STATE OF INFORMATION ON SALMON AQUACULTURE FEED AND THE ENVIRONMENT

by
Albert G.J. Tacon Ph.D.
Aquaculture Research Director
Aquatic Farms Ltd
49-139 Kamehameha Hwy
Kaneohe, HI 96744 USA

Email: agjtacon@aol.com

PREPARATION OF THIS REPORT

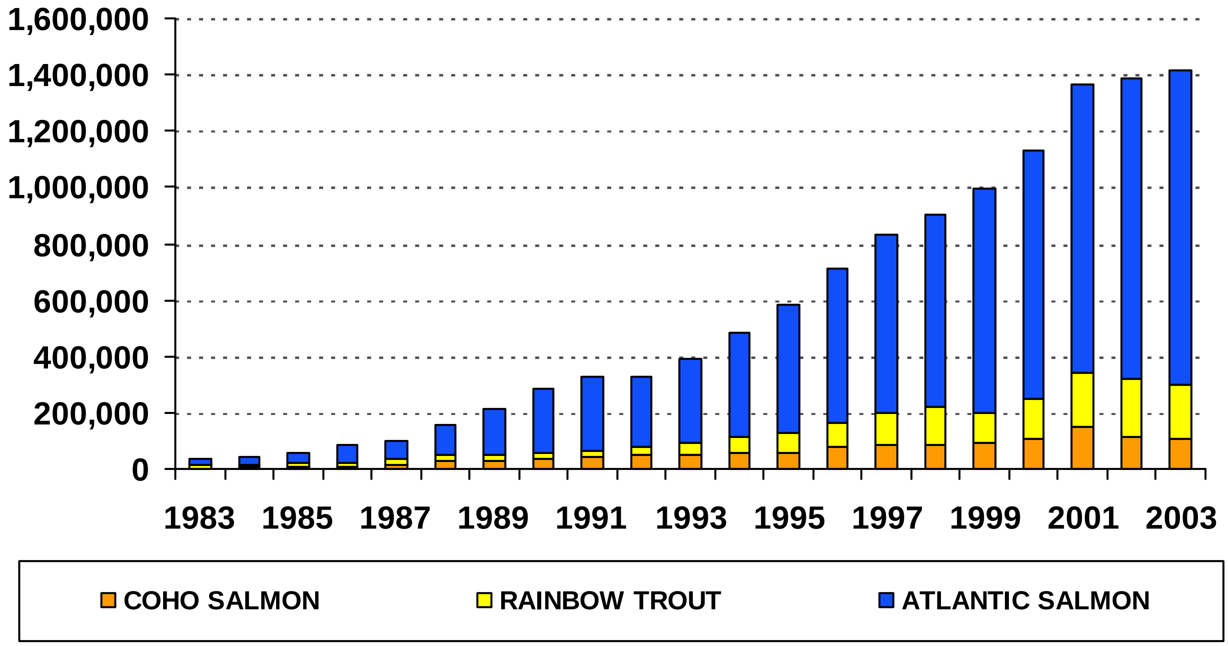
- WWF US initiated the Salmon Aquaculture Dialogue in February 2004. The goal of the Dialogue is to engage stakeholders in constructive dialogue to define environmentally, socially, and economically sustainable salmon farming, develop performance-based and verifiable standards, and foster their implementation. The Dialogue is currently headed by a multi-stakeholder steering committee.
- Six key areas of concern were identified as the main environmental issues associated with salmon farming: feed; chemical inputs; disease; benthic impacts and siting; nutrient loading and carrying capacity; and escapes. There is considerable controversy surrounding these six issues and the extent to which they are known to lead to environmental degradation.
- The Salmon Aquaculture Dialogue will commission state of information reports on each of these key areas of concern. The author(s) of each report will be jointly agreed upon by the Steering Committee, and the Committee will develop a suggested outline for the report. The feed report is the first to be commissioned. The report will provide thorough, up-to-the-minute information on the state of information on environmental and public health issues related to salmon feed, including the use of fishmeal and fish oil and the potential to reduce this use.
- For the purposes of this report, salmon feed is defined as feed to salmonids in seawater, including production of smolts for these species, and includes Atlantic salmon, Chinook salmon, Coho salmon and big (large) rainbow trout.
- Appendix 1 shows the suggested outline for the feed report as suggested by the Steering Committee and accepted by the chosen consultant, Albert G.J. Tacon Ph.D, Aquaculture Research Director, Aquatic Farms, Kaneohe, Hawaii 96744, USA.
- The following report is based on the findings of the field visits made by Dr. Tacon to the salmon aquaculture/aquafeed sector in Chile, Norway and the United Kingdom (March 27th to April 16th, 2005) and the inputs received from persons contacted and the professional experience of Dr. Tacon in the subject matter.
- Appendix 2 shows the organizations and persons who were contacted and provided valuable information and/or insights to Dr. Tacon for the preparation of this report.

1. BACKGROUND

1.1 Trends in volume of feed produced & used in salmon aquaculture

Total production of farmed salmon and marine-brackishwater reared rainbow trout in 2003 was 1,464,289 tonnes (the latest year for which official complete statistical information exists; FAO, 2005a), including Atlantic salmon 1,115,006 tonnes (76.1% total), rainbow trout 195,032 tonnes (13.3%), Coho salmon 105,786 tonnes (7.2%), and Chinook salmon 22,030 tonnes (1.5%; Figure 1.1.),

Figure 1.1.1 Total farmed salmon and brackishwater-marine rainbow trout production 1983 to 2003 (Source: FAO, 2005a)



By country, the largest producers in 2003 included Norway 576,540 tonnes (39.4% total production in 2003) and Chile 483,258 tonnes (33.0%), followed by the UK 146,606 tonnes (10.0%), Canada 107,250 tonnes (7.3%), Faeroe Islands 65,517 tonnes 4.5%), Ireland 16,717 tonnes (1.1%), USA 16,315 tonnes (1.1%), Australia 13,972 tonnes (0.9%), Finland 10,151 tonnes, Japan 9,208 tonnes and Denmark 7,994 tonnes (Figure 1.1.2).

Based on the above fish production figures and industry sources, it is estimated that the total production of compounded aquafeeds for salmon (includes large marine-brackishwater reared rainbow trout) was about 1.9 million tonnes in 2003 (Figure 1.1.3), including Norway 750,000 tonnes, Chile 725,000 tonnes, UK 225,000 tonnes, Canada

Figure 1.1.2 Total farmed salmon and large rainbow trout production by country 1983 to 2003 (Source: FAO, 2005a).

