants can convert into processed fish products. Often this means that the fishmeal plants obtain their raw material cheaply. Until a few years ago, the price hardly ever exceeded US$100 per tonne. This is a price that local consumers, even the poor, often can afford. Thus, the reason that larger quantities of fish are not consumed as food is not that the fish are too expensive for the consumer; it is rather that at the low prevailing prices demand for the fish as food is met, and if the surplus is not used as animal feed, it could at best be used as fertilizer or pet food. In such situations, fishers would soon reduce the volumes they bring ashore. At present, they make ends meet by bringing to fishmeal plants the large volumes of feedfish that they are able to catch. Thus, as a general rule the argument that existence of feed fisheries has reduced consumption of cheap fish by the poor does not hold.

The idea of landing large quantities of anchoveta, or sand eel, or most of the other species used in feed fisheries, and using them to provide food for the poor is a laudable objective, but unrealistic. By the time the poor can afford to purchase the resulting canned or cured fish products, they no longer will find themselves referred to as poor. Also, in the long run the market affects changes. In the middle of the last century most of the herring landed in Norway was converted into fishmeal; however, by the beginning of the twenty-first century the proportion had fallen to under 10 percent.

Nevertheless, there is a recurring argument that making fishmeal – and feeding it to fish – is wrong if the purpose is to maximize food production, as the practice leads to less food being available[42]. In theory, this is correct and would be of relevance for the poor, if they would have access to the fish supplied as feed (in the form of fishmeal and fish oil); but, as they do not have that access, the argument is misleading. In addition, one fish does not equal another. In the eyes of the consumer, they are not identical, some are strongly preferred (for reasons of taste, smell, appearance, ease of eating, etc.). So the argument does not give any weight to the economic realities or food preferences that govern the use of fish. The consequence is that the argument is seldom followed up by specific recommendations as to what should be done to alter the prevailing use of fish.

The argument is sometimes expressed as follows: as it takes at least 3 kg of fish (converted into fishmeal and then incorporated into fish feeds) to produce 2 kg of fish, the culture of carnivorous fish is self-defeating, as it reduces the supply of fish as an item of food[43]. The argument assumes that the fish that are about to be converted into fishmeal could in fact be sold to a waiting consumer. In virtually all reduction fisheries, and particularly in South America, this is not true. Only minute fractions of the large quantities of fish landed could be sold as food; and, as argued above, if the fish are to be preserved and transported – especially from one continent to another – they will end up being sold to the relatively better off – not to the poor.

Any attempt to modify this use of feedfish at a much faster pace than that imposed by the market will need public intervention to modify existing market forces. In most situations, such policies will involve a transfer of public funds or access to the benefits of using public funds, to entrepreneurs – and thus be classified as "subsidies" by those who prefer a status quo. Given the prevalence of international trade in fish, the use of subsidies will be scrutinized by competitors (especially by those countries where the fishing industry exports food products based on low-value pelagics) to see that any subsidies accorded to convert feed fisheries to food fisheries are WTO-compatible.

[42] In the 1970s, a third argument held sway: fishmeal should be produced to such a quality that it can be used, if not as a food in its own right, at least as an additive in other foods. FAO and various national governments (Norway and Peru being two) worked without success to establish such an industry.

[43] See http://endoftheline.com/

It would seem likely that any large-scale attempt to make food fisheries out of feed fisheries ought to take place under the umbrella of an international agreement among concerned countries.

Another possibility is to leave the fish in the water. As small pelagic species generally are prey for larger carnivorous fish, the volumes of predators will increase and the supply of fish from these fisheries will increase. As markets for such fish are often better – that is, the price per kg of fish is higher – this could be a better alternative. Yes, but not really. If the objective is to maximize the volume of fish as food, the argument must take into account that for an adult predator to grow in size by 1 kg, it will need to eat somewhere between 5 and 15 kg (most often about 10 kg) of prey. In that light, the conversion ratios obtained by aquaculture seem to be favourable: at least 1 kg of cultured carnivorous fish for 1.5 kg of fish (as converted into fishmeal)[44].

5.2.3 Unsustainable feed fisheries: an externality harming the poor?

Where feed fisheries are not managed sustainably, aquaculture today constitutes an important threat to world fish stocks because of aquaculture's reliance on fishmeal and thus on reduction fisheries. The recent increases in the world market price for fishmeal exacerbate overfishing in unmanaged feed fisheries, and aquaculture no doubt has contributed to the growing price of fishmeal and fish oil. Overfishing of reduction fisheries could lead to a long-term decline in the amounts of fish that can be extracted from the world´s oceans, as the species concerned are forage for fish at higher trophic levels. If a long-term decline were to occur, it would turn out that the farming of shrimp and carnivorous fish has not been paying the full costs of its use of fishmeal and fish oil (as it is incorporated into industrially manufactured fish feeds).

Several of the reduction fisheries in South America are currently producing at levels below historical highs. While the yields of Peruvian anchoveta, after a dip in landings following the occurrence of El Niño in 1997–1998, have recovered, and oscillate around 7 million tonnes per year, they have not reached the 10 million tonnes or more recorded in the 1970s.

