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

Albert G.J. Tacon[2]
Aquatic Farms Ltd.
49-139 Kamehameha Hwy, Kaneohe, HI 96744
United States of America

Tacon, A.G.J. 2009. Use of wild fish and other aquatic organisms as feed in aquaculture – a review of practices and implications in the Americas. *In* M.R. Hasan and M. Halwart (eds.). *Fish as feed inputs for aquaculture: practices, sustainability and implications.* FAO Fisheries and Aquaculture Technical Paper. No. 518. Rome, FAO. pp. 159-207.

[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.

[2] Current address: Grupo de Investigación en Acuicultura (GIA), ULPGC & ICCM, PO Box 56, 35200-Telde, Las Palmas, Canary Islands, Spain

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).

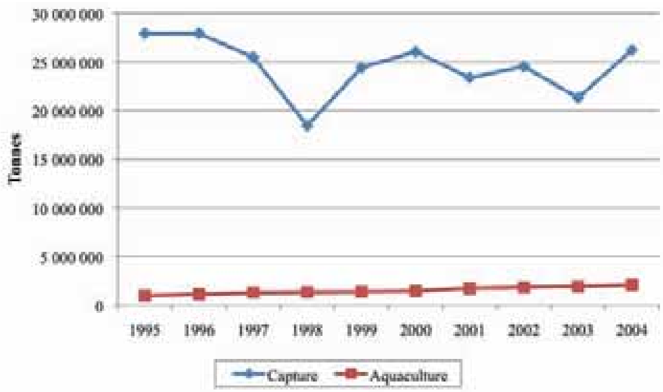
Thirty five countries (out of a possible 40 within the region) reported aquaculture production in 2004. The largest country producers were Chile at 694 693 tonnes

[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)

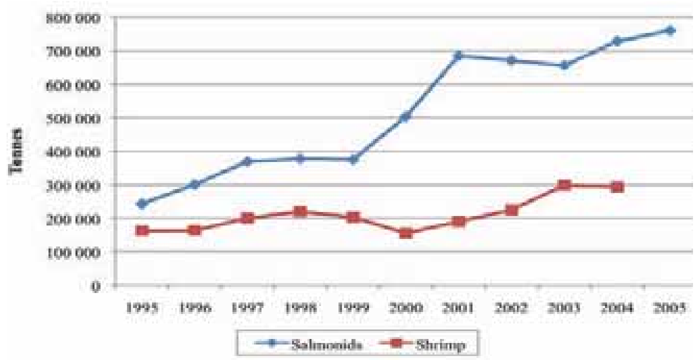
The main finfish and crustacean species farmed in the region are diadromous salmonids and penaeid shrimps (Figure 2) and to a lesser extent, freshwater finfishes (Figure 3). For example, in 2004 the major cultured finfish and crustaceans were as follows: Atlantic salmon, 446 830 tonnes (coldwater diadromous 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

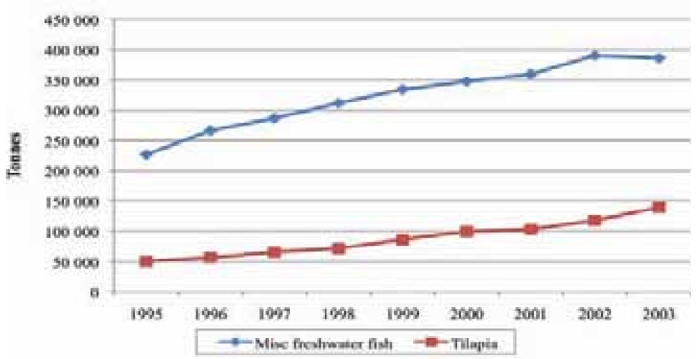
While the prospects for the aquaculture industry in the region are bright (Masser and Bridger, 2006; Rojas, Simonsen and Wadsworth, 2006; Flores-Nava, 2007), the sector has not been without its problems and constraints, which will have to be addressed if it is to grow in a sustainable manner, including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

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



Source: FAO (2006a)

- *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
- *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.

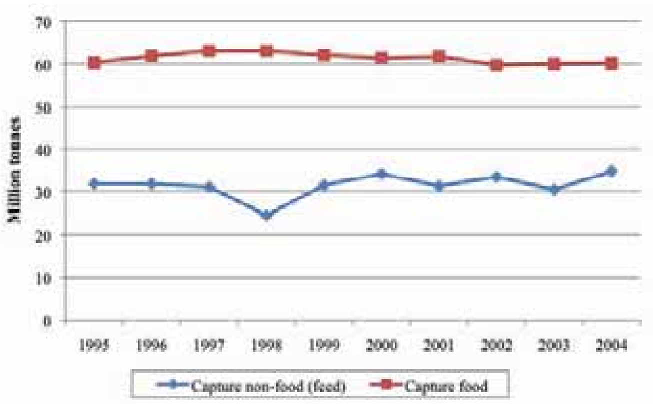
3. USE OF CAPTURE FISHERY PRODUCTS IN ANIMAL FEEDS

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).

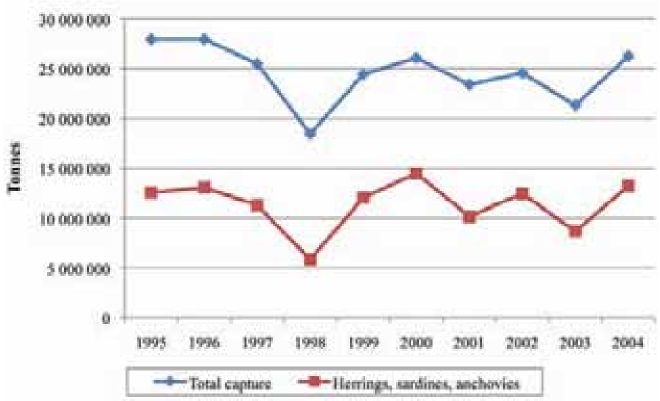
Within the Americas, the percentage of landings destined for non-food uses is significantly higher than the global percentage, with over 9.9 million tonnes or 47.2

FIGURE 4
Global finfish and shellfish production from capture fisheries, and disposition of the catch



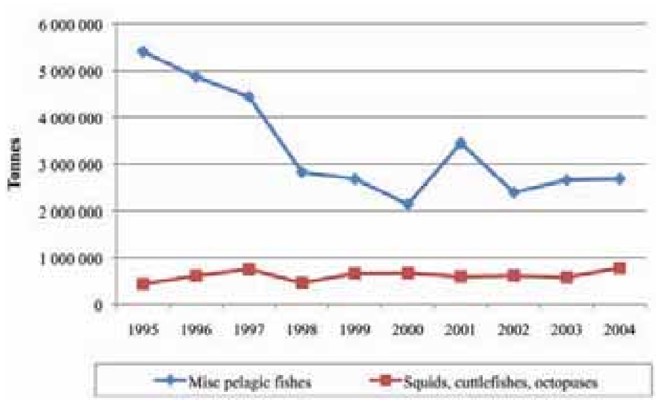
Source: FAO (2006a)

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

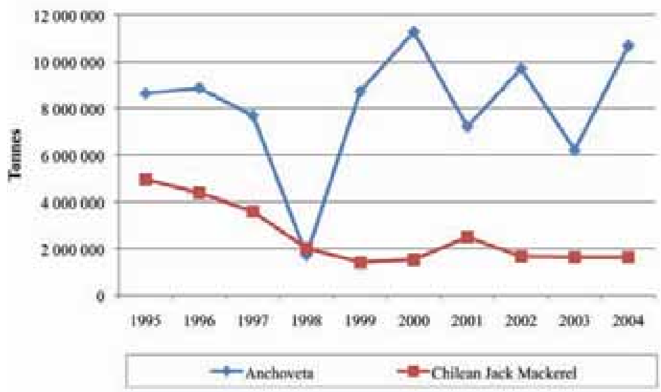
Small pelagic fish species form the bulk of capture fisheries landings destined for reduction in the Americas, with anchovies, herrings, pilchards, sprats, sardines and menhaden totalling 13.19 million tonnes or 50.2 percent of the total reported capture fisheries landings of 26.25 million tonnes in 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);

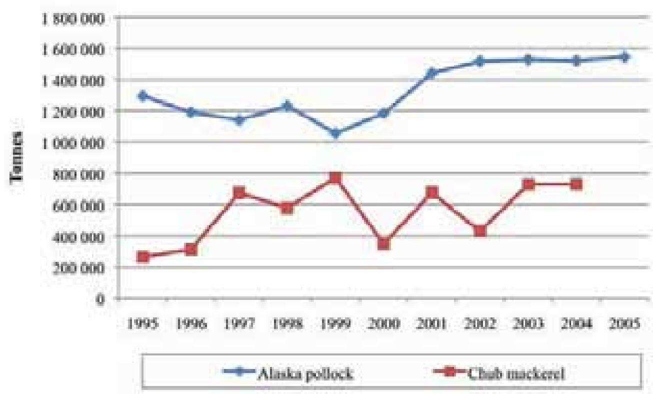
- Chilean jack mackerel – total reported landings of 1 638 530 tonnes in 2004, to which Chile contributed 88.6 percent and Peru 11.4 percent (Figure 7);
- Chub mackerel – total reported landings of 730 427 tonnes in 2004, to which Chile contributed 79.0 percent, Peru 8.5 percent, Ecuador 7.1 percent 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



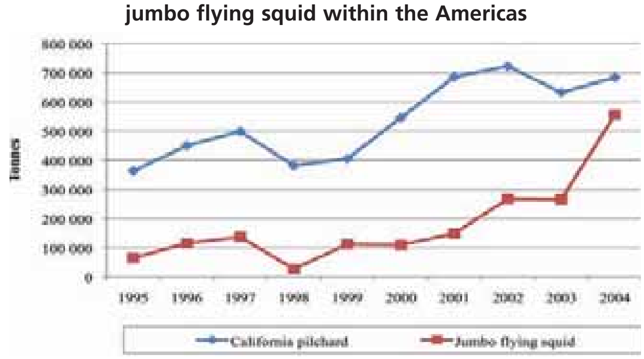
Source: FAO (2006a)

FIGURE 8
Total capture fisheries landings of Alaska pollock and chub mackerel within the Americas



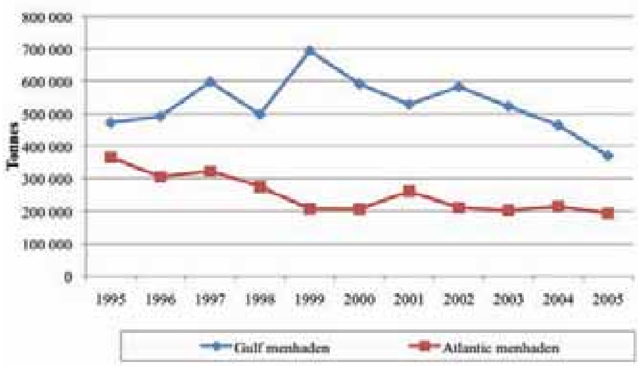
Source: FAO (2006a), except 2005 data from NMFS (2007)