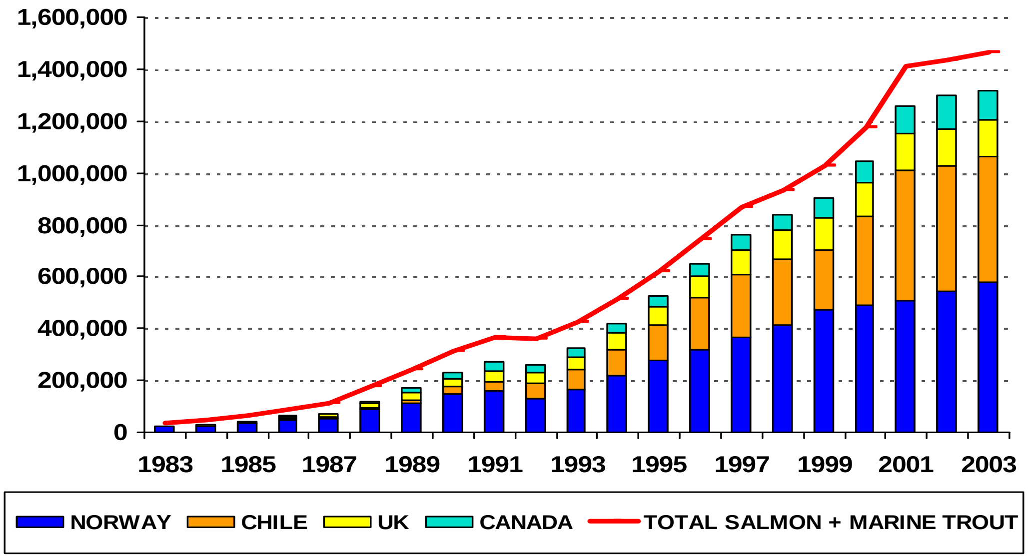
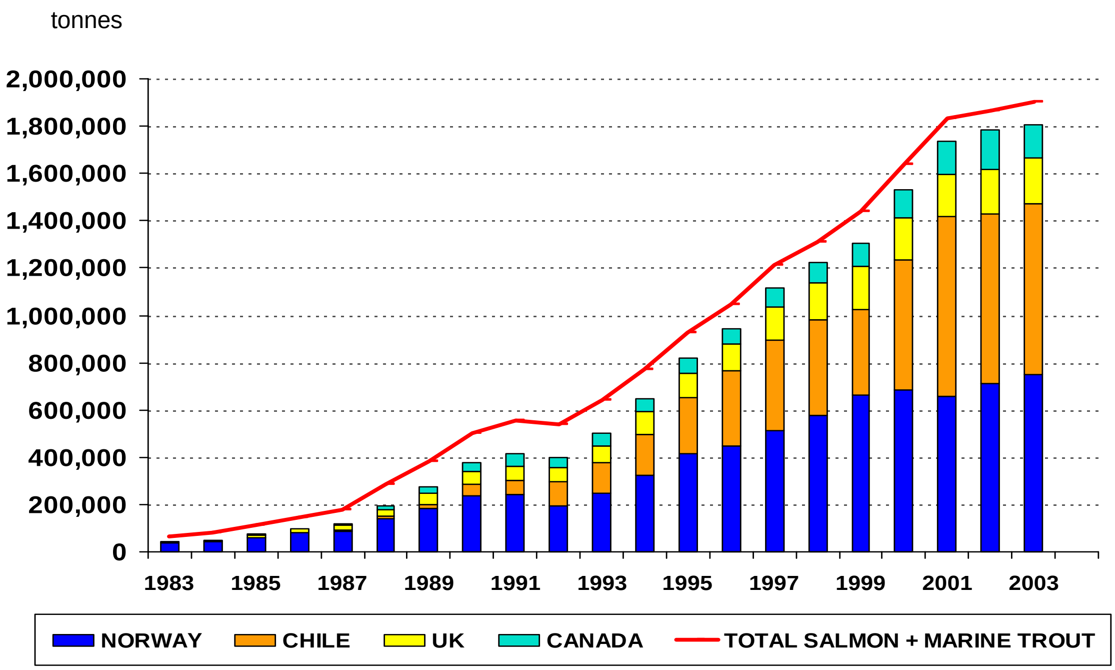


Figure 1.1.3 Total estimated aquafeed market for farmed salmon and large rainbow trout production by country 1983 to 2003 (FAO, 2005a).

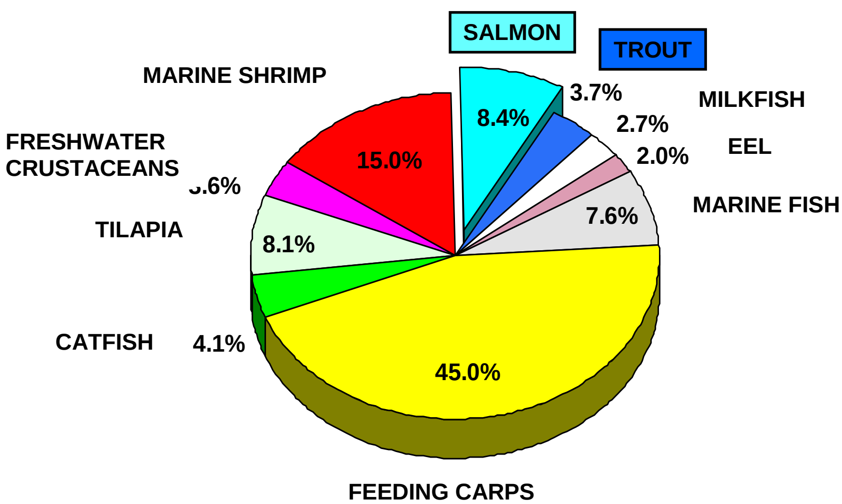


160,000 tonnes, and others 45,000 tonnes. Recent data indicates that Chile has now overtaken Norway as the largest salmon feed producer, with the total aquafeed market in Chile estimated at 850,000 tonnes in 2004 (Larraín, Leyton & Almendras, 2005), compared with 800,000 tonnes for Norway and about 200,000 tonnes for the UK.

However, it should be pointed out that approximately 85% and 50% of total aquafeed production and salmon production in Chile is produced by overseas companies, including the international feed companies Skretting (Nutreco, Netherlands), Ewos (Cermaq, Norway), Alitec (Provimi Group, Netherlands) and Biomar (Denmark), and the salmon companies Marine Harvest-Stolt (Nutreco) and Mainstream (Cermaq), respectively. Currently, over two-thirds of the total global salmon aquafeed production is produced by two companies, namely Skretting (Nutreco) and Ewos (Cermaq).

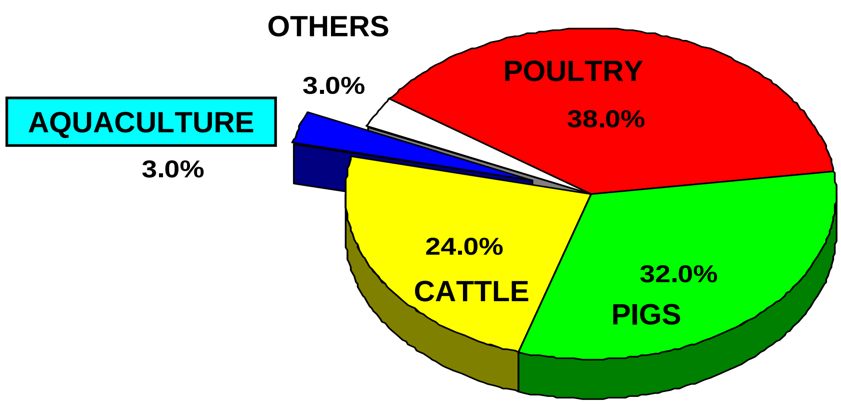
In global terms salmon feeds represent only 8.4% of total compound aquafeed production by weight in 2003 (Figure 1.1.4), with aquaculture in turn representing about 3% of total global industrial animal feed production in 2004 (Figure 1.1.5).

Figure 1.1.4 Estimated global compound aquafeed production in 2003 for the major farmed finfish and crustacean species (values are expressed as % total feed production, dry as-fed basis)



Total estimated compound aquafeed production in 2003 – 19.5 million tonnes

Figure 1.1.5 Estimated global industrial feed production in 2004 for the major farmed animal species (values are expressed as % dry as-fed basis)



Total estimated feed production in 2004 was 620 million tonnes (Source: Gill, 2005)

1.2 Overview of total global use of fishmeal & fish oil

At present over two thirds of salmon feeds by weight are composed of two marine feed ingredients, namely fishmeal and fish oil. Compared with other terrestrial animal and plant protein sources fishmeal is unique in that it is not only an excellent source of high quality animal protein and essential amino acids, but is also a good source of digestible energy, essential minerals and vitamins, and lipids, including the essential polyunsaturated fatty acids (Hertrampf & Piedad-Pascual, 2000).