During the 10 year period 1995 to 2004, the landings of Chilean jack mackerel fell. Landings in 1995 were about 5 million tonnes; three years later they were 2 million tonnes and have since oscillated around this figure. While the Chilean jack mackerel is believed to be fully or overexploited, the Peruvian anchoveta stock is qualified by FAO (2005) as fully exploited and recovering. The management of these fisheries follows modern principles that should, if adhered to, make the fisheries sustainable.

Given this situation, there does not seem to be any foundation for the argument that aquaculture threatens the sustainability of South American reduction fisheries and, therefore, endangers the food security of those who are already undernourished or the income levels of the poor in Chile, Peru or anywhere else. There are two reasons for this: on the one hand, management of the feed fisheries, even if not perfect, assures continuity of these fisheries, and on the other hand, those who want to buy and eat or commercialize fish normally destined for feed as food can do so as long as they are prepared to pay the price paid by the reduction industry, which usually is low in comparison with prices for foodfish.

The fishmeal industry in the United States of America[45] is based on menhaden, a type of fish that is not much liked as food, and whose only other main use is as bait (Tacon, 2009). There are two stocks of menhaden, both fully exploited. The fishery is

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[44] The main reason for this difference is that fish and shrimp feed contain other feedstuffs in addition to fishmeal and fish oil. With the exception of salmon feeds and feeds for special phases of the culture cycle for other species, ingredients other than fishmeal and fish oil make up the larger share of the feed.

[45] In Alaska, more than half the weight of the marine fish catch, mostly in the form of heads, viscera and frames obtained from the fish processing industries, is converted to fishmeal (Tacon, 2009).

a rather small one and does not significantly affect American society or the poor and undernourished in other parts of the world.

Feed fisheries in Europe are not well managed. The stocks of blue whiting and capelin have been exploited beyond the recommended catch limits. This may have future negative consequences for fishmeal production in Northern Europe, which in turn will worsen the feed situation, particularly for Norwegian cage-culture of salmon, trout and – in a possible future – cod. There may be negative consequences also for shrimp and fish farmers outside Europe that could threaten employment possibilities on fish and shrimp farms for the unskilled and poor in those regions.

In summary, available data and information do not support the thesis that feed fisheries create an externality (demise of these and other marine fisheries) that will significantly harm the world's poor and that, therefore, concerned public authorities need to correct. So, there does not seem to be a factual basis for holding fish and/or shrimp farmers responsible – at least not more responsible than any other user of fishmeal and fish oil (e.g. livestock producers, pet food manufacturers).

5.2.4 Country and regional notes

Chile and Peru

The west coast of South America is home to the world's largest capture fisheries. Chile and Peru together regularly account for between 12 and 15 percent of the world landing from capture fisheries. These two countries have a combined population of about 47 million, or about 0.7 percent of the world population. It is not surprising that they export a large part of their catch. Even if their populations consumed fish at the rate of the most fish-consuming populations (60 kg/capita/year, live, weight equivalent), they would still only consume about 2.8 million tonnes, or 20 to 25 percent of landings.

The governments of the two countries promote fish as food, and consumption is above the world average, reaching about 20 kg per person per year in both countries. However, populations in both countries prefer red meat, fish supplying between 15 and 20 percent of animal proteins in Chile and about 25 percent in Peru. However, in 2003, 15 percent of the population in Peru was undernourished and one quarter of the children were stunted.

In Chile and Peru, most of the landings from capture fisheries originate in reduction fisheries supplying pelagic fish to local fishmeal factories. The main reduction species are also consumed as food. For the anchoveta, the proportion of the total landings is increasing but small, still less than 1 percent of the volume landed in Peru. Of the Chilean horse mackerel landed in Chile, the proportion used as food is larger, and an important and growing volume is being exported. A large share of these exports is going to better-off consumers in West African countries and China.

In Chile and Peru, reduction fisheries do not mean a reduced access to fish as food, they mean employment and income for the poor. In these countries, the reduction fleets generate employment for the unskilled, and in Chile the salmon industry creates employment in the poorer regions of the country.

Elsewhere in South America

The reduction industries have relatively little influence in the rest of South America. The possible exceptions are Brazil and Ecuador, both of which have significant shrimp culture industries. While Ecuador produces enough fishmeal for its needs and is a net exporter, Brazil depends on imports of fishmeal for its expanding shrimp culture industry (65 000 tonnes in 2006). The poor in both countries can be said to be beneficiaries in terms of employment and income.

Africa

In Africa, fish is food. In many countries south of the Sahara, fish protein provides a large part of the animal protein in everybody's diet. Fisheries have a double function, providing a livelihood for many and nutrition for more. Thus, fisheries for purposes other than providing food have been exceptions and are likely to remain so for some time in most parts of the continent.

Nevertheless, some 15 percent of the continent's catches are reported (Laurenti, 2007) as destined for non-food uses. Morocco, Namibia, Senegal and South Africa account for more than 85 percent of this fish.The first three of these are countries with large fishery resources but relatively small population densities, no doubt a part of the explanation of why not all fish are used as food. In fact, the vast majority of African countries report no catches as destined for other than food purposes.

Fishmeal is produced at an industrial scale in South Africa and Morocco. In South Africa, there is a dedicated fishmeal fishery, while in Morocco fishmeal factories are supplied by vessels that fish not only for the reduction industry.