FIGURE 9
Total capture fisheries landings of California pilchard and jumbo flying squid within the Americas



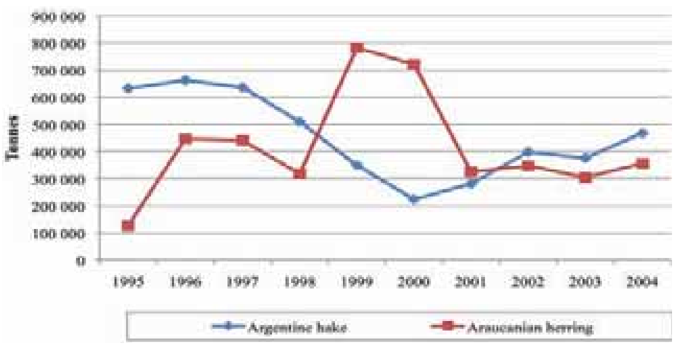
Source: FAO (2006a)

FIGURE 10
Total capture fisheries landings of Gulf menhaden and Atlantic menhaden within the Americas



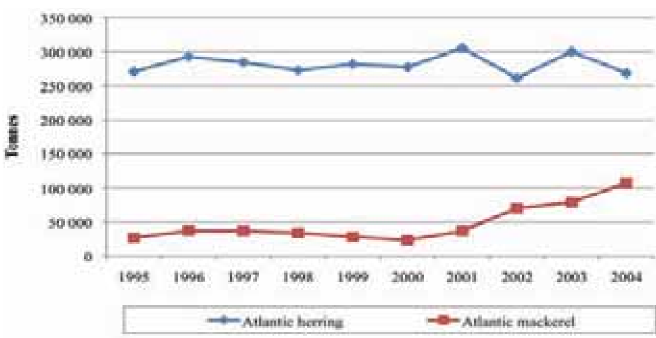
Source: FAO (2006a), except 2005 data from NMFS (2007)

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

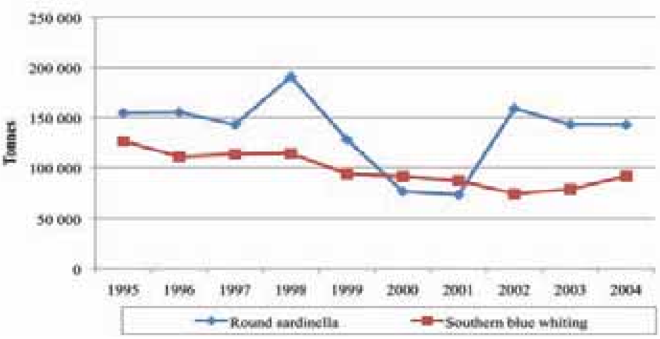
Islands (Malvinas) 1.7 percent (Figure 11); and

- 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.

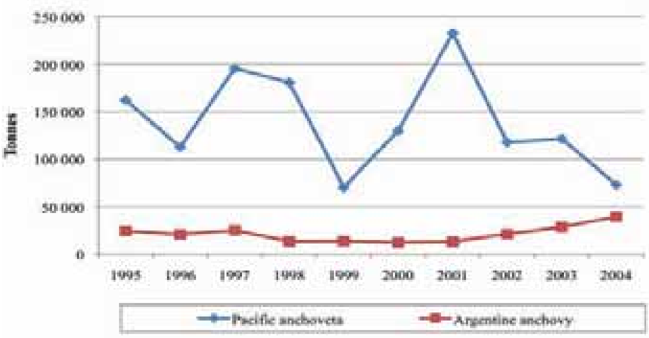
Information is currently only available at the country level (calculated from the FAO Food Balance Sheets) for 2003, with total fisheries production (capture fisheries and aquaculture combined) differentiated in terms of food uses (for direct human consumption) and non-food uses, including reduction 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



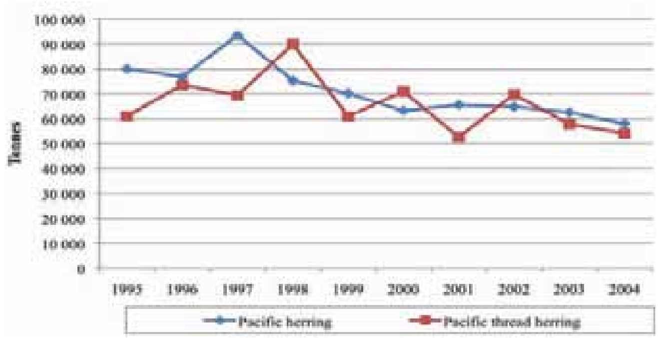
Source: FAO (2006a)

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



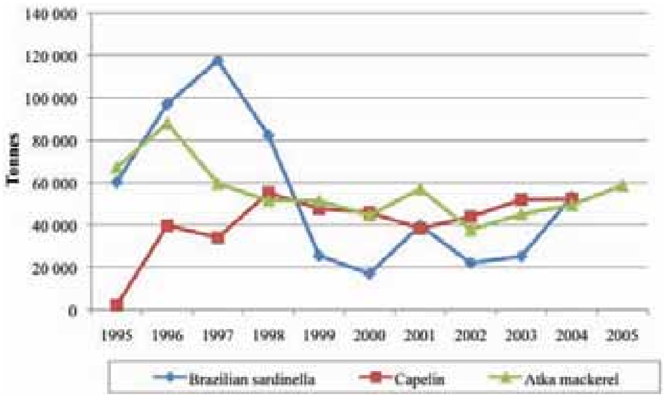
Source: FAO (2006a)

3.3 Fishmeal and fish oil production and trade

3.3.1 Fishmeal and fish oil production

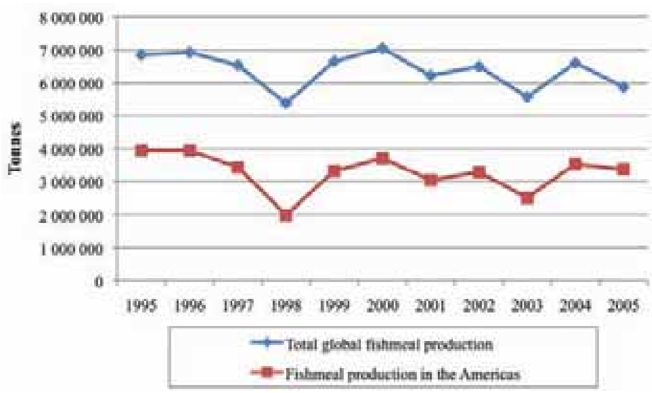
Total fishmeal and fish oil production within the Americas has fluctuated from a low of 2.0 million tonnes in 1998 to a high of 3.7 million tonnes in 2000 in the case of fishmeal (mean = 3.27 million tonnes) (Table 2, Figure 17) and from a low of 0.37 million tonnes in 1998 to a high of 0.90 million 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



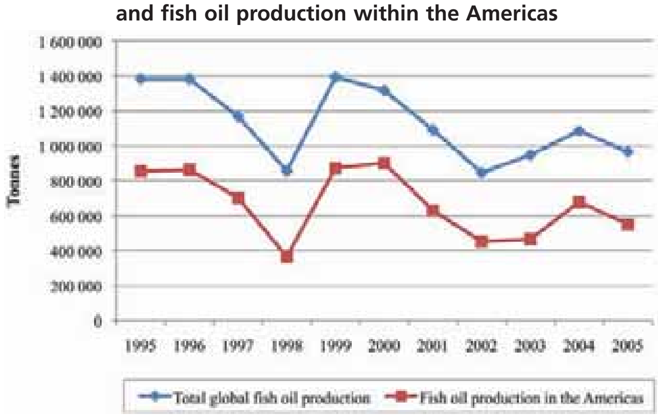
Source: FAO (2006a), except 2005 data from NMFS (2007)

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).

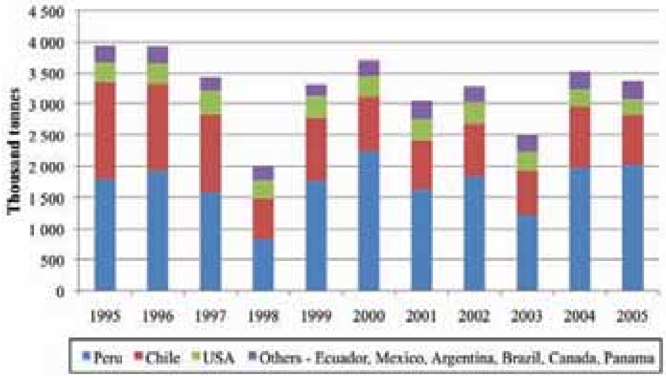
At the country level, Peru stands out as being the world's largest producer and exporter of fishmeal and fish oil (Figure 25) (FAO, 2006a; Mittaine, 2006).

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:

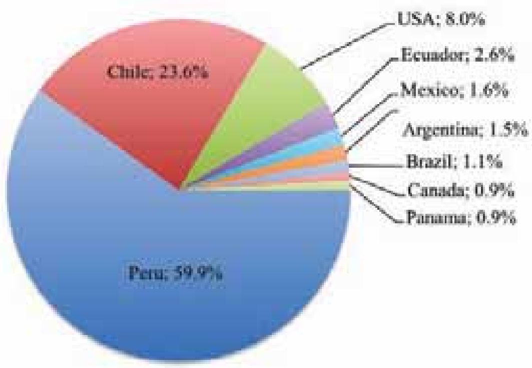
- United States of America (Figures 28 and 29): major exporter and increasing domestic consumer;
- Brazil (Figures 30 and 31): increasing domestic consumer;
- Ecuador (Figures 32 and 33): net exporter and increasing domestic consumer;

FIGURE 19
Fishmeal production by major country within the Americas



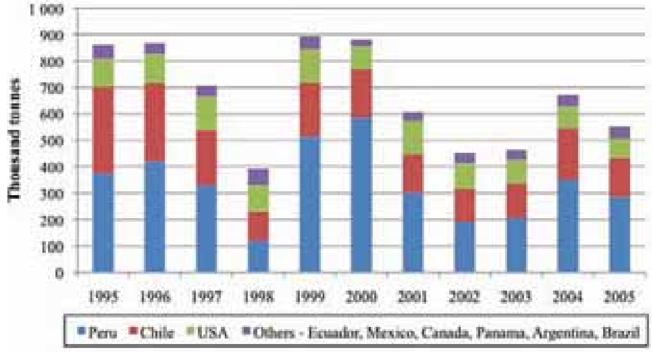
Source: FAO (2006a), except 2005 data from Mittaine (2006)