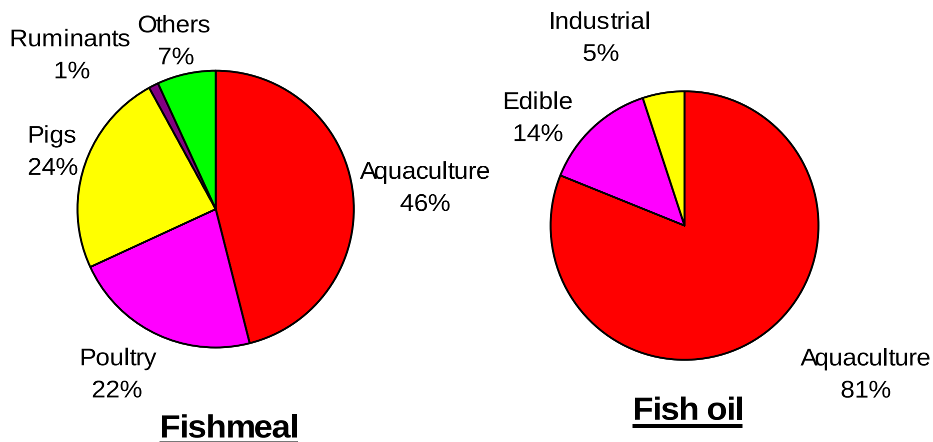
For example, commonly reported dietary fishmeal inclusion levels within conventional livestock feeds (FIN, 2004) and aquafeeds (Tacon, 2004a) include:

- Pig:creep 5-10%, weaner 5-10%, grower 3-5%, finisher 3%, sow 3%;
- Poultry: chick rearing up to 3%, broiler 2-5%, breeder 1-5%, layer 2%; turkey 3-10%, Pheasant/game 3-7%;
- Dairy cattle:late pregnant 2.5-10%, lactating 5-10%, calves 2.5-10%;
- Sheep:breeding ewes/pregnant 2-7.5%, lactating 5-10%, growing lambs 2.5-10%;
- Fish/carnivores: salmonids/eels/marine finfish):starter 35-75%, grower 20-50%;
- Fish/omnivores: carp/tilapia/catfish): starter 10-25%, grower 2-15%; and
- Marine shrimp: starter 25-50, grower 15-35%.

Apart from the use of fish oils for farmed aquatic animals as a source of dietary energy and essential fatty acids (inclusion levels ranging widely depending upon the species from as little as 0.5% to as high as 40%), 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. Moreover, fish oils may also be used for specific technical applications, such as in the manufacture of quick drying oils and varnishes, or as fatty acid precursors for the preparation of metallic soaps used in lubricating greases or as water proofing agents (Bimbo & Crowther, 1992).

Figure 1.2.1 shows the latest global estimate from the International Fishmeal and Fish Oil Organisation (IFFO) concerning the use of fishmeal and fish oil within aquaculture and animal feeds (Pike, 2005). From the data presented it can be seen that aquaculture's share currently stands at 46% in the case of fishmeal usage and 81% in the case of fish oil.

Figure 1.2.1 Reported global fishmeal and fish oil usage in 2002 (Pike, 2005)



*How does salmon/carnivorous finfish feed production fit into this context***?**

As seen from the above figure, the aquaculture sector is currently heavily dependent upon the use of fishmeal and fish oil within compound aquafeeds (Asche & Tveteras, 2004; Barlow, 2003; FIN, 2004, 2005; Hardy & Tacon, 2002; Huntington, 2004; Huntington et al. 2004; New & Wijkstrom, 2002; Pike, 2005; Seafeeds, 2003). In particular the dependency upon fishmeal and fish oil is particularly strong for those higher value species feeding high on the aquatic food chain, including all carnivorous finfish species and to a lesser extent most omnivorous/scavenging crustacean species (Allan, 2004; Hardy, 2003; Pike & Barlow, 2003; Tacon, 2004a; Zaldivar, 2004). The apparent higher dependency of marine/brackishwater carnivorous finfish and crustacean species for fishmeal and fish oil is primarily due to their more exacting dietary requirements for high quality animal protein, essential fatty acids and trace minerals (Hardy et al. 2001; Pike, 1998).

For example, finfish and crustacean species which are currently dependent upon fishmeal as the main source of dietary protein within compound aquafeeds include: Finfish - all farmed marine finfish (excluding mullets and rabbitfish), diadromous species - salmonids (salmon, trout, char), eels, barramundi, sturgeon, freshwater species - mandarin fish, pike, pike-perch, snakehead, certain freshwater Clarias catfishes); and Crustaceans: all marine shrimp, crabs, and to a lesser extent freshwater prawns. A similar dependency also exists for fish oil (as the main source of dietary lipids and essential fatty acids within compound aquafeeds) for the above species, with crustaceans being less dependent than carnivorous finfish due to the lower levels of dietary lipids generally used within commercial shrimp feeds (Coutteau, 2004).

In addition to the above species it must also be clearly stated that fishmeal and fish oil are also commonly used as a secondary source of dietary protein (usually included at low dietary inclusion levels) and lipid for many omnivorous cultured finfish species, including freshwater carps, tilapia and catfish. Table 1 shows the estimated global use of fishmeal and fish oil within compound aquafeeds from 1992 to 2003 according to both independent authors (New & Csavas, 1995; New & Wijkstrom, 2002; Tacon, 1998, 2003b, 2004a; Tacon & Forster, 2001; Tacon, the present paper) and estimates by the fishmeal and fish oil manufacturing sector (IFOMA, 2000; Pike, 1998, 2005; Pike & Barlow, 2003).

1.3 Trends in quantity of fishmeal and oil used in aquafeeds

From the data presented it can be seen that the total estimated amount of fishmeal and fish oil used within compound aquafeeds has grown over three-fold from 963 to 2,936 thousand tonnes and from 234 to 802 thousand tonnes from 1994 to 2003, respectively (Table 1). This increase in usage is in line with the almost three-fold increase in total finfish and crustacean aquaculture production over this period; total reported finfish and crustacean aquaculture production reportedly increasing from 10.9 to 29.8 million tonnes from 1992 to 2003 (FAO, 2005a).

On the basis of the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) used by FAO, the major calculated consumers of fishmeal and fish oil in 2003 can be ranked as follows:

Salmon:

- fishmeal usage increasing from 201 to 573 thousand tonnes from 1992 to 2003
- fish oil usage increasing from 60.4 to 409 thousand tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 261.4 to 982 thousand tonnes

Shrimp:

- fishmeal usage increasing from 232 to 670 thousand tonnes from 1992 to 2003
- fish oil usage increasing from 27.8 to 58.3 thousand tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 259.8 to 728.3 thousand tonnes

Table 1. Estimated use of fishmeal and fish oil in compound aquafeeds 1992-2003

	1992	1994	1995	1998	1999	2000	2001	2002	2003
Species Group	Thousand tonnes (dry as-fed basis)								
SHRIMP[1]									
Fishmeal									
New & Csavas (1985)	232	-	-	-	-	-	-	-	-
Pike (1998)	-	241	-	-	-	-	-	-	-
Tacon (1998)	-	-	420	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	486	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	407	-	-	-	-
IFOMA (2000)	-	-	-	-	-	372	-	-	-
Tacon (2003b)	-	-	-	-	-	428	-	-	-
Tacon (2004a)	-	-	-	-	-	-	510	480	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	487	-
Pike (2005)	-	-	-	-	-	-	-	522	-
Tacon (current paper)	-	-	-	-	-	-	-	-	670
Fish oil									
New & Csavas (1985)	27.8	-	-	-	-	-	-	-	-
Pike (1998)	-	29	-	-	-	-	-	-	-
Tacon (1998)	-	-	42	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	34.7	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	33	-	-	-	-
IFOMA (2000)	-	-	-	-	-	30	-	-	-
Tacon (2003b)	-	-	-	-	-	36	-	-	-
Tacon (2004a)	-	-	-	-	-	-	42.5	41.7	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	39	-
Pike (2005)	-	-	-	-	-	-	-	42	-
Tacon (current paper)	-	-	-	-	-	-	-	-	58.3
FRESHWATER CRUSTACEANS[2]									
Fishmeal									
New & Csavas (1985)	9.5	-	-	-	-	-	-	-	-
Tacon (2003b)	-	-	-	-	-	93	-	-	-

Tacon (2004a)	-	-	-	-	-		119	122	-
Pike (2005)	-	-	-	-	-	-	-	60	-
Tacon (current paper)	-	-	-	-	-	-	-	-	139

<u>Fish oil</u>

New & Csavas (1985)	0.5	-	-	-	-	-	-	-	-
Tacon (2003b)	-	-	-	-	-	7.7	-	-	-
Tacon (2004a)	-	-	-	-	-	-	10.4	12.2	-
Pike (2005)	-	-	-	-	-	-	-	12	-
Tacon (current paper)	-	-	-	-	-	-	-	-	13.9

MARINE FINFISH[3]

<u>Fishmeal</u>

New & Csavas (1985)	180	-	-	-	-	-	-	-	-
Pike (1998)	-	100	-	-	-	-	-	-	-
Tacon (1998)	-	-	266	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	419.9	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	492	-	-	-	-
IFOMA (2000)	-	-	-	-	-	635	-	-	-
Tacon (2003b)	-	-	-	-	-	533	-	-	-
Tacon (2004a)	-	-	-	-	-	-	505	640	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	417	-
Pike (2005)	-	-	-	-	-	-	-	702	-
Tacon (current paper)	-	-	-	-	-	-	-	-	590