With a few exceptions, there is little culture of marine shrimp (the exception being Madagascar) and carnivorous marine finfish in Africa. Thus, little locally produced fishmeal becomes part of fish feed. Most of the fishmeal produced is used as feed for livestock and poultry or exported.

Madagascar

This country is interesting; although it is among the world's poorest nations, it can be argued that its poor benefit from reduction fisheries. This happens because the Malagasy shrimp culture industry employs unskilled manpower.

In Madagascar, culture of marine shrimp is well established, reaching a volume of 6 000 to 8 000 tonnes per year. From a poverty and food security perspective, the industry has direct impacts, in that it provides employment. For the industry as a whole, the employment is reported to be on the order of 4 000 to 5 000 individuals in shrimp farming proper. A majority of those employed are low-skilled, manual workers. Employment, income and fish supplies are important, as more than one-third of the country's population is undernourished and the consumption of proteins is below recommended levels (FAO, 2008a).

The industry employs modern semi-intensive methods, and the feed is industrially manufactured dry feed incorporating fishmeal and fish oil. Tacon and Metian (2009) estimate that the industry used between 18 000 and 20 000 tonnes of feed in 2006. The industry relies on imported fishmeal, as the quantity of fish destined for non-food uses in Madagascar is low. During the period from 2001 to 2003, the average amount of fishmeal produced per year was about 1 000 tonnes (Laurenti, 2007).

In summary, the use of fishmeal in shrimp feeds seems to benefit the poor and food insecure in Madagascar, in the sense that some of them are able to obtain an income that might not otherwise be available.

South Africa

It is mostly pelagic fish that are used for fishmeal in South Africa. The quantities supplied to fishmeal factories declined drastically during the 1970s, stabilizing during the 1980s at about 0.5 million tonnes per year only to fall drastically during the 1990s. During the first few years of the last decade, quantities rose again to reach 380 000 tonnes in 2003 (Laurenti, 2007). If South Africans had eaten the fish used for fishmeal in 2003, it would have meant a per capita apparent consumption of 15.5 kg[46], more than double the amount recorded for the year.

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[46] Live-weight equivalent.

Are these fisheries sustainable? “South African anchovy and pilchard are both managed in South Africa through total allowable catches (TACs) set each year on the basis of estimated biomass of stocks. Catches of South African anchovy have increased steadily since falling to a minimum of 42 000 tonnes in 1996, reaching 289 000 tonnes in 2001 and decreasing to 255 000 tonnes in 2002. Catches of South African pilchard were 265 000 tonnes in 2002, the highest on record since 1976” (FAO, 2005). As South Africa is reported to have well-developed management systems for its pelagic fisheries, there is a possibility that these fisheries will remain sustainable.

From a food security point of view, the fishmeal production does not appear to have removed fish from the poor. There are two reasons for this. First, supplies of fish for human consumption have been rather stable in South Africa but have never been high. The level of fish consumption in the country increased to about 10 kg per capita in the late 1980s to fall back to about 7 kg 10 to 15 years later. Simultaneously, there have been dramatic fluctuations in the quantities of fish used for non-food purposes, reflecting fluctuations in capture fisheries landings. This would seem to indicate that the food market has been satisfied and surplus landings have been used in fishmeal factories. Thus, fishmeal manufacture has not pre-empted the access of the South African population to fish. The second reason for not considering this outcome as undesirable is that contrary to the situation in most other countries south of the Sahara, fish proteins provide only a very small part – less than 10 percent – of the animal proteins of the average South African diet. Also, as fish consumption has fallen, other animal proteins have taken the place of fish, and the overall supply of animal proteins per person has remained stable at between 24 and 28 g per capita per day (Laurenti, 2005).

In addition, it should be pointed out that aquaculture production in South Africa is modest. Total aquaculture production (not including plants) reached about 3 500 tonnes in 2006. The bulk of the fishmeal produced in the country is used for purposes other than aquaculture or is exported. In 2006, compound fish-feed production in South Africa is reported to have reached about 1 500 to 2 000 tonnes (Tacon and Metian, 2008).

In summary, fishmeal production in the country does not seem to have generated negative consequences for the poor and undernourished in South Africa or elsewhere in the region (through shifts in fish supplies) or seems likely to do so in the future (through externalities in the form of overexploited pelagic resources).

Morocco

The situation in Morocco has similarities with that in South Africa. The fishmeal industries are supplied by the pelagic fisheries. The quantities of fish reported to be used for purposes other than food increased slowly to the middle of the 1990s and fluctuated around 350 000 tonnes between 1994 and 2003. Morocco exports almost all the fishmeal it produces. Some is used locally as animal feed; however, as freshwater fish completely dominates the small Moroccan aquaculture sector, virtually no fishmeal is used by local aquaculture.

A survey of stocks of small pelagic fish off the northwest coast of Africa has concluded that the combined catch of small pelagic fish should not be higher than the average landings for the period 1998–2003 (FAO, 2005). Management of these fisheries is complicated by the presence of fishing fleets from non-coastal countries, some of them fishing in the Moroccan Exclusive Economic Zone (EEZ). Thus, the future of these stocks is uncertain; whether or not a collapse can be avoided remains to be seen.

Morocco regularly exports more fish (300 000 to 350 000 tonnes[47]) than is consumed locally per year (230 000 to 270 000 tonnes). This rate of consumption works out to an

[47] Live-weight equivalent.

apparent consumption of about 8 kg per person per year. If all the fish now used for non-food purposes were eaten, it would mean that each inhabitant would consume an additional 11 kg per year.