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

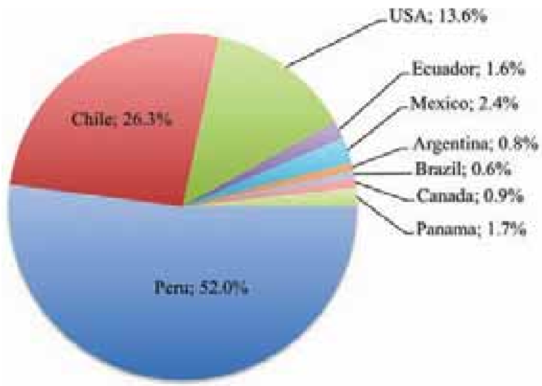
It is estimated that in 2004 the global finfish and crustacean aquaculture sector consumed 3 452 000 tonnes of fishmeal (Figure 40), which equates to 52.3 percent of the total global fishmeal production of 6 604 229 tonnes in 2004, and 893 400 tonnes of fish oil (Figure 41) or 82.2 percent of the total 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:

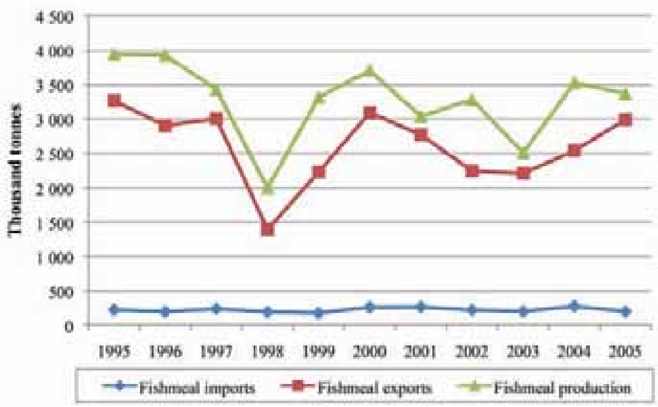
- **Salmon:** total production, 554 511 tonnes; feed use, 720 000 tonnes; average fishmeal content, 35 percent; fish oil content, 25 percent; estimated fishmeal use, 252 000 tonnes; fish oil use, 180 000 tonnes; total, 432 000 tonnes;
- **Shrimp:** total production, 294 227 tonnes; feed use, 455 000 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



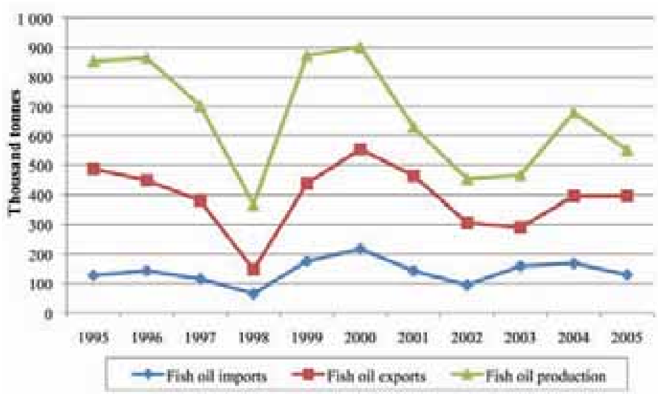
Source: Mittaine (2006)

FIGURE 23
Americas: fishmeal balance sheet



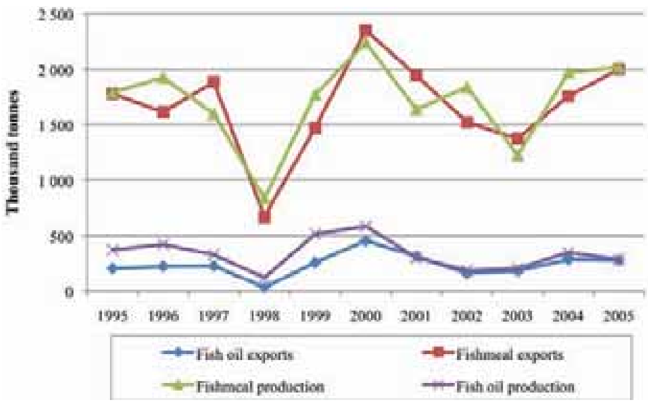
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 24
Americas: fish oil balance sheet



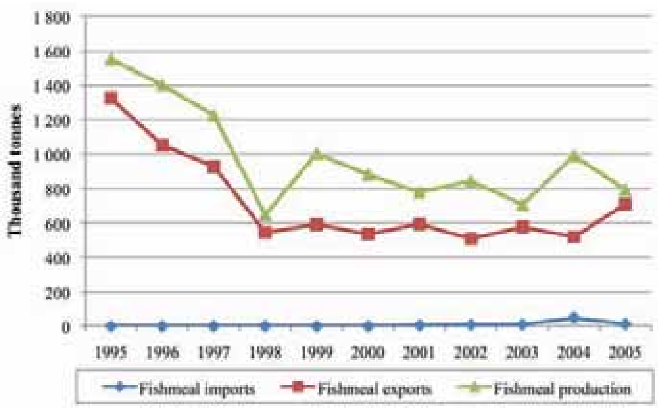
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 25
Peru: fishmeal and fish oil balance sheet



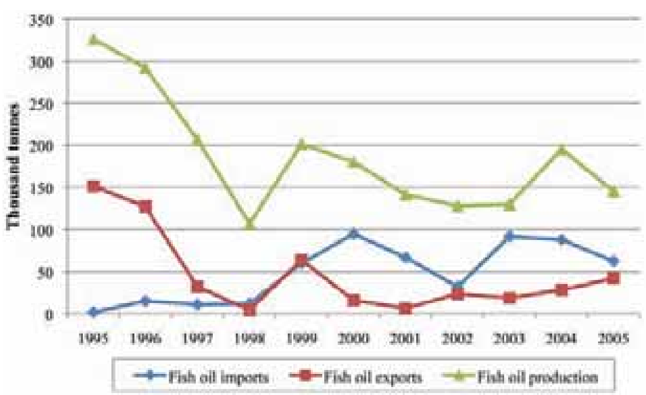
Source: FAO (2006a), except 2005 data from Mittaine (2006)

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.

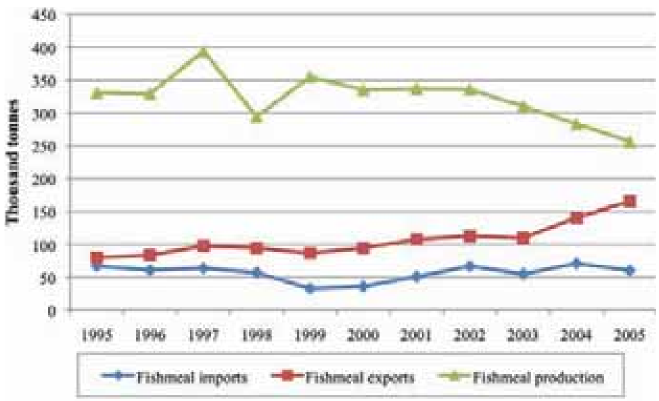
According to Aguila (2006), the salmonid aquaculture sector in Chile consumed 900 000 tonnes of compound aquafeeds in 2005, including 300 000 tonnes of domestically produced fishmeal and all of the nationally produced fish oil (over 117 300 tonnes in 2005).

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.

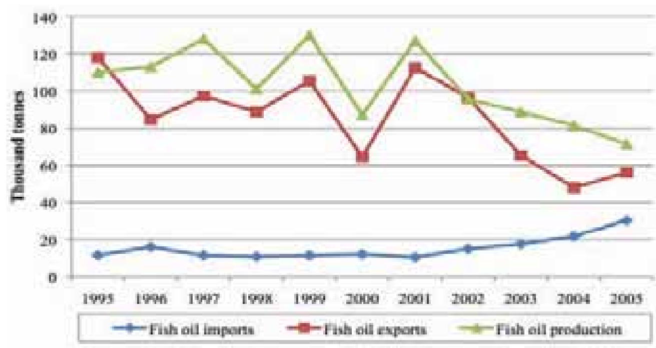
However, according to industry estimates, and in particular that of the International Fishmeal and Fish Oil Organisation (IFFO), fishmeal and fish oil use is expected to steadily increase, such that by 2012 aquaculture would use 60 percent of the global supplies of fishmeal and 88 percent of the global supplies of fish oil (Figures 44 and 45) (Jackson, 2006).

FIGURE 28
United States of America: fishmeal balance sheet



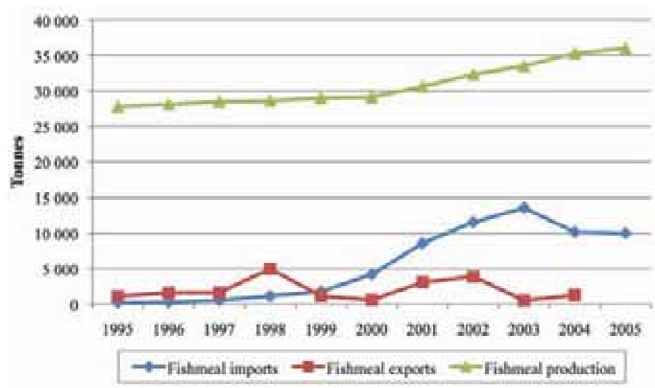
Source: FAO (2006a), except 2005 data from NMFS (2007)

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

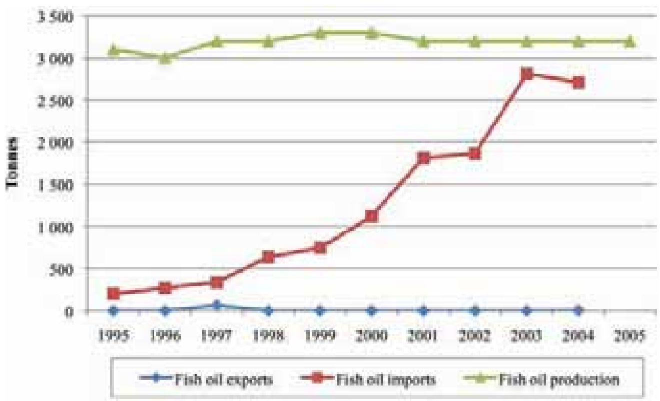


Source: FAO (2006a), except 2005 data from Mittaine (2006)

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)

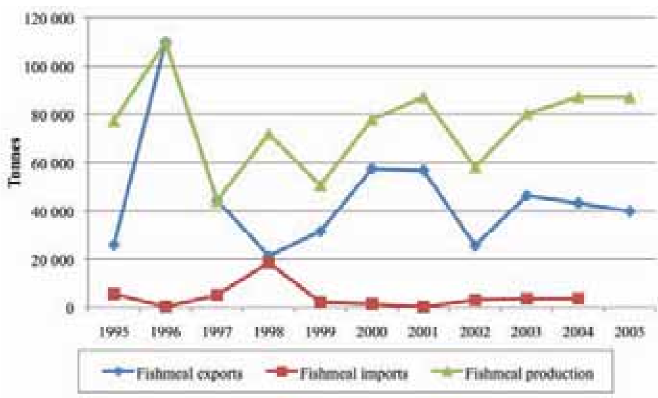
to Shepherd (2005) 14 percent of the total global production of fish oils in 2002 was used for edible purposes. However, no precise official statistical information exists concerning the use of fish oils for human consumption within the Americas.