<u>Fish oil</u>

New & Csavas (1985)	36	-	-	-	-	-	-	-	-
Pike (1998)	-	20	-	-	-	-	-	-	-
Tacon (1998)	-	-	80	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	122.5	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	170	-	-	-	-
IFOMA (2000)	-	-	-	-	-	249	-	-	-
Tacon (2003b)	-	-	-	-	-	121	-	-	-
Tacon (2004a)	-	-	-	-	-	-	120	140	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	106	-
Pike (2005)	-	-	-	-	-	-	-	125	-
Tacon (current paper)	-	-	-	-	-	-	-	-	110.6

SALMON[4]

<u>Fishmeal</u>

New & Csavas (1985)	201	-	-	-	-	-	-	-	-
Pike (1998)	-	351	-	-	-	-	-	-	-
Tacon (1998)	-	-	317	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	485.7	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	437	-	-	-	-
IFOMA (2000)	-	-	-	-	-	491	-	-	-
Tacon (2003b)	-	-	-	-	-	525	-	-	-
Tacon (2004a)	-	-	-	-	-	-	595	554	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	455	-
Pike (2005)	-	-	-	-	-	-	-	554	-
Tacon (present paper)	-	-	-	-	-	-	-	-	573

Fish oil

New & Csavas (1985)	60.4	-	-	-	-	-	-	-	-
Pike (1998)	-	169	-	-	-	-	-	-	-
Tacon (1998)	-	-	176	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	264.9	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	273	-	-	-	-
IFOMA (2000)	-	-	-	-	-	307	-	-	-
Tacon (2003b)	-	-	-	-	-	262	-	-	-
Tacon (2004a)	-	-	-	-	-	-	282	253	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	364	-
Pike (2005)	-	-	-	-	-	-	-	443	-
Tacon (present paper)	-	-	-	-	-	-	-	-	409

TROUT[5]

Fishmeal

New & Csavas (1985)	142	-	-	-	-	-	-	-	-
Pike (1998)	-	171	-	-	-	-	-	-	-
Tacon (1998)	-	-	202	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	219.4	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	170	-	-	-	-
IFOMA (2000)	-	-	-	-	-	189	-	-	-
Tacon (2003b)	-	-	-	-	-	159	-	-	-
Tacon (2004a)	-	-	-	-	-	-	179	169	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	180	-
Pike (2005)	-	-	-	-	-	-	-	221	-
Tacon (present paper)	-	-	-	-	-	-	-	-	216

Fish oil

New & Csavas (1985)	47.3	-	-	-	-	-	-	-	-
Pike (1998)	-	91	-	-	-	-	-	-	-

Tacon (1998)	-	-	115	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	123.4	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	85	-	-	-	-
IFOMA (2000)	-	-	-	-	-	95	-	-	-
Tacon (2003b)	-	-	-	-	-	93	-	-	-
Tacon (2004a)	-	-	-	-	-	-	104	96	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	168	-
Pike (2005)	-	-	-	-	-	-	-	147	-
Tacon (present paper)	-	-	-	-	-	-	-	-	126

EEL[6]

Fishmeal

New & Csavas (1985)	72.3	-	-	-	-	-	-	-	-
Pike (1998)	-	93	-	-	-	-	-	-	-
Tacon (1998)	-	-	136	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	133.5	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	182	-	-	-	-
IFOMA (2000)	-	-	-	-	-	173	-	-	-
Tacon (2003b)	-	-	-	-	-	186	-	-	-
Tacon (2004a)	-	-	-	-	-	-	180	179	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	174	-
Pike (2005)	-	-	-	-	-	-	-	190	-
Tacon (present paper)	-	-	-	-	-	-	-	-	171

Fish oil

New & Csavas (1985)	18.1	-	-	-	-	-	-	-	-
Pike (1998)	-	19	-	-	-	-	-	-	-
Tacon (1998)	-	-	68	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	21.4	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	36	-	-	-	-
IFOMA (2000)	-	-	-	-	-	17	-	-	-
Tacon (2003b)	-	-	-	-	-	14.9	-	-	-
Tacon (2004a)	-	-	-	-	-	-	15	15.2	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	1	-
Pike (2005)	-	-	-	-	-	-	-	10	-
Tacon (present paper)	-	-	-	-	-	-	-	-	11.4

MILKFISH

Fishmeal

New & Csavas (1985)	19.3	-	-	-	-	-	-	-	-
Tacon (1998)	-	-	32	-	-	-	-	-	-

Tacon & Forster (2001)	-	-	-	26.6	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	37	-	-	-	-
IFOMA (2000)	-	-	-	-	-	36	-	-	-
Tacon (2003b)	-	-	-	-	-	37	-	-	-
Tacon (2004a)	-	-	-	-	-	-	37	38	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	42	-
Pike (2005)	-	-	-	-	-	-	-	57	-
Tacon (present paper)	-	-	-	-	-	-	-	-	36

<u>Fish oil</u>

New & Csavas (1985)	9	-	-	-	-	-	-	-	-
Pike (1998)	-	9	-	-	-	-	-	-	-
Tacon (1998)	-	-	11	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	8	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	9	-	-	-	-
IFOMA (2000)	-	-	-	-	-	6	-	-	-
Tacon (2003b)	-	-	-	-	-	3.7	-	-	-
Tacon (2004a)	-	-	-	-	-	-	4.2	4.7	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	6	-
Pike (2005)	-	-	-	-	-	-	-	10	-
Tacon (present paper)	-	-	-	-	-	-	-	-	5.2

FEEDING CARP[7]

<u>Fishmeal</u>

New & Csavas (1985)	51.5	-	-	-	-	-	-	-	-
Pike (1998)	-	45	-	-	-	-	-	-	-
Tacon (1998)	-	-	332	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	362.1	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	64	-	-	-	-
IFOMA (2000)	-	-	-	-	-	350	-	-	-
Tacon (2003b)	-	-	-	-	-	368	-	-	-
Tacon (2004a)	-	-	-	-	-	-	366	414	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	337	-
Pike (2005)	-	-	-	-	-	-	-	334	-
Tacon (present paper)	-	-	-	-	-	-	-	-	438

<u>Fish oil</u>

New & Csavas (1985)	25.8	-	-	-	-	-	-	-	-
Pike (1998)	-	30	-	-	-	-	-	-	-
Tacon (1998)	-	-	42	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	60.3	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	13	-	-	-	-

IFOMA (2000)	-	-	-	-	-	0	-	-	-
Tacon (2003b)	-	-	-	-	-	0	-	-	-
Tacon (2004a)	-	-	-	-	-	-	73.1	82.7	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	0	-
Pike (2005)	-	-	-	-	-	-	-	0	-
Tacon (present paper)	-	-	-	-	-	-	-	-	43.8

TILAPIA[8]

Fishmeal

New & Csavas (1985)	29	-	-	-	-	-	-	-	-
Tacon (1998)	-	-	69	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	72	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	61	-	-	-	-
IFOMA (2000)	-	-	-	-	-	55	-	-	-
Tacon (2003b)	-	-	-	-	-	61	-	-	-
Tacon (2004a)	-	-	-	-	-	-	70	68	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	73	-
Pike (2005)	-	-	-	-	-	-	-	95	-
Tacon (present paper)	-	-	-	-	-	-	-	-	79

Fish oil

New & Csavas (1985)	0	-	-	-	-	-	-	-	-
Pike (1998)	-	2	-	-	-	-	-	-	-
Tacon (1998)	-	-	5	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	7.2	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	9	-	-	-	-
IFOMA (2000)	-	-	-	-	-	8	-	-	-
Tacon (2003b)	-	-	-	-	-	10	-	-	-
Tacon (2004a)	-	-	-	-	-	-	11.6	13.5	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	10	-
Pike (2005)	-	-	-	-	-	-	-	14	-
Tacon (present paper)	-	-	-	-	-	-	-	-	15.8

CATFISH[9]

Fishmeal

New & Csavas (1985)	23.4	-	-	-	-	-	-	-	-
Pike (1998)	-	22	-	-	-	-	-	-	-
Tacon (1998)	-	-	22	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	50.5	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	18	-	-	-	-
IFOMA (2000)	-	-	-	-	-	15	-	-	-