The population of Morocco is relatively well off nutritionally; less than 5 percent of the population is undernourished (FAO, 2008a), although between 10 and 20 percent of children are reported to be underweight or stunted. Animal protein consumption in Morocco is low, some 16 g per capita per day, but fish contribute no more than 15 to 17 percent of this amount. Consumption of proteins is within the recommended amounts (FAO, 2008a). Fish consumption has increased over the last few decades but seems to have stabilized at about 7 to 8 kg (live-weight equivalent) per person during a 15-year period ending in 2003.

Morocco has a long-established and modern fish canning industry based on small pelagics. It exports high-quality canned products worldwide. Thus, Moroccans have access to cheap fresh fish and high-quality canned and processed products at competitive prices. These has been made available because of the pelagic fisheries, not in spite of them. Just as in South Africa, in Morocco fishmeal industries cannot be seen as having had a negative influence on food availability for the poor.

Europe

The poor and undernourished are few in Europe and found mainly in the eastern parts. Although some carp culture is carried out in those regions, and modern farms include some fishmeal in the fish feeds used, feed fisheries cannot be said to have any measurable impact on the poor and food insecure of Eastern Europe. Neither will fishmeal plants have significant impacts in the areas of Western Europe where they are located.

Asia

Most fishmeal production in Asia makes use of bycatch, or of "surplus" catches in food fisheries of small pelagics and, increasingly, of heads, guts and viscera from industrial fish processing. However, in Japan the large-scale culture of Japanese amberjack (*Seriola quinqueradiata)* of about 150 000 tonnes became possible as large volumes of low-value fish (sardines and sandlance) were landed and used as direct feed. In recent years, fishmeal, as part of pelleted feeds, has replaced a considerable part of the direct feed as landings of sardine fell.

China

The country is a large net importer of fishmeal and fish oil. In 2006, imports amounted to just under 1 million tonnes, having been substantially higher in 2004 and 2005 (FAO, 2008b). At the same time, exports amounted to only a few thousand tonnes. Fishmeal use in shrimp and fish feed is reported to have been about 526 000 tonnes in China in 2006 (Tacon and Metian, 2009). This was 41 percent of all fishmeal used for livestock. The shrimp culture and fish culture industries are large employers of poor and unskilled staff. Without access to imported fishmeal, employment in these industries would have been substantially lower.

India

The country has no feed fisheries of its own. Fishmeal is produced from bycatch and from excess landings of small pelagic species. However, the standards of the fishmeal industry are comparatively low. Few plants separate out the fish oil and at the time of writing, the shrimp culture industry imports the fishmeal it needs in feeds.

Non-food uses have traditionally been low in India and are of little consequence for country wide nutrition (quantities have generally been below 0.1 kg per capita per year). Nevertheless, an expanding poultry industry and a boom in marine shrimp culture in the 1990s led to an increase in fishmeal production and, therefore, use of bycatch and small pelagics as raw material.

The total volume of fish used for non-food purposes expanded to over 0.4 million tonnes in the 1990s but has since fallen and was about 0.35 million tonnes in 2003. However, most of the fish used for non-food purposes is of pelagic origin, the shrimp-trawler bycatch accounting for about 20 percent of the total.

In the coastal areas of southern India, some of the poor benefit through employment and income from feed fisheries conducted outside the subcontinent. They do so because these foreign fisheries provide the fishmeal that is included in the industrially manufactured shrimp feeds used in Indian shrimp culture.

There do not seem to be any figures on the employment in Indian shrimp farming. If labour productivity is similar to that in Madagascar, employment may be in the order of 0.1 million; however, as much shrimp farming in India is of the smallholder kind, employment productivity is not likely to be as high as in Madagscar, and, therefore, total employment in the shrimp culture industry is considerably above 0.1 million (man-year equivalent), with a large share of those employed being unskilled and unorganized.

Any national or international policy originating in a desire to lessen the use of fishmeal as an ingredient in shrimp feed that leads to a fall in the production of cultured shrimp in India would initially lead to increased poverty in some coastal areas of the country, and, therefore, a worsened food security situation of concerned households. Naturally, with time, pond owners will attempt to culture species not dependent on fishmeal and fish oil, or will find uses for their ponds that are outside aquaculture (although the increased soil salinity will reduce the possibilities).

Japan

The country regularly uses more than 0.5 million tonnes of fishmeal a year, but produces only about 0.2 million tonnes. The difference is imported. The fishmeal ingredients used in the farming of Japanese amberjack and red seabream should not exceed 0.1 million tonnes per year (or 1.2–1.3 percent of food-fish supply). Given that most fishmeal made in Japan is also used within the country, the Japanese feed fisheries and manufacture of fishmeal have no direct implications for the poor and undernourished elsewhere.

Viet Nam and Indonesia

The shrimp culture industries in Indonesia and Viet Nam are in almost the same situation as that just described for India. Although both countries have local fishmeal factories, their supplies are not based in feed fisheries, and as they do not produce enough fishmeal for their respective needs, imports are needed. Also in these countries, the employment of coastal poor in shrimp culture is tied to imports of fishmeal, which almost always is high-quality fishmeal based on feed fisheries and complemented with fish offal. It seems that in both countries, if the only source of raw material is bycatch, then local fishmeal plants have difficulties in competing with other sectors. The volumes are small at any one point[48] and the competition from other uses and the fresh fish market, are too severe.