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

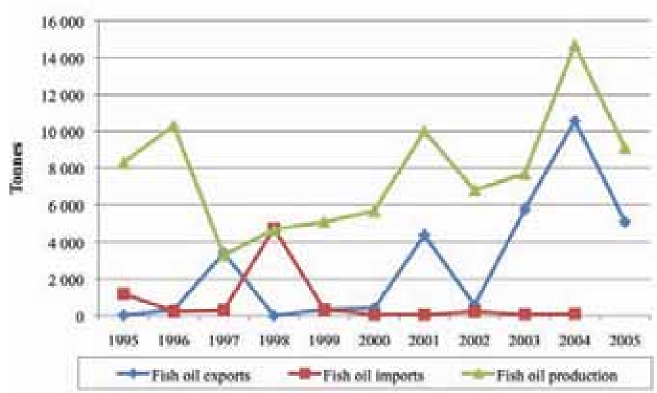
In addition to the targeted reduction of fish and shellfish species into fishmeal and fish oil, other non-food uses of fishery products include: 1) the use of fish as a direct aquaculture feed or within farm-made aquafeeds, 2) the use of fish and shellfish species as fishing bait for commercial fishing 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.

FIGURE 32
Ecuador: fishmeal balance sheet



Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 33
Ecuador: fish oil balance sheet



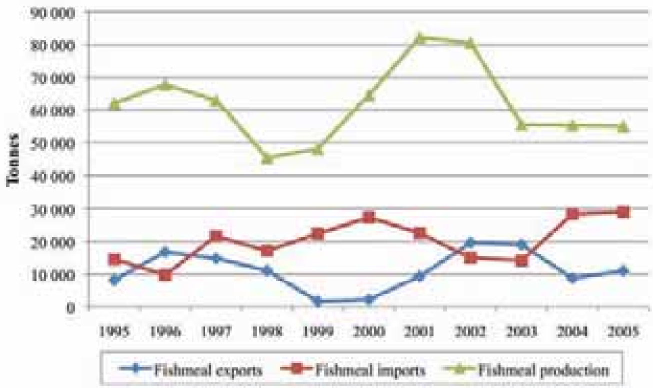
Source: FAO (2006a), except 2005 data from Mittaine (2006)

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 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.

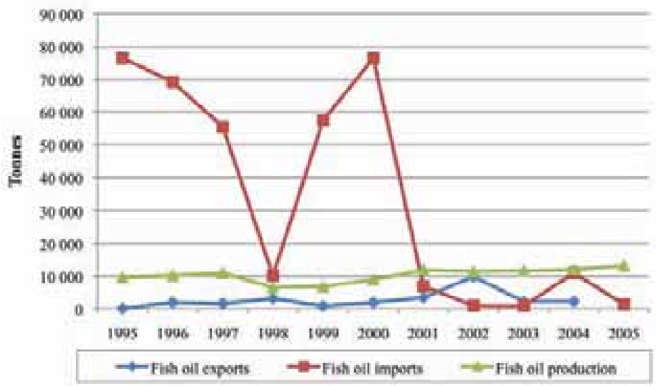
Other baitfish species reportedly used in the United States of America are anchovies (99 percent of all landings of 11 349 tonnes used as fish bait; NMFS, 2007), menhaden (small amounts used as bait for the Gulf Coast blue crab fishery; anon., 2000), mackerel (O'Malley, 2004) and sardines (Dalton, 2004).

FIGURE 34
Mexico: fishmeal balance sheet



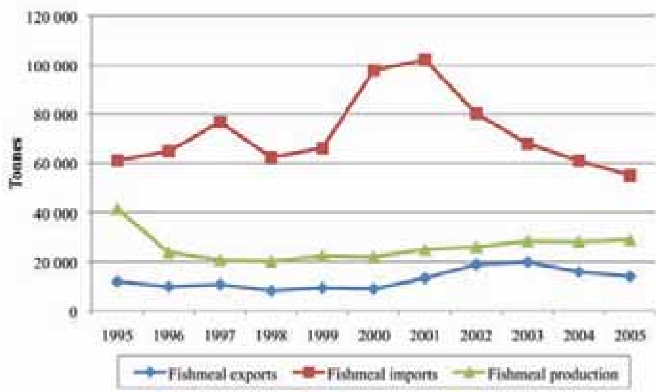
Source: FAO (2006a), except 2005 data from Mittaine (2006)

FIGURE 35
Mexico: fish oil balance sheet



Source: FAO (2006a), except 2005 data from Mittaine (2006)

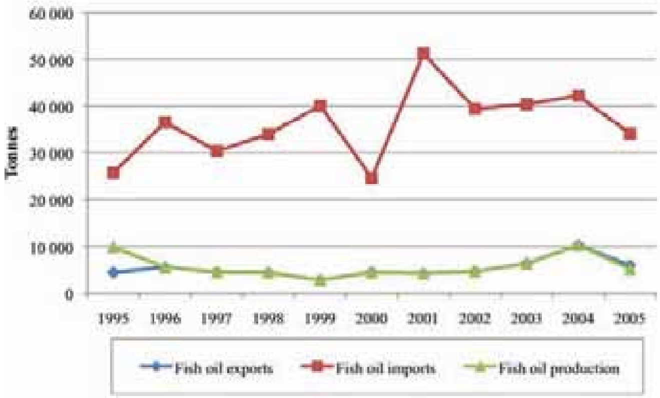
FIGURE 36
Canada: fishmeal balance sheet



Source: FAO (2006a), except 2005 data from Mittaine (2006)

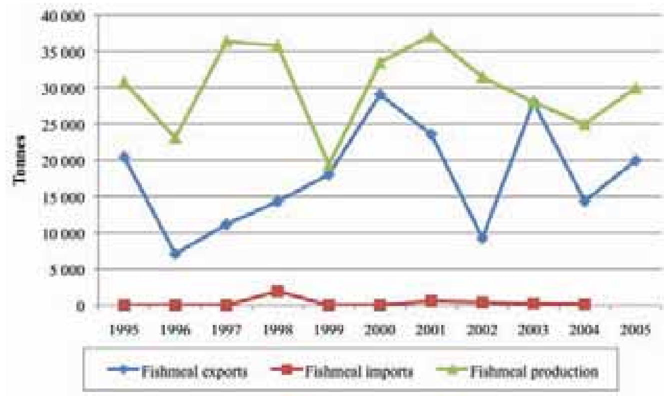
From the data presented in Table 6, South America (particularly because of Peru and Chile) stands out in that non-food uses of fishery products exceed that of food uses.

FIGURE 37
Canada: fish oil balance sheet



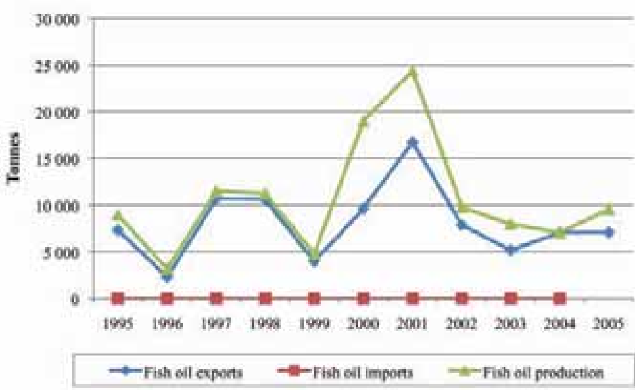
Source: FAO (2006a), except 2005 data from Mittaine (2006)

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.

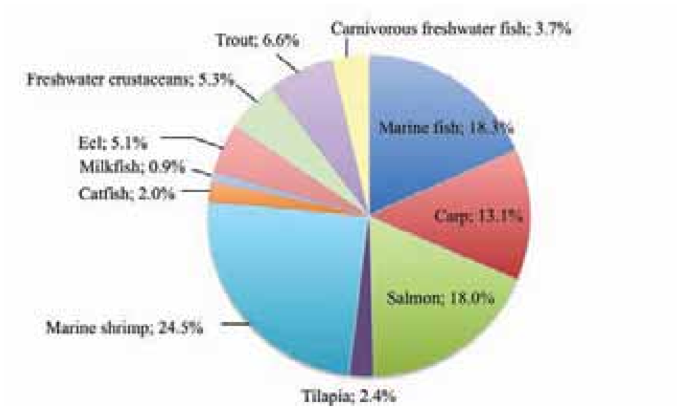
**** Adapted from Tacon (2006), and includes 6.2 and 1.2 thousand tonnes of fishmeal and fish oil for freshwater colossoma fish species.

§ 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)

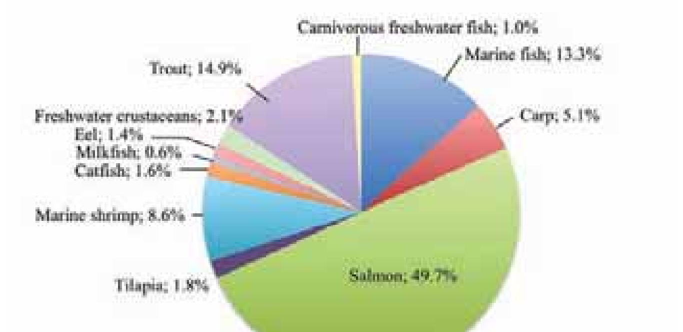
- **Antarctic krill:** Only the United States of America reported landings of 8 550 tonnes of Antarctic krill in 2004 (total global landings reported as 118 165 tonnes in 2004; FAO, 2006a). Krill is the one of the basic building blocks of the marine aquatic food chain and in reduced meal form is a good 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)

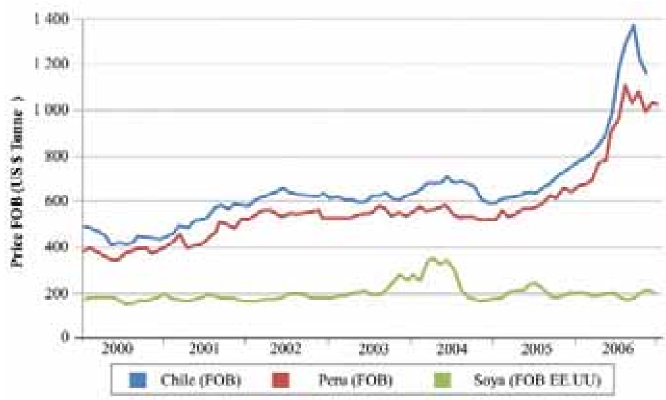
of high-quality marine protein and essential lipids, cholesterol, phospholipids, phosphorus and trace elements (Devresse, 1995; Chamberlain and Hunter, 2001; Cordova-Murueta and Garca-Carreno, 2002). The global market for squid meal in commercial aquafeeds is estimated to be between 25 000 and 75 000 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).