Tacon (2003b)	-	-	-	-	-	23	-	-	-
Tacon (2004a)	-	-	-	-	-	-	24	21	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	12	-
Pike (2005)	-	-	-	-	-	-	-	14	-
Tacon (present paper)	-	-	-	-	-	-	-	-	24

<u>Fish oil</u>

New & Csavas (1985)	9.3	-	-	-	-	-	-	-	-
Pike (1998)	-	8	-	-	-	-	-	-	-
Tacon (1998)	-	-	9	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	6.3	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	6	-	-	-	-
IFOMA (2000)	-	-	-	-	-	5	-	-	-
Tacon (2003b)	-	-	-	-	-	5.8	-	-	-
Tacon (2004a)	-	-	-	-	-	-	6	7.2	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	6	-
Pike (2005)	-	-	-	-	-	-	-	7	-
Tacon (present paper)	-	-	-	-	-	-	-	-	8

CARNIVOROUS FRESHWATER FISH[10]

<u>Fishmeal</u>

New & Wijkstrom (2002)	-	-	-	-	78	-	-	-	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	40	-
Pike (2005)	-	-	-	-	-	-	-	124	-

<u>Fish oil</u>

New & Wijkstrom (2002)	-	-	-	-	15	-	-	-	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	16	-
Pike (2005)	-	-	-	-	-	-	-	19	-

TOTAL

<u>Fishmeal</u>

New & Csavas (1985)	963	-	-	-	-	-	-	-	-
Pike (1998)	-	1,084	-	-	-	-	-	-	-
Tacon (1998)	-	-	1,728	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	2,256	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	2,091	-	-	-	-
IFOMA (2000)	-	-	-	-	-	2,316	-	-	-
Tacon (2003b)	-	-	-	-	-	2,413	-	-	-
Tacon (2004a)[11]	-	-	-	-	-	-	2,585	2,685	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	2,217	-

Pike (2005)	-	-	-	-	-	-	-	2,873	-
Tacon (present paper)	-	-	-	-	-	-	-	-	2936

Fish oil

New & Csavas (1985)	234	-	-	-	-	-	-	-	-
Pike (1998)	-	380	-	-	-	-	-	-	-
Tacon (1998)	-	-	494	-	-	-	-	-	-
Tacon & Forster (2001)	-	-	-	649	-	-	-	-	-
New & Wijkstrom (2002)	-	-	-	-	662	-	-	-	-
IFOMA (2000)	-	-	-	-	-	716	-	-	-
Tacon (2003b)	-	-	-	-	-	554	-	-	-
Tacon (2004a)[11]	-	-	-	-	-	-	668.8	666.2	-
Pike & Barlow (2003)	-	-	-	-	-	-	-	732	-
Pike (2005)	-	-	-	-	-	-	-	829	-
Tacon (present paper)	-	-	-	-	-	-	-	-	802

[1] Shrimp includes all marine shrimps, prawns etc. according to the FAO International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) Code 45 (FAO, 2005a);
[2] Freshwater crustaceans includes freshwater prawn, river crab and crayfish according to ISSCAAP Code 41;
[3] Marine finfish includes all marine fishes according to ISSCAAP Code 3, with the exception of mullets;
[4] 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;
[5] Trout includes all the trout species listed in ISSCAAP Code 23, including Rainbow trout, Sea trout, Brook trout;
[6] Eel includes all river eel species listed in ISSCAAP Code 22;
[7] 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;
[8] Tilapia includes all tilapia species listed in ISSCAAP Code 12, with the exception of other cichlids;
[9] Catfish includes all omnivorous catfish species listed in ISSCAAP Code 13;
[10] Carnivorous freshwater fish species include Chinese bream, mandarin fish, yellow croaker, long-nose catfish but excluding eel (Barlow & Pike, 2003).
[11] Excludes fishmeal and fish oil usage within compound aquafeeds given to filter feeding fish species (7,036 thousand tonnes produced in 2003), freshwater fish species (species unknown: 3,373 thousand tonnes produced in 2003), marine crabs and other marine crustaceans (183 thousand tonnes produced in 2003), Mandarin fish (150 thousand tonnes produced in 2003), and other miscellaneous freshwater fish species (including climbing perch, snakeheads, colossoma, gourami ca. 158 thousand tonnes produced in 2003; FAO, 2005a).

Marine finfish:
- fishmeal usage increasing from 180 to 590 thousand tonnes from 1992 to 2003
- fish oil usage increasing from 36 to 110.6 thousand tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 216 to 700.6 thousand tonnes

Feeding carp:
- fishmeal usage increasing from 51.5 to 438 thousand tonnes from 1992 to 2003
- fish oil usage increasing from 25.8 to 43.8 thousand tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 77.3 to 481.8 thousand tonnes

Trout:
- fishmeal usage increasing from 142 to 216 thousand tonnes from 1992 to 2003
- fish oil usage increasing from 47.3 to 126 thousand tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 189.3 to 342 thousand tonnes

Eel:
- fishmeal usage increasing from 72.3 to 171 thousand tonnes from 1992 to 2003
- fish oil usage decreasing from 18.1 to 11.4 thousand tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 90.4 to 182.4 thousand tonnes

Freshwater crustaceans:
- fishmeal usage increasing from 9.5 to 139 thousand tonnes from 1992 to 2003
- fish oil usage increasing from 0.5 to 13.9 thousand tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 10 to 152.9 thousand tonnes

Tilapia:
- fishmeal usage increasing from 29 to 79 thousand tonnes from 1992 to 2003
- fish oil usage increasing from 0 to 15.8 thousand tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 29 to 94.8 thousand tonnes

Milkfish:
- fishmeal usage increasing from 19.3 to 36 thousand tonnes from 1992 to 2003
- fish oil usage decreasing from 9 to 5.2 thousand tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 28.3 to 41.2 thousand tonnes

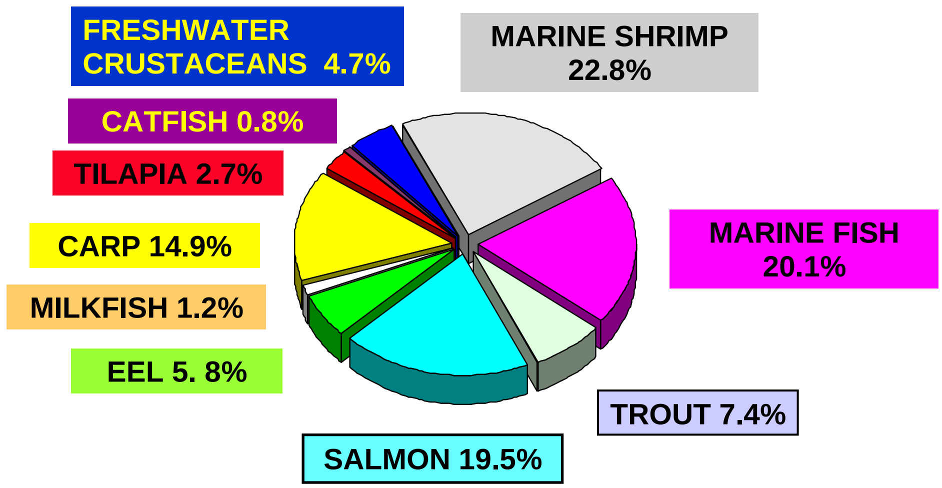
Catfish:
- fishmeal usage increasing from 23.4 to 24 thousand tonnes from 1992 to 2003
- fish oil usage decreasing from 9.3 to 8 thousand tonnes from 1992 to 2003
- total fishmeal and fish oil used decreasing from 32.7 to 32 thousand tonnes

The total use of fish meal and fish oil within compound aquafeeds is almost certainly higher than the figure given above, as an additional 4.17 million tonnes of finfish and crustacean production (equivalent to 14.2% total finfish and crustacean production in 2003) was not included in these calculations (footnote 11 in Table 1 refers).