5.2.5 Fattening of Bluefin Tuna

Beyond the Asia-Pacific region, the direct use of wild fish as aquaculture feed is uncommon. It is only in recent years, with the advent of an industry based on the

[48] Edwards *et al.*(2004) reported that a fishmeal plant in Viet Nam would need daily supplies of about 120 tonnes of raw material to keep the plant operating economically.

fattening of bluefin tuna, that the practice is employed in a modern and expanding industry. However, it is not clear to what extent the provision of feed, often pelagic species, is obtained through specialized fisheries.

Apart from in Australia, fattening of bluefin tuna is now carried out in the eastern Central Pacific (Mexico) and in several countries bordering the Mediterranean Sea. Virtually all of the cultured bluefin tuna is shipped to Japan, where it enters the sashimi market.

Overall, the amount of wild fish used annually as feed in this industry is probably about 0.2 million tonnes. Most of this total is made up of small pelagic species (Huntington and Hasan, 2009). Local fisheries generally provide this fish, while it is reported that northwest African pelagic fisheries have been providing feeds to bluefin tuna kept for fatting in the Mediterranean Sea. In most regions, the quantities so far used are small in relation to pelagic fisheries in total[49].

Where supplies are removed from fish that normally would have been processed into fishmeal, the effects on food supplies can generally be considered as small. The effects on employment and income in the region where the fisheries take place could be positive (value added in freezing, storing and transport of whole fish – probably higher than the value added linked to fishmeal production), but overall the value is likely to be small.

5.2.6 Conclusions

Feed fisheries, through aquaculture, generate employment and income for poor in many coastal areas of the world. At the same time, they provide employment at sea and in fishmeal factories for unskilled workers, particularly in South America and in a few African countries.

Also, as a rule, these fisheries do not limit the access of the poor and undernourished to fish as food. The exception to this rule may be fisheries that supply feed to capture-based culture of tunas. Given the extraordinarily high prices paid for such tunas in the Japanese markets, those who raise bluefin tuna in captivity can afford to pay more for sardines and other pelagic species than do those who prepare this fish for the food market (Zertuche-González *et al.,* 2008).

Feed fisheries, in common with most marine fisheries, experience management difficulties because fishers often exceed established catch limits. In many of these fisheries difficulties are exacerbated by oscillations in the biomass of the species concerned, oscillations that are linked to a fluctuating and changing marine environment. Nevertheless, as these fluctuations follow varying rhythms, the fluctuations for the sector as a whole will be less dramatic than that of any individual fishery, and overall it seems plausible that the feed fisheries will continue to provide raw material to fishmeal plants according to a pattern that will not differ much from the recent past. The exception at present seems to be the North Atlantic feed fisheries. However, if appropriate management action is taken in the North Atlantic fisheries, the world's feed fisheries are unlikely to be exploited by such high levels of fishing effort that these fisheries will threaten overall yields of marine fisheries.

The above discussion of the use of fishmeal and fish oil in aquaculture feeds seems to support the affirmation of Willmann (2005) that "Globally, evidence is weak, if any, that expanding aquaculture has significantly contributed to increased fishing pressure on reduction fish species. The primary reason for over-exploitation is the absence of effective fisheries management and increase in the demand and price of food fish."

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[49] However, the share can also be significant at the local level. It is reported that in 2006 about half of the Pacific sardines (*Sardinops sagax caerulea*) landed in Ensenada on the west coast of Mexico was used as feed in local capture-based culture of the northern bluefin tuna (*Thunnus orientalis*) (Zertuche-González *et al.,* 2008).

5.2.7 Outlook

The data used above include some information for 2006. They do not, therefore, reflect the convulsions that the fishmeal and fish oil industry and associated markets have experienced as prices sky-rocketed for fishmeal and fish oil in 2007 and 2008. The immediate effects were reduced demand, but also an increased ability by fishmeal manufacturers to pay for raw material. Simultaneously, however, the least proficient aquaculture enterprises may have experienced difficulties in affording the increase in feed prices. Simultaneously, they would have had difficulties in passing on cost increases to consumers, as several of the more important markets experienced stagnation and/or recession.

The increase that has taken place in the real prices of fishmeal and fish oil, on the one hand, will speed up the gradual replacement of fishmeal and fish oil in aquaculture feeds by plant proteins and vegetable oils[50] and, on the other hand, lead to reduced inclusion of fish proteins in feeds for omnivorous species. In addition, it will lead to increased efforts to include offal obtained when foodfish are processed industrially, which may reach 50 percent of the live weight. Eventually these developments will help the aquaculture industry to grow and the poor to keep their employment in and income from shrimp and fish culture.

Until the middle of the first decade in the present century, the aquaculture industry's use of fishmeal and fish oil grew rapidly. This has not led to any real increase in the volumes of fishmeal and fish oil produced, but to a shift in the use of what has been produced – instead other users of these products have reduced their share. However, this trend has now come close to its natural end – there is little output left to shift to aquaculture.