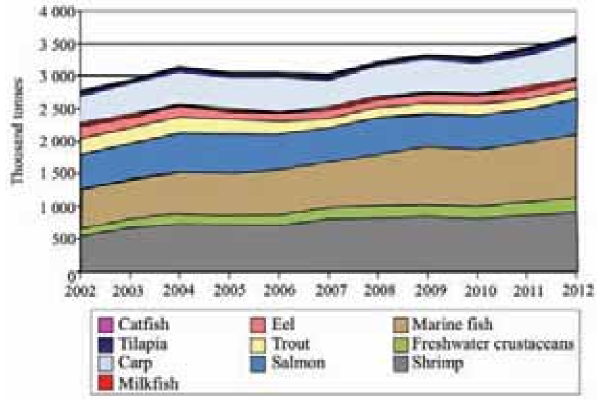
4. SUSTAINABILITY OF REDUCTION FISHERIES AND FEED USE

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.

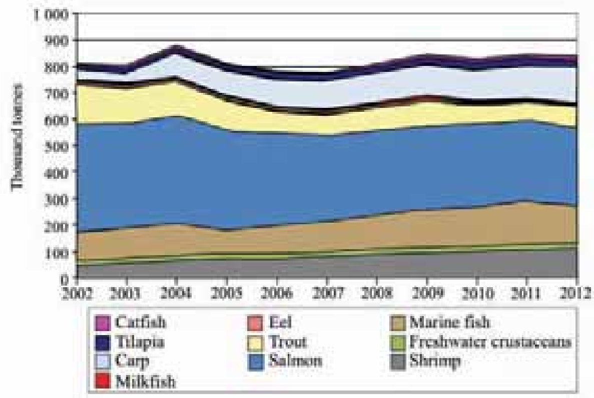
FIGURE 44
Projections of the use of fishmeal for the major fed species in aquaculture until 2012



Source: Jackson (2006)

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 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).

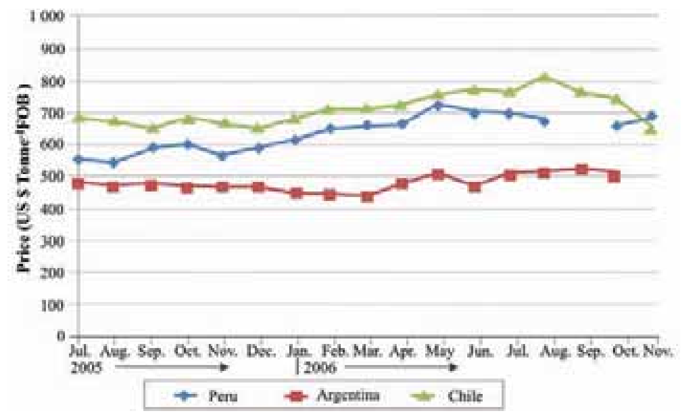
Apart from food security issues, there are also growing ecosystem function concerns regarding the potential accumulation of environmental contaminants (which include persistent organic pollutants (POPs) and heavy metals) within wild fish stocks and the possible short-and long-term impacts of these contaminants 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



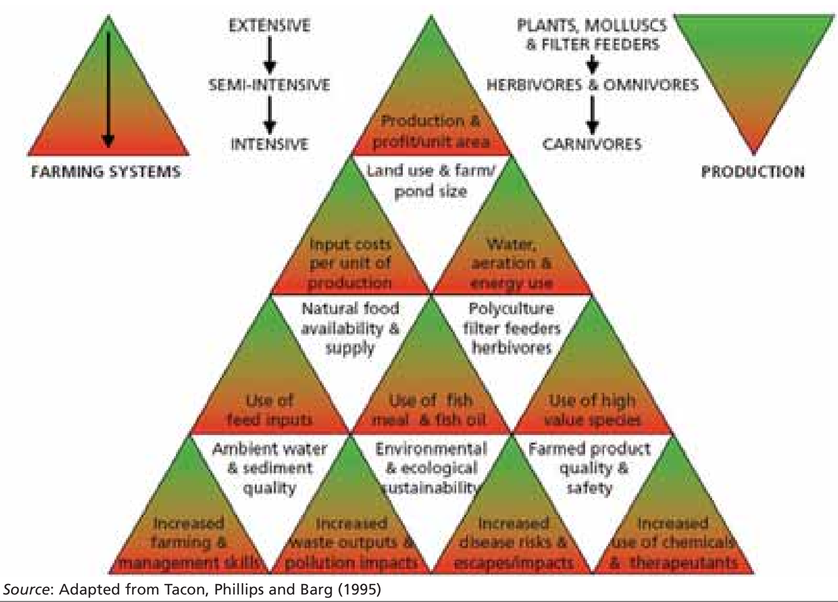
Source: anon (2007)

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

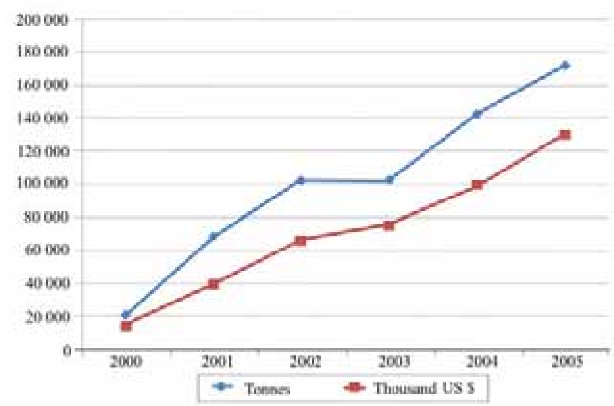
Direct environmental impacts include:

- 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:

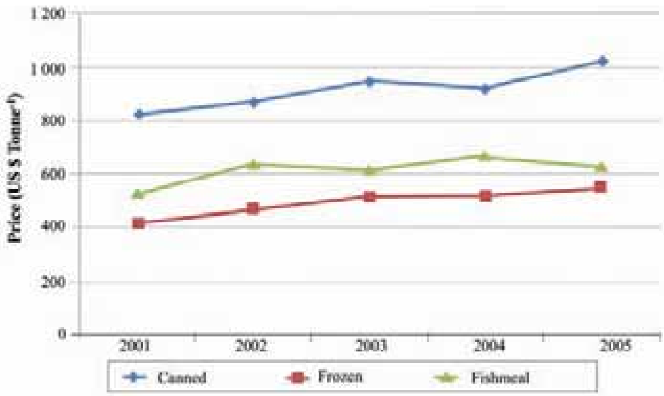
- removal of large quantities of forage fish species from the

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

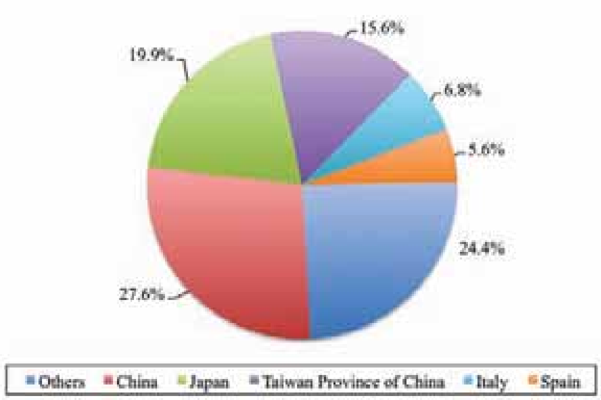
As mentioned previously, an increasing portion of the catch of Chilean jack mackerel and other pelagics (e.g. Patagonian grenadier and chub mackerel) is being processed for direct human consumption (Figure 48). Despite the fact that the average price for frozen jack mackerel and fishmeal is very similar (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).

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).

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).

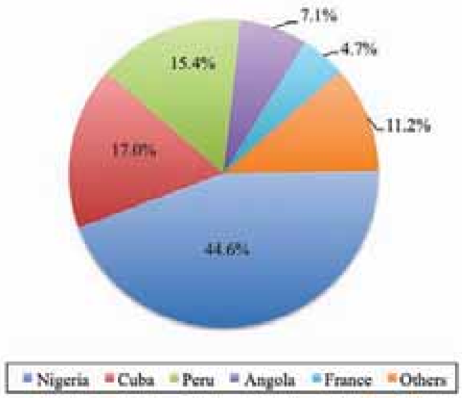
It is frequently stated that there is no cultural tradition for consumption of anchoveta in Peru (RPP, 2006; anon., 2007), and that it is for this reason that the bulk of the anchoveta catch is reduced to fishmeal for export and foreign cash earnings. However, this is not the case, as the earliest known 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 50
Principal export markets for Chilean jack mackerel fishmeal, 2004



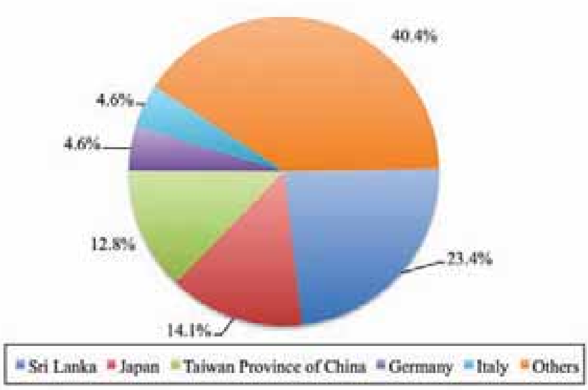
Source: SUBPESCA (2005)

FIGURE 51
Principal export markets for frozen Chilean jack mackerel, 2004



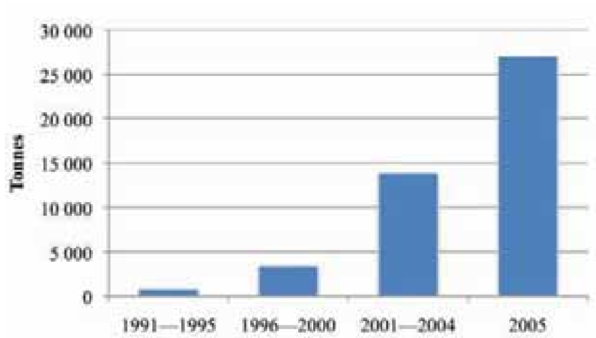
Source: SUBPESCA (2005)

FIGURE 52
Principal export markets for preserved Chilean jack mackerel, 2004



Source: SUBPESCA (2005)

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.