According to the above estimates for 2003, the aquafeed sector consumed about 52.6%

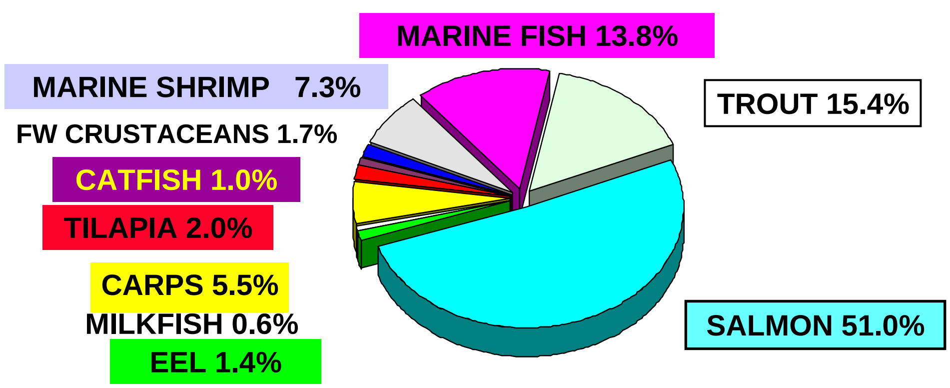
(Figure 1.3.1) and 86.8% (Figure 1.3.2) of the total global production of fishmeal and fish oil in 2003.

Figure 1.3.1 Estimated global use of fishmeal within compound aquafeeds in 2003 by major species (% total fishmeal used within aquafeeds, dry as-fed basis)



Total estimated fishmeal used in aquafeeds in 2003 was 2, 936 thousand tonnes or 52.6% of total reported world fishmeal production of 5,582 thousand tonnes in 2003 (FAO, 2005a)

Figure 1.3.2 Estimated global use of fish oil within compound aquafeeds in 2003 by major cultivated species (% total fishmeal used within aquafeeds, dry as-fed basis)

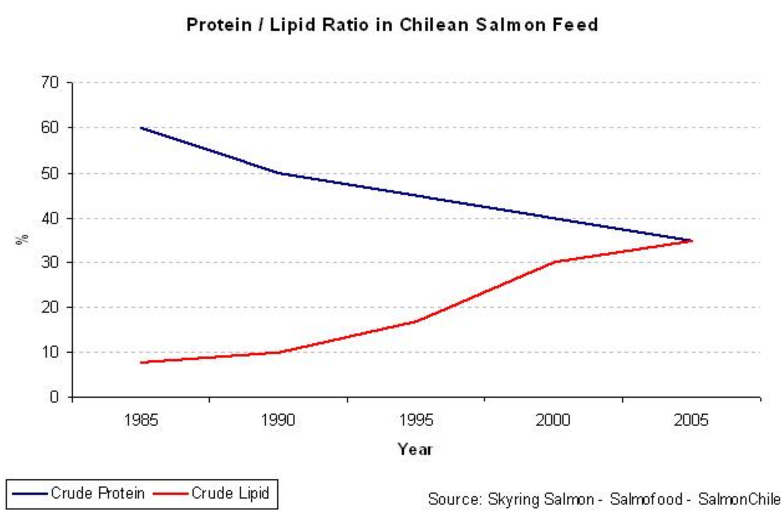


Total estimated fish oil used in aquafeeds in 2003 was 802 thousand tonnes or 86.8% of total reported world fish oil production of 924,426 tonnes in 2003 (FAO, 2005a)

1.4 Trends in percentage of fishmeal & fish oil used in salmon feeds

The percentage of dietary fishmeal and fish oil used within salmon feeds has changed dramatically over the past two decades, with fishmeal inclusion levels decreasing from an average level of 60% in 1985, 50% in 1990, 45% in 1995, 40% in 2000, to the present level of 35%. This decrease in dietary fishmeal and dietary protein level has been accompanied by an equivalent increase in dietary lipid levels, increasing from a low of 10% in 1985, 15% in 1990, 25% in 1995, 30% in 2000, to a high of 35-40% in 2005 (Figure 1.4.1).

Figure 1.4.1 Reported changes in salmon feed dietary protein and lipid levels from 1985 to the present day (Source: from Larrain et al. 2005).



The rationale behind these changes has been to increase the dietary energy density of the feeds, with a consequent improvement in fish growth and feed conversion efficiency; salmon production cycles in Chile being at least 20-25% shorter today than they were 10 years ago due to the use of higher energy and lower protein feeds (Larrain et al. 2005).

Although on an industry basis the current average level of fishmeal and fish oil used in salmon feeds is approximately 35% and 25% respectively, significant differences exist between the major producing countries, as follows:

Canada: mean fishmeal level 20-25%, mean fish oil level 15-20%;
Chile: mean fishmeal level 30-35%, mean fish oil level 25-30%;
Norway: mean fishmeal level 35-40%, mean fish oil level 27-32%; and
UK: mean fishmeal level 35-40%, mean fish oil level 25-30%.

To a large extent these differences are due to the local market availability and cost of adequate fishmeal and fish oil replacers within the major salmon producing countries (i.e. such as the ready availability of rendered animal byproduct meals and plant oilseed meals and oils in Canada and Norway) and the intended market for the farmed salmon (i.e. the USA not currently having market restrictions to the importation of Canadian salmon fed rations containing plant pulse meals and/or terrestrial animal byproduct meals). In marked contrast, the utilization of terrestrial animal byproduct meals, GMO-based plant protein meals, and the replacement of dietary fish oils with plant oils is currently restricted within the UK, primarily due to the demands of the resident national salmon farming associations and major salmon retailers/supermarket chains (Huntingdon, 2004).

At the present time, Canada and Norway lead the way in terms of the current level of dietary marine protein and lipid substitution at 55-70% and 50%, followed by Chile at 60% and 20%, and the UK at 45% and 10%, respectively.

1.5 How much fishmeal and fish oil is produced from by-products

At present no official statistical information is available from FAO concerning the total global production of fishmeals and oils produced from trimmings, offal and/or by-catch (FAO, 2005a). Clearly, this situation needs to be rectified.

Despite this, within the European Union (EU) it is estimated that in 2002 about 33% of the fishmeal produced in the EU-15 was manufactured from trimmings from food fish processing, including Spain 100% trimmings, France 100%, Germany 100%, Italy 100%, UK 84%, Ireland 60%, Sweden 25%, and Denmark 10% (Huntington et al. 2004).

1.6 What impact have fishmeal and fish oil prices on use

Since between 50 and 75% of commercial salmon feeds are currently composed of fishmeal and fish oil it follows that any price increases in these finite commodities will have a significant effect on feed price and farm profitability; salmon feeds and feeding representing between 60 to 70% of total farm production costs. The above is particularly critical in view of the general trend toward decreasing farm salmon prices (due to increased farmed salmon production and market supply) and increases in feed ingredient prices due to increased market demand and competition.

In general, the price of fishmeal and fish oil is determined by market forces depending upon the quality and quantities/availability of the products in question in the market and the cost and availability of similar competing products. As with any commodity, because of the stratified nature of the market, the value of fishmeal is set by its lowest value outlet. In this instance, these are the lower quality Fair Average Quality (FAQ) fishmeals which are available in the largest volumes, and there is a very clear relationship between the market price of FAQ meals with that of soybean meal (Figure 1.6.1 & 1.6.2); soybean being its closest and largest oilseed competitor for use as a protein source within livestock feeds (FAO, 2004b; Tacon & Forster, 2001). A similar relationship exists between the price of fish oil and its competitors for use within the edible food industry or within animal feeds, namely plant oils such as palm oil, soybean oil and rapeseed oil (Figure 1.6.3, 1.6.4 & 1.6.5) and to a lesser extent rendered terrestrial livestock fats such as tallows, lard and greases.

Over the past ten years, the price of fish meal (FOB Peru) has averaging between 2 to 3 times the price of soybean meal, except during the 1997-1998 El Niño when at one stage the price of FAQ fish meal shot up to 3.8 times the price of soybean meal and the price of fish oils soared to over $ 750/tonne (Jystad, 2001). The drastic effect of the 1997-1998 El Niño event on fish meal and fish oil availability and subsequent price and use is clearly illustrated by comparing fish meal and fish oil usage in the late eighties (prior to the major El Niño event) with current usage. For example, according to Barlow and Pike (2001) in 1988 poultry were by far the largest consumers of fish meal (60% in 1988), with aquaculture's share being a modest 10%; the latter also reflecting the smaller size of the aquaculture industry during this period (total global finfish and crustacean aquaculture production in 1988 being only 8.2 million tonnes, FAO, 2005a). However, after the 1997-1998 El Niño event and the resulting soaring fish meal prices, the poultry sector was forced to find cheaper alternative protein sources; their share of global fish meal production decreasing to only 24% in 2000 (with demand halved from 2.4 to 1.2 million tonnes and the sector switching to less expensive soybean meal; Jystad, 2001).