While the recent price increase leads to increased supply of fishmeal and oil, it simultaneously reduces demand and spurs the development of alternative feeds. This will help the aquaculture industry expand; but how will it affect the poor and undernourished? For them, the employment/income effect will be the sum of two divergent trends. On the one hand, employment in aquaculture will be maintained and possibly expand, but on the other hand, employment will fall in fish processing as the share of a stagnant world marine fisheries output that is dedicated to feed fisheries expands. Simultaneously, a growing population will face a contracting supply of (comparatively) cheap fish that is instead used for feed. This is a possible future negative outcome.

Finally, with time, weak states will become stronger. Corruption will decline and managers will have a better chance to manage fisheries effectively. This ought to improve sustainability in feed fisheries and reduce fluctuations in supply of fishmeal and fish oil also to aquaculture feed manufacturers.

6. DISCUSSION OF PUBLIC POLICIES FOR MODIFYING NEGATIVE OUTCOMES FOR THE POOR AND UNDERNOURISHED DERIVING FROM THE PRACTICE OF USING WILD FISH AS AQUACULTURE FEED

So far this paper has looked at the issues surrounding the use of fish as aquaculture feed from a global perspective. It has found that on the whole feed fisheries provide considerable benefits to many. Nevertheless, governments hosting export-oriented reduction industries may want to shift the use of fish away from feed to food. Apart from improving the nutritional status of local populations, such policies may also lead to more local employment and, therefore, contribute to economic growth.

With regard to the use of bycatch as aquaculture feed, the situation is much less favourable. It is evident that such usage has reduced the availability of cheap fish in

[50] Feed producers and academic research institutions are making an enormous effort in this field, which is likely to produce results in the near future (see Naylor *et al.*, 2009).

communities adjacent to fishing centres and that the bycatch often contains such a high percentage of juveniles that negative externalities are created, i.e. that other fisheries suffer serious negative consequences. Governments are struggling to control bycatch fisheries and may also want to promote food-use of sustainable bycatch.

What could and should governments do if they want to promote a modification in the use of feedfish or a different usage of sustainable bycatch? A number of possible actions come to mind. They are likely to be a combination of economic incentives/disincentives and straight-out regulations. Before adopting any measure, governments will want to (i) investigate the effectiveness of the proposed measure and (ii) make certain that it is compatible with the economic policies that it applies nationally and must adhere to internationally.

Entrepreneurs in the fisheries field very often trade their products in the international market[51], and they will not want to contravene international trade agreements. National governments will not want to be seen as enacting economic policies towards the fisheries and aquaculture sector that differ in their basic principles from those applied to the economies generally.

6.1 Undesirable outcomes of economic growth

Today most countries organize their economies as market economies. However, the "invisible hand" at work in market economies does not direct economic activities so that the poor and food insecure automatically benefit. Neither, as has become painfully obvious during the last decades, will the market economy ensure sustainable use of land and water. In rural areas of straggling economies, the market may act so that the poor and food insecure are disadvantaged, i.e. that their income and/or wealth shrinks or their access to food is impaired in the short and/or long run. The fundamental reason for this is that a market economy is organized (and supported by a legal regime) to generate wealth in the economy, but does not automatically ensure that the wealth is distributed in line with what might appear appropriate to many. A market economy generates economic growth, not an equitable distribution of the resulting income or wealth.

When the income of the poor falls or their access to food is curtailed, the reasons are usually related to market swings and/or externalities. The problem is that in most situations market forces will not automatically counteract externalities and market swings. Those economic actors who benefit from market swings or externalities will argue that the negative outcomes they cause are not very important; those who suffer them will argue the contrary. Thus, it is up to those concerned to call the situation to the attention of public authorities so that these can assess whether to intervene or not, and subsequently take appropriate legal or regulatory actions.

Those who participate in debates about negative outcomes intend to persuade public authorities that they need to intervene to nullify or defend, as the case may be, the negative outcomes. In such discussions, the rural poor in struggling economies often start with a handicap. They may be illiterate and they may be ignorant of their legal rights.

6.1.1 Market swings

A market swing[52] is a situation that occurs when a commodity or service appears or disappears in a market. When the swing peters out and trade stabilizes, a market shift has occurred. Such changes can occur at different scales, at different speeds and in regional, national or world markets. They can be seen as positive or negative.

[51] FAO has estimated that in 2006, some 38 percent of all fish products (capture fisheries and aquaculture) entered international trade in one form or another (S. Vanuccini, FAO, personal communication, 2009).

[52] In the traditional macroeconomic literature, such changes in the market are often described as "shifts" in the supply or demand curves.

Market swings appear not only for finished goods and services, but also for factors of production.

Market shifts are common in market economies. In fact, they are an inherent part of economic growth: slide rules are replaced by computers, mechanical typewriters by electric keyboards, telegrams by emails, etc. This "destructive growth"[53] generally is seen as something positive in the long run.

As long as the rate of change is not faster than that it permits a redeployment of those who become unemployed and does not cause sustained harm to consumers, the market shift is normally permitted to proceed. In these situations, public authorities mostly limit their interventions to making it easier for the unemployed to find employment. However, those who suffer the changes of market swings will argue that the market shift has had such strong negative consequences that the authorities need to intervene to modify them or roll them back entirely.