REFERENCES

ACIAR. 2001. *Management of tuna baitfish resources in Eastern Indonesia: final report 2001.* Canberra, Australia, A.C.T. Australian Centre for International Agricultural Research. 118 pp.

Aguila, M.P. 2006. Salmonicultura chilena en el 2005. Santiago, TechnoPress S.A., *Aqua Magazine*, May 2006, pp. 6–12.

Allan, G. 2004. Fish for feed vs fish for food. *In* A.G. Brown (ed.) *Fish, aquaculture and food security: sustaining fish as a food supply*, pp. 20–26. Record of a conference conducted by ATSE Crawford Fund, Parliament House, Canberra, 11 August 2004.

Anon. 2000. *Baitfish*. Florida Fish and Wildlife Conservation Commission, St. Petersburg, Florida, Florida Marine Research Institute (available at www.floridamarine.org).

Anon. 2002. *First city in the new world*? (available at www.smithsonianmag.com/history-archaeology/firstcity.html).

Anon. 2003. *Dioxins and PCBs in four commercially important fish stocks in the North East Atlantic*. A report financed by Nordisk Atlantsamarbejde (NORA) together with the Icelandic Association of Fish Meal Manufacturers and p/f Havsbrun Faroe Island. 57 pp.

Anon. 2005. *Risk on local fish populations and ecosystems posed by the use of imported feed fish by the tuna farming industry in the Mediterranean*. World Wildlife Fund Mediterranean Programme (available at www.wwf.or.jp/activity/marine/lib/wwfonenvironmentalriskoftunafarming-e.pdf).

Anon. 2007. Retornos de ostion del Norte aumentaron un 38 percent. Estadisticas de acuicultura y pesca. Santiago, TechnoPress S.A., *Aqua Magazine.* 88 pp. (available at www.aqua.cl/estadisticas/ESTADISTICASaqn111.pdf).

Anthonysamy, S.M. 2005. Anchovies: a rising star in the Malaysian seafood menu. *INFOFISH International*, 2/2005: 49–53.

AquaVision. 2006. *Kontali analyse*. AquaVision 2006 Meeting Conference Brochure, Stavanger, Norway, 25–27 September 2006 (available at www.aquavision.org)

Bechtel, P.J. 2003. *Advances in seafood by-products: 2002 conference proceedings*. Alaska Sea Grant College Program, University of Alaska, Fairbanks, Alaska. 566 pp.

Bell, J.G., McGhee, F., Dick, J.R. & Tocher D.R. 2005. Dioxin and dioxin-like polychlorinated biphenyls (PCBs) in Scottish farmed salmon (*Salmo salar*): effects of replacement of dietary marine fish oil with vegetable oils. *Aquaculture*, 243(1–4): 305–314.

Bentis, C.A., Zotos, A. & Petridis, D. 2005. Production of fish-protein products (surimi) from small pelagic fish (*Sardinops pilchardus*), underutilized by the industry. *Journal of Food Engineering*, 68(3): 303–308.

Bertullo, E., Pollak, A., Gilardoni, D., Gomez, F. & Cantera, C. 2004. Producing surimi from under-exploited resources. *INFOPESCA Internacional*, 20: 29–34.

Bethune, C., Seierstad, S.L., Sljeflot, I., Johansen, O., Arnesen, H., Meltzer, H.M., Rosenlund, G., Froyland, L. & Lundebye, A-K. 2006. Dietary intake of differently fed salmon: a preliminary study on contaminants. *European Journal of Clinical Investigation*, 36(3): 193–201.

Bimbo, A.P. & Crowther, J.B. 1992. Fish meal and fish oil: current uses. *Journal of the American Oil Chemists Society*, 69: 221–227.

Bjørndal, T., Gordon, D., Kaitala, V. & Lindroos, M. 2004. International management strategies for a straddling fish stock: a bio-economic simulation model of the Norwegian spring-spawning herring fishery. *Environmental and Resource Economics*, 29(4): 435–457.

Black, K.D. 2001. *Environmental impacts of aquaculture*. Sheffield, England, United Kingdom, Sheffield Academic Press. 228 pp.

Brooks, K.M., Mahnken, C. & Nash, C. 2002. Environmental effects associated with marine netpen waste and emphasis on salmon farming in the Pacific Northwest. *In* R.R. Stickney and J.P. MacVey (eds.). *Responsible marine aquaculture*, pp. 159–204. New York, CABI Publishing. 391 pp.

Cabrer, A.I., Casales, M.R. & Yeannes, M.I. 2002. Physical and chemical changes in anchovy (*Engraulis anchoita*) flesh during marination. *Journal of Aquatic Food Product Technology*, 11(1): 19–30.

Careche, M., Garcia, R. & Borderias, J. 2002. Anchovy shelf life as affected by different chilling methods during distribution. *Journal of Food Protection*, 65(2): 353–361.

Chamberlain, G.W. & Hunter, B. 2001. Feed additives: global shrimp OP: 2001 preliminary report. *The Global Aquaculture Advocate*, 4(4): 61–65.

Cho, C.Y. & Bureau, D.P. 2001. A review of diet formulation strategies and feeding systems to reduce excretory and feed wastes in aquaculture. *Aquaculture Research*, 32(Suppl. 1): 349–360.

Chquin, C. 2006. *Gobierno peruano busca promover consumo humano de anchoveta, jurel, caballa y pota*. Pescaaldia, plataforma de servicios y comercio electronico para la industria pesquera y acuicultora. 28 November 2006.

Cordova-Murueta, J.H. & Garca-Carreno, F.L. 2002. Nutritive value of squid and hydrolyzed protein supplement in shrimp feed. *Aquaculture*, 210(1): 371–384.

Crapo, C. & Bechtel, P. 2003. Utilization of Alaska's seafood processing by-products. *In* P.J. Bechtel (ed.). *Advances in seafood by-products: 2002 conference proceedings*, pp. 105–119. Alaska Sea Grant College Program, University of Alaska, Fairbanks, Alaska.

Crowther, J.B., Booth, B.H. & Blackwell, D.D. 2002. *Process for producing edible quality refined fish oil from menhaden, and other similar fish containing omega-3 long chain fatty acids*. United States Patent number 6190715 (available at www.freepatentsonline.com/6190715.html).

Dalton, R. 2004. Fishing for trouble. *Nature*, 431: 502–504.

Diei-Ouadi, Y. 2005. *Minced sardinella fillets in fish-landing and marketing sites in Senegal*. FAO Fisheries Circular No. 999. Rome, FAO. 20 pp.

Devresse, B. 1995. Nutrient levels in some commercial shrimp feeds and feed ingredients of Asia and Latin America – a comparative analysis. In *Proceedings of the Feed Ingredients Asia '95*, pp. 49–70. Singapore International Convention & Exhibition Centre, Singapore, 19–21 September 1995. United Kingdom, Turret Group PLC.

Dorea, J.G. 2006. Fish meal in animal feed and human exposure to persistent bioaccumulative and toxic substances. *Journal of Food Protection*, 69(11): 2777–2785.

Easton, M.D.L., Luszniak, D. & Von der Geest, E. 2002. Preliminary examination of contaminant loadings in farmed salmon, wild salmon and commercial salmon feed. *Chemosphere*, 46(7): 1053–1074.

EC. 2002. *Preparatory actions in the field of dioxin and PCBs*. Executive summary. European Commission, European POPs Expert Team, April 2002. 14 pp.

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, Canberra, Australia, Australian Centre for International Agricultural Research. 56 pp.

Elliot, M. 2006. *American lobster Homarus americanus*. Seafood Watch Seafood Report. Monterey Bay Aquarium, 2 February 2006. 66 pp. (available at www.montereybayaquarium.org/cr/cr_seafoodwatch/content/media/MBA_SeafoodWatch_AmericanLobsterReport.pdf).

Falandysz, J. 2003. Chloronaphthalenes as food-chain contaminants: a review. *Food Additives and Contaminants*, 20(11): 995–1014.

FAO. 1986. *The production of fishmeal and oil*. FAO Fisheries Technical Paper No. 142 (Rev.1). Rome. 63 pp.

FAO. 1995. *Code of conduct for responsible fisheries*. Rome, FAO. 41 pp.

FAO. 1998. *Responsible fish utilization*. FAO Technical Guidelines for Responsible Fisheries No. 7. Rome. 33 pp.

FAO. 1999. *Indicators for sustainable development of marine capture fisheries*. FAO Technical Guidelines for Responsible Fisheries No. 8. Rome. 68 pp.

FAO. 2003. *Fisheries management 2. The ecosystem approach to fisheries*. FAO Technical Guidelines for Responsible Fisheries No. 4 (Suppl. 2). Rome. 112 pp.

FAO. 2004. *Overfishing on the increase in Asia-Pacific seas: decline in valuable fish species, better management required*. FAO report, FAO Newsroom (available at www.fao.org/newsroom/en/news/2004/49367/index.html).

FAO. 2005. *Review of the state of world marine fishery resources*. FAO Fisheries Technical Paper No. 457. Rome. 235 pp.

FAO. 2006a. *Fishstat plus: universal software for fishery statistical time series*. Aquaculture production: quantities 1950–2004, aquaculture production: values 1984–2004; capture production: 1950–2004; commodities production and trade: 1950–2004; total production: 1970–2004, Vers. 2.30. FAO Fisheries Department, Fishery Information, Data and Statistics Unit.

FAO. 2006b. *State of world aquaculture 2006*. FAO Technical Paper No. 500. Rome. 134 pp.

FAO. 2006c. *Undernourishment* (latest version available at http://www.fao.org/faostat/foodsecurity).

FAO. 2006d. *Fish and fishery products: apparent consumption* (available at www.fao.org).

FAO. 2006e. *FAOSTAT database-population* (latest version available at http://faostat.fao.org/site/452/default.aspx).

Flores, R. 2006. *Experiencia del Peru en el sistema de administracion de asignacion de cuotas indivuales de pesca*. Paper presented at the "Taller sobre Cuotas Individuales Transferibles", 5–6 September 2006, Lima, Comision Permanente del Pacifico Sur – CPPS.

Flores-Nava, A. 2007. Feeds and fertilizers for sustainable aquaculture development: a regional development for Latin America. *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. 49–75. FAO Fisheries Technical Paper No. 497. Rome, FAO.

Foran, J.A, Carpenter, D.O., Coreen, H.M., Knuth, B.A. & Schwager, S.J. 2005. Risk-based consumption advice for farmed Atlantic and wild Pacific salmon contaminated with dioxins and dioxin-like compounds. *Environmental Health Perspectives*, 113(5): 552–556.

Fountain, H. 2001. Archaeological site in Peru is called oldest city in Americas. *The New York Times*, 27 April 2001 (available at http://192.211.16.13/curricular/hacop/CaralPeru.htm).