In general, regular or FAQ fish meals (ca. over 50% of total global fish meal production) are used as dietary protein sources for animal species with less demanding protein requirements (and therefore more elastic in demand), including terrestrial livestock species such as poultry (broiler grower, poultry finisher, layers) and pigs (grower), and farmed herbivorous/omnivorous aquatic species such as carps, tilapias, catfish, and to a lesser extent shrimp. By contrast, the higher quality and higher priced low-temperature and special select fish meals are used primarily by the more demanding carnivorous finfish and crustacean species (and therefore are least elastic in demand), including salmonids, marine finfish, intensively reared marine shrimp, and to a lesser extent for early weaning pig diets, poultry starter diets and ruminants (FIN, 2004; Pike, 1998; SCAHAW, 2003; Tacon, 2003a). Clearly, as the growth of the more demanding carnivorous species increases, then a greater and greater share of the fish meal demand will become less elastic. A similar situation exists with fish oil, with carnivorous aquatic animal species such as marine finfish and to a lesser extent salmonids being the least elastic of all.

In general the effect of increasing prices on fishmeal and fish oil use, include 1) fishmeal: increased substitution with cheaper dietary protein sources, and increased dietary supplementation within limiting essential nutrients, such as amino acids and trace elements (potential for reduced growth and nutrient digestibility); and 2) fish oil: increased substitution with cheaper dietary plant and/or terrestrial animal lipid sources (potential negative effect on perceived product quality and reduced digestibility).

Figure 1.6.1. Mean yearly prices for fishmeal & soybean (values given in US $ per tonne: Jean-François Mittaine, IFFO – pers.com., February 2005)

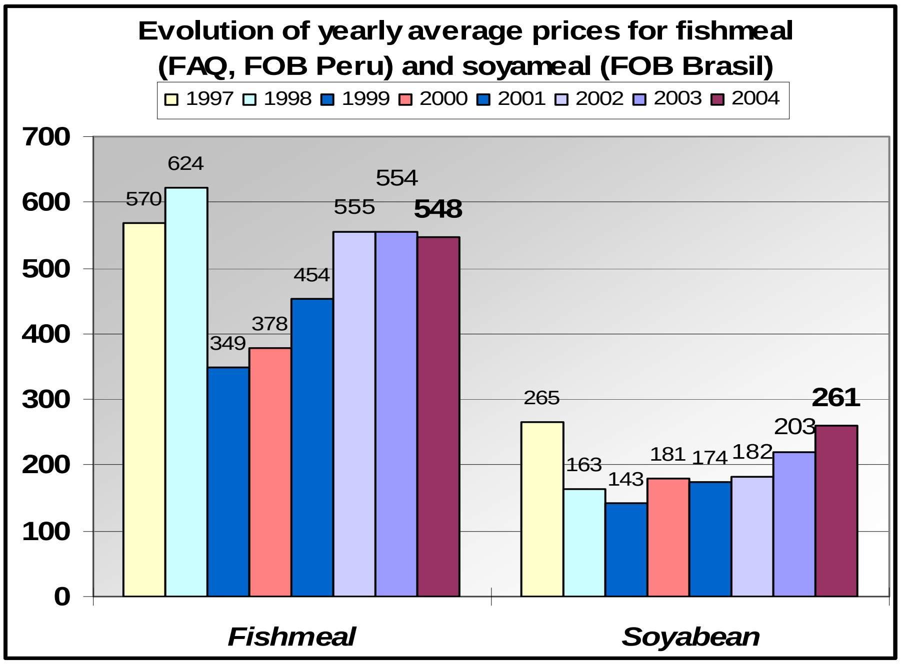


Figure 1.6.2. Reported fishmeal:soybean meal price ratio (Jean-François Mittaine, IFFO – personal communication, April 2005)

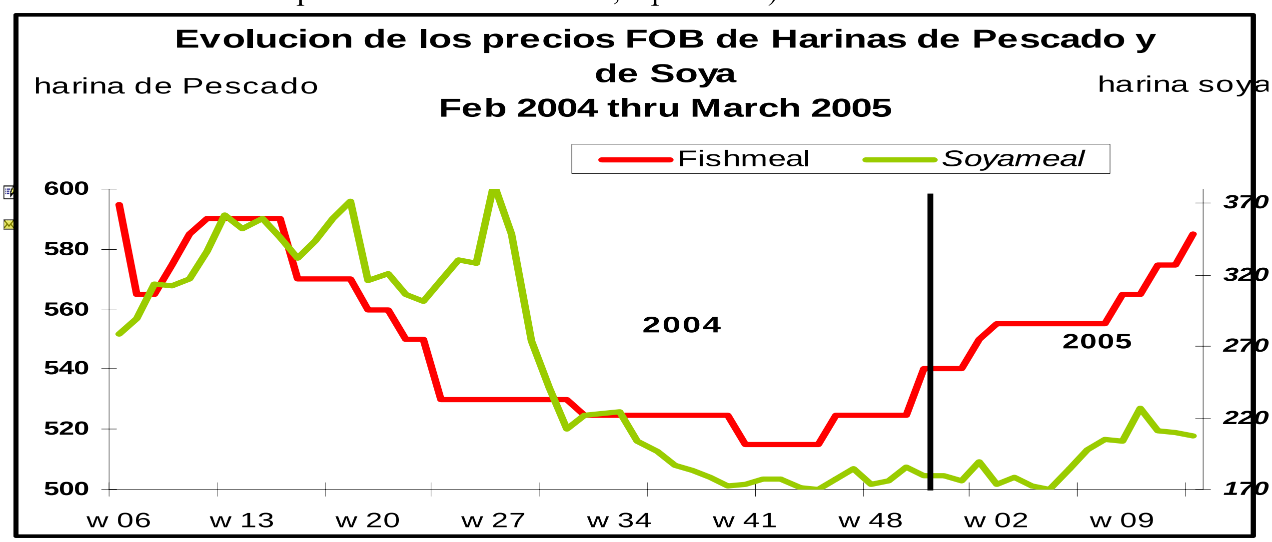


Figure 1.6.3 Mean yearly prices for fish oil and soy oil (values given in US $ per tonne: Jean-François Mittaine, IFFO – pers.com., February 2005)

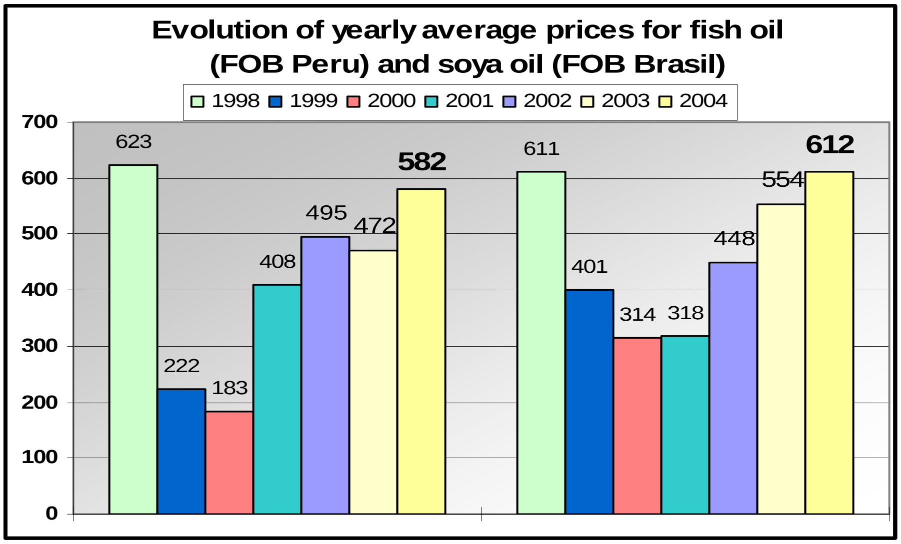


Figure 1.6.4 Reported average fishmeal/oil and soybean meal/oil price ratios (Jean-François Mittaine, IFFO – personal communication, February 2005)