Rapid market swings for food products are, in fact, prone to quick and sometimes drastic interventions by public authorities. The rapid increases in world food prices that occurred in 2007 and 2008 illustrate this. Demand for biofuels led to higher maize prices, which in turn caused higher prices for substitutes, among them rice. This led a large number of governments to restrict exports of rice, and the world price of rice rose drastically in the course of a matter of months (FAO, 2009b).

Market swings that are modest but long lasting and affect low-priced products receive less attention. The use of wild fish as aquaculture feed is one such change in supply. As discussed earlier, in East Asia, where it is common to use wild fish as aquaculture feed, this practice has led to a decrease in supplies of cheap fish. There are those who argue that this practice should not be permitted to continue. However, it seems that few authorities have intervened to redress this situation.

Both in North America and in Europe, imports of cultured fish and shellfish (catfish, Atlantic salmon and marine shrimp) have generated protests from producers in importing markets who have seen their livelihoods threatened (Norman-López and Asche, 2006). North American salmon fishers and catfish producers have protested successfully. There are probably several reasons for the success of these protests. In respect of salmon, it may have to do with the "up-market", luxury nature of the salmon (definitely not food for the poor when aquaculture was started), and, therefore, it was difficult for importers to argue that imports of cultured salmon were needed for reasons of food security. The second reason for the success is probably most salmon fishers were – and are – North American, while those who culture salmon are found principally in Norway and Chile. The North American fishers used to dominate the world market for salmon with wild species caught in the North Pacific. Where fishers and aquaculturists are of the same nationality (as in the culture of seabass in the Mediterranean Sea), the rise of aquaculture has been easier to accept for both those involved and public authorities.

Some argue that in a certain situation a market swing ought to have taken place, and the fact that it has not is harmful to sections of the community. These situations can be seen as "unrealized market swings". The following argument is an illustration of the concept "unrealized market swing": if Peruvian anchoveta was not turned into fishmeal – and then incorporated into aquaculture feed – the world (and the poor in particular) would have more fish available as food, and, therefore, aquaculture using fishmeal should not be permitted to continue to turn perfectly good food into animal feeds.

[53] In 1942, the Austrian economist Joseph Schumpeter in his book Capitalism, Socialism and Democracy used the term to describe the process of transformation that accompanies radical innovation.

6.1.2 Negative externalities: income for some – costs for others

When shrimp farming started on the east coast of India, it was common to convert rice fields to shrimp ponds. However, as shrimp farmers flushed shrimp ponds with brackish water, they eventually caused a build up of salt in the soil and also in the surrounding lands. This made these lands less suitable for growing rice or other crops, and the farming households who where not part of the shrimp culture activities would see their income fall. This is an example of an externality[54] created by aquaculture.

In a growing and functioning economy, the availability of factors of production fluctuates following modification of existing technologies and/or access to new markets. This means that enterprises have more or less difficulty in making ends meet as needed labour or raw materials may increase in price or the demand for the finished product may fall. The beneficial side of these shifts in availability is that factors of production are used where they produce the most value. Therefore (and sometimes in spite of much protest), governments are generally reluctant to interfere in the market to redirect the use of factors of production.

However, when an enterprise causes externalities, those who suffer them have a better chance of obtaining public redress than do those who protest about market swings. The individual who suffers the consequences of an externality can point to a "failure" in the market: the fact that the entrepreneur does not compensate those who suffer economically (or otherwise) because of his/her enterprise[55].

Dealing with undesirable outcomes in most economies is a political process. The issue for public authorities, who should act in this process, is one of deciding how to deal with market swings and negative externalities. A decision on their part must include information on the extent and nature of the externalities. How many individuals are concerned and how are they affected? In poor economies, effects on income and nutrition are fundamental knowledge.

However, given international agreements on trade and national practice in respect of economic and fiscal policies, most governments have limited freedom to effectively use pro-poor policies to mitigate negative outcomes originating in the practice of using fish as feed in aquaculture.

6.2 Pro-poor, national policies for feed fisheries

The previous discussion of feed fisheries has shown that governments may want to intervene in feed fisheries in order to improve the situation of the poor and undernourished. Their situation may be improved as measured by: food supplies, employment and income generation, and sustainability of marine fisheries.

6.2.1 Food supplies

Governments could buy small pelagics on the open market and provide them at a subsidized cost in institutional feeding programmes (hospitals, schools, military, etc.). However, given the public expenditures involved, it would seem unlikely that in poor economies such schemes could be maintained for any length of time or cover a

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[54] An economic side-effect. Externalities are costs or benefits arising from an economic activity that affects someone other than the people engaged in the economic activity and are not reflected fully in prices. For instance, smoke pumped out by a factory may impose clean-up costs on nearby residents; bees kept to produce honey may pollinate plants belonging to a nearby farmer, thus boosting his crop. Because these costs and benefits do not form part of the calculations of the people deciding whether to go ahead with the economic activity, they are a form of market failure, because the amount of the activity carried out if left to the free market would be an inefficient use of resources. If the externality is beneficial, the market would provide too little; if it is a cost, the market would supply too much. (http://www.economist.com/research/Economics/alphabetic.cfm?LETTER=E)

[55] A few decades ago, many aquaculture activities were rightly blamed for causing pollution, an externality, in many ecosystems. At present, there exists a considerable body of knowledge about how to deal with pollution caused by aquaculture, and the industry has done much to reduce it.

significant share of the landings in feed fisheries. Thus, impacts on fishmeal and fish oil users, including aquaculture farms, would be marginal.