Fox, C.J., Blow, P., Brown, J.H. & Watson, I. 1994. The effect of various processing methods on the physical and biochemical properties of shrimp head meals and their utilization by juvenile *Penaeus mondon* Fab. *Aquaculture*, 122: 209–226.

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

Gelman, A., Cogan, U., Mokady, S., Drabkin V. & Glatman, L. 2003. Obtaining human food from whole under utilized fish. *In* P.J. Bechtel (ed.). *Advances in seafood by-products: 2002 conference proceedings*, pp. 403–420. Alaska Sea Grant College Program, University of Alaska, Fairbanks, Alaska.

Gill, T.A. 2000. *Waste from processing aquatic animals and animal products: implications on aquatic pathogen transfer*. FAO Fisheries Circular No. 956. Rome, FAO. 26 pp.

Goldburg, R., Elliot, M.S. & Naylor, R.L. 2001. *Marine aquaculture in the United States: environmental impacts and policy options*. Arlington, Virginia, USA, Pew Oceans Commission. 33 pp.

Goldburg, R. & Naylor, R. 2005. Future escapes, fishing, and fish farming. *Frontiers in Ecology and the Environment*, 3(1): 21–28.

Hansen, P. 1996. Food uses of small pelagics. *INFOFISH International*, 4: 46–52.

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

Harrington, J.M., Myers, R.A. & Rosenberg, A.A. 2005. Wasted fishery resources: discarded by catch in the United States of America. *Fish & Fisheries*, 6(4): 350–361.

Herrmann, T., Collingro, C. & Papke, O. 2004. Overview of levels of dioxins, PCBs and other POPs found in fish meal, fish oil and fish feed marketed in the EU. In *Organohalogen compounds*, Volume 66, pp. 2122–2126.

Hertrampf, J.W. & Piedad-Pascual, F. 2000. *Handbook on ingredients for aquaculture feeds*. Dordrecht, Boston, London, Kluwer Academic Publishers. 573 pp.

Hill, S.L., Murphy, E.J., Reid, K., Trathan, P.N. & Constable, A.J. 2006. Modelling southern ocean ecosystems: krill, the food-web, and the impacts of harvesting. *Biological Reviews,* 81(4): 581–608.

Hinck, J., Schmitt, C., Echols, K., May, T., Orazio, C. & Tillitt, D. 2006. Environmental contaminants in fish and their associated risk to piscivorous wildlife in the Yukon river basin, Alaska. *Archives of Environmental Contamination and Toxicology*, 51(4): 661–672.

Hites, R.A., Foran, J.A., Carpenter, D.O., Hamilton, M.C., Knuth, B.A. & Schwager, S.J. 2004a. Global assessment of organic contaminants in farmed salmon. *Science*, 303: 226–229.

Hites, R.A, Foran, J.A., Schwager, S.J., Knuth, B.A., Hamilton, M.C. & Carpenter, D.O. 2004b. Global assessment of polybrominated diphenyl ethers in farmed and wild salmon. *Environmental Science & Technology,* 38(19): 4945–4949.

Huntington, T.C. 2004. *Feeding the fish: sustainable fish feed and Scottish aquaculture*. Report to the Joint Marine Programme (Scottish Wildlife Trust and WWF Scotland) and RSPB Scotland. Lymington, Hampshire, United Kingdom, Poseidon Aquatic Resource Management Ltd. 41 pp. (available at www.wwf.org.uk/filelibrary/pdf/feedingthefish.pdf).

Huntington, T., Frid, C., Banks, R., Scott, C. & Paramor, O. 2004. *Assessment of the sustainability of industrial fisheries producing fish meal and fish oil.* Report to the Royal Society for the Protection of Birds (RSPB). Lymington, Hampshire, United Kingdom, Poseidon Aquatic Resource Management Ltd. 105 pp. (available at www.rspb.org.uk/Images/fishmeal_tcm9-132911.pdf).

Ida, T. 2006. Tuna farms that are feeding Japan seen as a threat to natural stocks. *The Japan Times*, Jan 24, 2006 (available at http://search.japantimes.co.jp/cgi-bin/nn20060124f1.html)

Jackson, A.J. 2006. The importance of fishmeal and fish oil in aquaculture diets. *International Aquafeed*, 9(6): 18–21.

Jara, C.T. 2006. *Cuotas individuales por empresa: perspectivas empresarial*. Paper presented at the "Taller sobre cuotas individuales transferibles", Lima, Peru, 5–6 de September 2006. Comision Permanente del Pacifico Sur (CPPS).

Jo, J-H., Oh, S-W. & Choi, J-G. 1999. Processing of fermented and powdered anchovy seasoning material. *Journal of the Korean Fisheries Society*, 32(6): 725–729.

Joas, R., Potrykuse, A. & Chambers, G. 2001. *Effects on the fisheries industry of the Commission proposals (SANCO) on dioxin content of fish, fish oil and fish meal as part of animal feed regulations*. Scientific and Technological Options Assessment Series. European Parliament Directorate-General for Research, Working Paper STOA 101 EN. 55 pp.

Kaba, N. 2006. The determination of technology and storage period of surimi production from anchovy (*Engraulis encrasicholus,* L., 1758). *Turkish Journal of Fisheries and Aquatic Sciences*, 6(1): 29–35.

Kelleher, K. 2005. *Discards in the world's marine fisheries. An update*. FAO Fisheries Technical Paper No. 470. Rome, FAO. 131 pp.

Korsager, H. 2004. *Commercial implications to the European fishmeal and fish oil industry*. Paper presented at a workshop on possibilities of decontamination of fish oil and fish meal for dioxins, PCBs and other persistent organochloride compounds, Brussels, 3 September 2004.

Kotzamanis, Y.P., Alexis, M.N., Andriopoulou, A., Castritsi-Cathariou, I. & Fotis, G. 2001. Utilization of waste material resulting from trout processing in gilthead bream (*Sparus aurata* L.) diets. *Aquaculture Research*, 32(1): 288–295.

Kristofersson, D. & Anderson, J.L. 2006. Is there a relationship between fisheries and farming? Interdependence of fisheries, animal production and aquaculture. *Marine Policy*, 30: 721–725.

Lankester, K. 2005. *Sustainability in the anchoveta fisheries in Peru: descriptive background document*. Report to the Netherlands Committee for IUCN. Amsterdam, the Netherlands. 24 pp.

Letcher, R.J.,Fernie, K, Wesloh, D.V.C., Shahmiri, S. & Gauthier, L. 2006. *Novel brominated and chlorinated hydrocarbon contaminants in fish-eating waterbirds from the Great Lakes: presence and trends in herring gulls* (Larus argentatus) *and peregrine falcons* (Falco peregrinus). Paper presented at the Annual Conference on Great Lakes Research. Great Lakes in a Changing Environment, Windsor, Ontario, Canada, 22–26 May 2006.

Lin, C.K. & Yi, Y. 2003. Minimizing environmental impacts of freshwater aquaculture and reuse of pond effluents and mud. *Aquaculture*, 226: 57–68.

Low, L.L. 2003. Future of Alaska's fisheries resources. *In* P.J. Bechtel (ed.). *Advances in seafood by-products: 2002 conference proceedings*, pp. 83–103. Alaska Sea Grant College Program, University of Alaska, Fairbanks, Alaska, USA.

Masser, M.P. & Bridger, C.J. 2006. *A review of cage culture in North America*. Paper presented at the 2nd International Symposium on Cage Aquaculture in Asia, Hangzhou, China, 3–8 July 2006.

Mente, E., Pierce, G.J., Santos, M.B. & Neofitou, C. 2006. Effect of feed and feeding in culture of salmonids on the marine aquatic environment: a synthesis for European aquaculture. *Aquaculture International,* 14: 499–522.

Miles, R.D. & Chapman, F.A. 2006. *The benefits of fish meal in aquaculture diets.* Document FA122, Department of Fisheries and Aquatic Sciences, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. 7 pp. (available at http://edis.ifas.ufl.edu/pdffiles/FA/FA12200.pdf).

Mittaine, J-F. 2006. *Fishmeal and fish oil statistical yearbook*. 2006 annual conference, Barcelona, Spain. St. Albans, United Kingdom, International Fishmeal and Fish Oil Organisation. 45 pp.

Muñoz, J.N. 2006. *Synopsis of salmon farming impacts and environmental management in Chile.* Consultancy Technical Report. Valdivia, Chile, WWF. 46 pp.

Murphy, E.J., Watkins, J.L., Trathan, P.N., Reid, K., Meredith, M.P., Thorpe, S.E., Johnston, N.M., Clarke, A., Tarling, G.A., Collins, M.A., Forcada, J., Shreeve, R.S., Atkinson, A., Korb, R., Whitehouse, M.J., Ward, P., Rodhouse, P.G., Enderlein, P., Hirst, A.G., Martin, A.R., Hill, S.L., Staniland, I.J., Pond, D.W., Briggs, D.R., Cunningham, N.J. & Fleming, A.H. 2007. Spatial and temporal operation of the Scotia Sea ecosystem: a review of large-scale links in a krill centred food web. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences*, 362(1477): 113–148.

Naylor, R.L., Goldberg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. & Troell, M. 2000. Effects of aquaculture on world fish supplies. *Nature*, 405: 1017–1024.

Naylor, R., Hindar, K., Fleming, I.A., Goldburg, R., Williams, S., Volpe, J., Whoriskey, F., Eagle, J., Kelso, D. & Mangel, M. 2005. Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture. *BioScience*, 55: 427–473.

Nicol, S. 2006. Krill, currents, and sea ice: *Euphausia superba* and its changing environment. *BioScience*, 56(2): 111–120.

Nicol, S. & Endo, Y. 1997. *Krill fisheries of the world*. FAO Fisheries Technical Paper No. 367. Rome, FAO. 100 pp.

NMFS. 2007. *Fisheries of the United States 2005.* Current Fisheries Statistics No. 2005. Silver Spring, Maryland, United States of America, National Marine Fisheries Service, National Oceanic and Atmospheric Administration. 104 pp.

Normile, D. 2002. Poor to feel pinch of rising prices. *Science*, 298: 5596.

O'Malley, J.M. 2004. *Trap-weight influence on catches of Hawaiian spiny lobster (Panulirus marginatus) and scaly slipper lobster (Scyllarides squammosus) from the northwestern Hawaiian Islands*. Pacific Islands Fisheries Science Center, Administrative Report H-04-06. Honolulu, Hawaii, Joint Institute for Marine and Atmospheric Research, University of Hawaii. 12 pp.

Oterhals, A. 2004. *Reduction of persistent organic pollutants (POPs) in fish oil and fish meal – technical possibilities and perspectives*. Paper presented at a workshop on possibilities of decontamination of fish oil and fish meal for dioxins, PCBs and other persistent organochlorine compounds. Brussels, 3 September 2004.

Ottolenghi, F., Silvestri, C., Giordano, P., Lovatelli, A. & New, M.B. 2004. *Capture-based aquaculture. The fattening of eels, groupers, tunas and yellowtails*. Rome, FAO. 308 pp.

Park, J.W. 2005. *Surimi and surimi seafood.* 2nd Edn. Boca Raton, Florida, Taylor & Francis. 960 pp.

Park, J.W. & Lanier, T.C. 2000. Processing of surimi and surimi seafoods. In Martin, R. E., Carter, E.P., Flicks, Jr., G. J., and L.M. Davis (eds.). *Marine and freshwater products handbook*, pp. 417–444. Technomic Publishing Co, Lancaster, Pennsylvania.

Parsons, S. 2005. Ecosystem considerations in fisheries management: theory and practice. *International Journal of Marine & Coastal Law*, 20(3–4): 381–422.

Pescaaldia. 2007. *Chile: precios de harina de pescado se mantendran sobre los US$1 000*. Plataforma de servicios y comercio electronico para la industria pesquera y acuicultora, 5 February 2007 (available at www.catpes.com/ver2.asp?ID=3772).

Piedrahita, R.H. 2003. Reducing the potential environmental impact of tank aquaculture effluents through intensification and recirculation. *Aquaculture*, 226(1): 35–44.

Pongmaneerat, J., Kasornchandra, J., Boonyaratpalin, S. & Boonyaratpalin, M. 2001. Effect of dietary shrimp head meal contaminated with white spot syndrome virus (WSSV) on detection of WSSV in black tiger shrimp (*Penaeus monodon,* Fabricius). *Aquaculture Research,* 32(1): 383–387.

Reid, K. & Croxall, J.P. 2001. Environmental response of upper trophic-level predators reveals a system change in an Antarctic marine ecosystem. *Proceedings of the Royal Society London, Series B, Biological Sciences,* 268(1465): 377–384.

Rojas, A., Simonsen, S. & Wadsworth, S. 2006. *A review of cage culture in Latin America and the Caribbean.* Paper presented at the Second International Symposium on Cage Aquaculture in Asia, Hangzhou, China, 3–8 July 2006.

Ross, P.S. 2002. The role of immunotoxic environmental contaminants in facilitating the emergence of infectious diseases in marine mammals. *Human and Ecological Risk Assessment*, 8(2): 277–292.

RPP. 2006. Contra la desnutricion: anchoveta. 6 de diciembre 2006. Radio Programas del Peru.

Rutman, M., Diaz. L. & Hinrichsen, J.P. 2003. By-products from Chile and the Antarctic. *In* P.J. Bechtel (ed.). *Advances in seafood by-products: 2002 conference proceedings*, pp. 63–67. Alaska Sea Grant College Program, University of Alaska, Fairbanks, Alaska.

Sanchez-Monsalvez, I., De Armas-Serra, C., Martinez, J., Dorado, M. Sanchez, A. & Rodriguez-Cabeiro, F. 2005. A new procedure for marinating fresh anchovies and ensuring the rapid destruction of *Anisakis* larvae. *Journal of Food Protection*, 68(5): 1066–1072.

SCAHAW. 2003. *The use of fish by-products in aquaculture*. Report of the Scientific Committee on Animal Health and Animal Welfare. European Commission. (available at http://ec.europa.eu/food/fs/sc/scah/out87_en.pdf)

SCAN. 2000. *Opinion of the Scientific Committee on Animal Nutrition on the dioxin contamination of feedingstuffs and their contribution to the contamination of food of animal origin, adopted on 06.11.2000*. European Commission, DG Health and Consumer Protection.

SEAFEEDS. 2003. *Sustainable Environmental Aquaculture Feeds*. Final report of the SEAFEEDS workshop organized and chaired by Nautilus Consultants in association with the Stirling University Institute of Aquaculture, Stirling, United Kingdom, 8–9 April 2003. (available at www.nautilus-consultants.co.uk/seafeeds/Files/Final%20Report.pdf).

Sen, M.K.C. & Temelli, S. 2003. Microbiological and chemical qualities of marinated anchovy prepared with different vegetable additives and sauce. *Revue de Medecine Veterinaire*, 154(11): 703–707.

SERNAC. 2007. *Consejos: en semana santa: coma pescado sano, coma pecado en conserva*. Gobierno de Chile, February 2007. Servicio Nacional del Consumidor. (available at www.sernac.cl/consejos/detalle.php?id=1211).

Shepherd, J. 2005. Fishmeal and fish oil: sustainability and world market prospects. *International Aquafeed*, 8(4): 19–21.

Shi, L., Shan, Z., Kong, D. & Cai, D. 2006. The health and ecological impacts of organochlorine pesticide pollution in China: bioaccumulation of organochlorine pesticides in human and fish fats. *Human & Ecological Risk Assessment*, 12(2): 402–407.

Skewgar, E., Boerma, P.D., Harris, G. & Caille, G. 2007. Anchovy fishery threat to Patagonian ecosystem. *Science*, 315: 45.

Smith, J.W. & Ahrenholtz, D.W. 2000. The ancillary harvest of Atlantic menhaden, *Brevoortia tyrannus*, roe on the North Carolina coast. *Marine Fisheries Review*, 62(1): 1–7.

SNP. 2006. *Perspectivas del sector pesquero privado del Peru*. Paper presented at the "Taller sobre cuotas individuales transferibles", Lima, Peru, 5–6 September 2006. Sociedad Nacional de Pesqueria. Comision Permanente del Pacifico Sur (CPPS).

SUBPESCA. 2005. *Cuota global annual de captura de jurel, ano 2006*. Informe tecnico (r.pesq.), No. 103/2005, Subsecretaria de Pesca, Gobierno de Chile (available at www.subpesca.cl).

SUBPESCA. 2006a. *Informe consolidado de pesca y acuicultura 2005*. Departamento de Analisis Sectorial, Subsecretaria de Pesca, Gobierno de Chile (available atwww.subpesca.cl).

SUBPESCA. 2006b. A*nchoveta* (Engraulis ringens) *I–IV & V–X. Ficha biologica pesquera*. Subsecretaria de Pesca, Gobierno de Chile (available at www.subpesca.cl).

SUBPESCA. 2006c. *Merluza de tres aletas* (Micromesistius australis*)*. Ficha Pesquera No. 4. Subsecretaria de Pesca, Gobierno de Chile (available at www.subpesca.cl).

SUBPESCA. 2006d. *Estado de situacion de los recursos pesqueros - 2005, fichas tecnicas de recursos-peces, informes sectoriales, estudios sectorales*. Subsecretaria de Pesca, Gobierno de Chile (available at www.subpesca.cl).

SUBPESCA. 2007. *Ficha harina de pescado No. 1/07, fichas ecomicas periodicas – harina de pescado*. Subsecretaria de Pesca, Gobierno de Chile (available atwww.subpesca.cl).

Tabilo-Munizaga, G. & Barbosa-Canovas, G.V. 2004. Ultra high pressure technology and its use in surimi manufacture: an overview. *Food Science & Technology International*, 10(4): 207–222.

Tacon, A.G.J. 2002. *Global review of feeds and feed management practices in shrimp aquaculture*. Report prepared under the World Bank, NACA, WWF and FAO Consortium Programme on Shrimp Farming and the Environment. Work in Progress for Public Discussion. 68 pp.

Tacon, A.G.J. 2005. Salmon aquaculture dialogue: status of information on salmon aquaculture feed and the environment. *International Aquafeed*, 8(4): 22–37.

Tacon, A.G.J. 2006. *Pellets and fishmeal substitution*. Paper presented at the Asia-Pacific Fishery Commission regional consultative forum meeting, Kuala Lumpur, Malaysia, Bangkok, 16–19 August 2006. FAO Regional Office for Asia and the Pacific.

Tacon, A.G.J. & Akiyama, D.M. 1997. Feed ingredients for crustaceans. *In* L.R. D'Abramo, D.E. Conklin and D.M. Akiyama (eds.). *Crustacean nutrition,* Advances in World Aquaculture, Volume 6, pp. 411–472. Baton Rouge, Louisiana, World Aquaculture Society.

Tacon, A.G.J. & Forster, I.P. 2003. Aquafeeds and the environment: policy implications. *Aquaculture*, 226(1–4): 181–189.

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

Tacon, A.G.J., Phillips, M.J. & Barg, U.C. 1995. Aquaculture feeds and the environment: the Asian experience. *Water Science Technology,* 31(10): 41–59.

Tacon, A.G.J., Rausin, N., Kadari, M. & Cornelis, P. 1991. The food and feeding of tropical marine finfish in floating net cages. 2. Asian seabass *Lates calcarifer* (Bloch) and the brownspotted grouper *Epinephelus tauvina* (Forskal). *Aquaculture and Fisheries Management,* 22: 165–182.

Turchini, G.M., Gunasekera, R.M. & De Silva, S.S. 2003. Effect of crude oil extracts from trout offal as a replacement for fish oil in the diets of the Australian native fish murray cod *Macculochella peelii peelii*. *Aquaculture Research*, 34(9): 685–783.

Villarreal, H., Hernandez-Llamas, A., Rivera, M.C., Millan, A. & Rocha, S. 2004. Effect of substitution of shrimp meal, fish meal and soy meal with red crab *Pleuroncodes planipes* (Stimpson) meal in pelleted diets for postlarvae and juvenile *Farfantepenaeus californiensis* (Holmes). *Aquaculture Research*, 35: 178–183

Volpe, J., Benetti, D., Boehlert, G., Boesch, D., Davis, A., Dethier, M., Goldburg, R., Kent, M., Mahnken, C., Marra, J., Rensel, J., Sandifer, P., Stickney, R., Tacon, A. & Tyedmers, P. 2006. *Integrating aquacultural and ecological sciences for sustainable offshore aquaculture*. Annual Meeting of the World Aquaculture Society, Florence, Italy, 9–13 May 2006. Book of Abstracts. p. 810.

Wang, C., Xue, C., Liu, Y., Lou, W. & Chen, X. 1996. Utilization of fish protein and oil from the anchovy *Engraulis japonicus*. *Asian Fisheries Science*, 9: 201–208.

Weber, K. & Goerke, H. 2003. Persistent organic pollutants (POPs) in Antarctic fish: levels, patterns, changes. *Chemosphere*, 53(6): 667–678.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J. & Watson, R. 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science*, 314: 787–790.

Wray, T. 2001. Making the most of jack mackerel. *Seafood International*, July 2001: 39–43.

Wright, I. 2004. Salmon by-products. *Aqua Feeds: Formulation & Beyond*, 1(1): 10–12.

Yndestad, H. & Stene, A. 2002. System dynamics of the Barents Sea capelin. *ICES Journal of Marine Science*, 59(6): 1155–1166.