6.2.2 Employment and income generation

In countries like Chile and Peru, the employment generated ashore by the huge reduction fisheries is probably experienced as small and insufficient. One avenue for modifying the situation is simply to prohibit the use of fish – which is also sold as food – as raw material for fishmeal and fish oil. Obviously, such a policy would have to be introduced gradually and slowly, if it is meant to roll back an existing industry. If applied pre-emptively, it is of course much easier to achieve. This was done successfully in Argentina for the anchovy fishery out of Mar-del-Plata. The measure has been in force for several decades, and a shore-based food processing industry exists. Only in the case of a significant roll-back of existing feed fisheries could these policies affect aquaculture based on fish as feed, and if so, negatively. It would then be a matter of weighing the loss of employment in aquaculture (and possibly in the livestock sector)– most of which is likely to be undertaken in countries that import fishmeal and fish oil – against the expected increase in employment in shore-based industries.

It may be tempting to provide economic incentives (referring to an "infant industry argument") in order to establish a local fish processing industry using feedfish as raw material. Given the international trade that occurs in tinned fish products, such a policy is likely to run into complaints about unfair competition and eventual referral to the WTO. Thus, it is not a likely avenue for most countries.

6.2.3 Sustainability

Managing feed fisheries sustainably is difficult. The problem in these fisheries is a traditional fisheries management problem that they share with many other fisheries. How to control fishing effort so that established catch quotas are not exceeded? This is much debated in the fisheries management literature and will not be discussed further here.

Instead, it should be stated that appealing to consumers of aquaculture products not to buy certain species in the hope that this will reduce the fishing pressure in feed fisheries is a very blunt instrument. It is a blunt instrument because fishmeal has many uses and what is not incorporated into fish and shrimp feeds may well be used to produce feed for poultry and/or livestock or incorporated into pet foods. Furthermore, a consumer boycott is also a strategy that is wasteful from the economic point of view, as it attempts to direct fishmeal to uses other than those that the market considers the most profitable.

If such policies are successful against fishmeal produced in Northern Europe, the consequence for the poor and undernourished in tropical countries is loss of employment and income, and to achieve international support such policies should probably be accompanied with support for development of alternative livelihoods in areas where shrimp and marine fish farming are common.

6.3 Pro-poor national policies for bycatch fisheries

Bycatch fisheries and the use of bycatch for aquaculture feed also impacts the poor's (i) access to food, and (ii) possibilities to find paid employment either directly or in the long term, as a consequence of crumbling fish stocks.

Food supplies

There is no easy method available to alter the allocation of bycatch in the market so that the access of the poor is favoured. One possibility is to prohibit the use of bycatch for aquaculture feed. However, in most locations such a prohibition would be difficult and costly to enforce. In theory, rich governments could purchase those parts of the bycatch that they would like to reserve as food – by paying a price higher than aquaculturists could afford – and then put them on the wet fish market at subsidized prices. In any such scheme, the transactions costs that would need to be incurred to prevent subsidized fish from finding their way back to aquaculturists may turn out to be substantial.

6.3.2 Employment and income generation

If effective, a prohibition to use bycatch as feed would lead to more bycatch being used for other purposes such as raw material for cured products, fresh sales, etc. This would, in turn increase employment. An effective stop to the landing of bycatches would of course, lead to loss of employment in several post-harvest sectors. This creates a dilemma for those who have to deal with the sustainability issues related to bycatch, as the loss of the "bycatch" could run into stiff opposition in local communities, whose needs for income and food associated with the bycatch are immediate and pressing.

6.3.3 Sustainability

The bycatch issue is a classic and well-known fisheries management problem. Various technical measures have been developed to deal with it, but if they are not enforced, and this is frequently the case in countries where bycatch is used as aquaculture feed, then the bycatch problem remains. Also, bycatch is not easy to deal with by applying consumer pressure (through labels of various kinds), as some parts of the bycatch are composed of non-commercial species or of damaged commercial species, for which animal feed is probably the best possible use. The transaction costs involved in monitoring the flow of bycatch could be very high indeed.

It is quite evident that in many fisheries, and not only in Asia and Africa, bycatch is a big and in some cases growing issue, and no matter how it is dealt with the poor will be affected.

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This technical paper provides a comprehensive review of the use of wild fish as feed inputs for aquaculture covering existing practices and their sustainability as well as implications of various feed-fish fisheries scenarios. It comprises four regional reviews (Africa and the Near East, Asia and the Pacific, Europe, and Latin America and North America) and three case studies from Latin America (Chile, Peru and the study on the use of the Argentine anchoita in Argentina, Uruguay and Brazil). The four regional reviews specifically address the sustainable use of finite wild fish resources and the role that feed-fish fisheries may play for food security and poverty alleviation in these four regions and elsewhere. With additional information from case studies in China and Viet Nam, a global synthesis provides a perspective on the status and trends in the use of fish as feed and the issues and challenges confronting feed-fish fisheries. Based on the information presented in the global synthesis, regional reviews and three case studies, and through the fresh analysis of information presented elsewhere, an exploratory paper examines the use of wild fish as aquaculture feed from the perspective of poverty alleviation and food security.

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