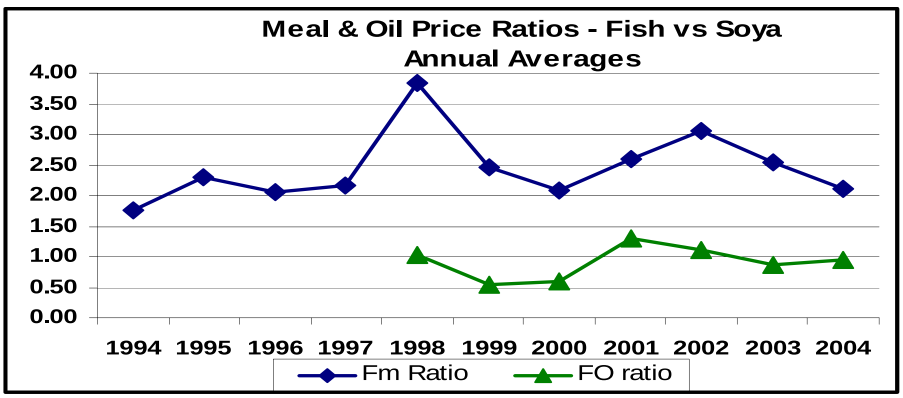
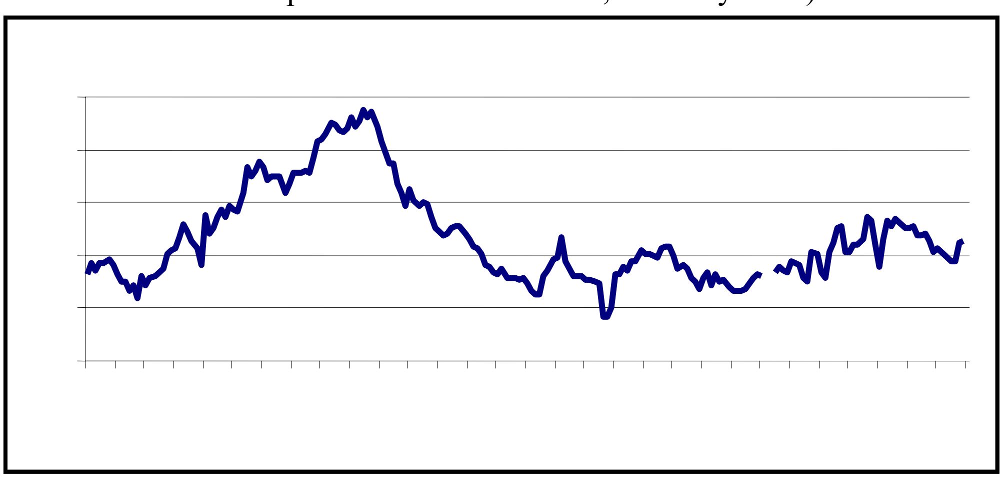


Figure 1.6.5 Reported fish oil/rapeseed oil price ratio (Jean-François Mittaine, IFFO – personal communication, February 2005)



1.7 Trends in use of other feed ingredients in salmon feeds

As mentioned previously, trends regarding the current dietary replacement of fishmeal and fish oil substitution varies from country to country, depending upon feed ingredient market availability and cost, transportation/importation and processing costs prior to usage, and the intended market where the salmon is to be sold (and the specific requirements and constraints of these markets).

For example, at the time of writing this report, the following feed ingredients were being considered for use of dietary fishmeal and fish oil replacers within the major salmon producing countries, namely:

Canada: Up to 70% and 50% of dietary protein and lipid in non-marine form, including the possible use of canola meal, pea meal, soybean meal, canola (rapeseed) oil, maize gluten meal, soybean protein concentrate, feather meal, poultry byproduct meal, poultry oil and the crystalline amino acids lysine and/or methionine;

Chile: Up to 60% and 20% of dietary protein and lipid in non-marine form, including the possible use of canola meal, soybean meal, rapeseed oil, maize gluten meal, lupin, feather meal, poultry byproduct meal, and the crystalline amino acids lysine and/or methionine;

Norway: Up to 55% and 50% of dietary protein and lipid in non-marine form, including the possible use of soybean protein concentrate, soybean meal, corn gluten meal, wheat gluten, rapeseed oil, and the crystalline amino acids lysine and/or methionine; and

UK: Up to 45% replacement of dietary protein, with only a limited replacement of fish oil (up to 5 to 10% of added oil can be non-marine) due to market demands, including the possible use of maize gluten, soya products (mostly extracted), wheat gluten, rapeseed oil, and crystalline amino acids.

1.8 Trends in salmon feed manufacturing techniques

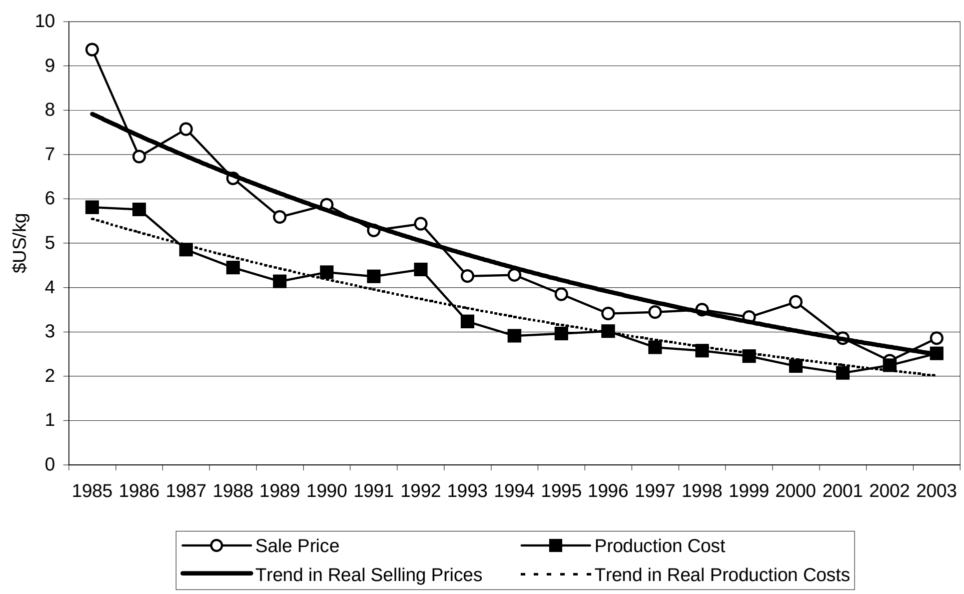
The changes observed in the level of fishmeal and fish oil within salmon feeds over the past two decades would not have been possible if it were not for the changes which occurred in feed manufacturing technology over this period (Kearns, 2005).

Initially, in the early eighties salmon feeds consisted essentially of farm-made semi-moist pelleted feeds composed of a blend of minced sardines/low-value feed fish mixed with wheat flour and a vitamin/mineral premix. Although these semi-moist feeds were usually readily consumed by the salmon, their manufacture depended upon a regular daily supply of fresh `top quality' sardines/lower-value fish, with the diets generally exhibiting poor water stability and feed conversion ratios (FCR: total feed fed ÷ total weight gain, typically ranging from 4 to 6). However, between the mid eighties to the early nineties these farm-made feeds were gradually replaced with dry commercially manufactured steam pelleted feeds, characterized by their high protein and low fat (<18-20%) content, and much improved feed efficiency (FCR 1.6-1.8).

From 1993 to the present conventional steam pelleted feeds have been replaced with extruded salmon feeds. Extrusion feed processing has resulted in salmon feeds with improved durability (less fines and wastage), increased carbohydrate and nutrient digestibility (due to the increased starch gelatinization and/or destruction of heat-labile plant anti-nutrients), and with improved physical characteristics (including altered density and adjustable pellet buoyancy/sinking characteristics); the latter in turn has facilitated the addition of higher dietary fat levels (and the consequent formulation of higher energy diets) through spraying or top coating. These modern lower protein and higher lipid (up to 40% by weight) salmon feeds typically yield economic FCRs (total feed input ÷ total live fish output, thus allowing for fish mortality) from 1.3 to under 1 (Larrain et al. 2005). The main reason for the lower FCRs with these extruded feeds has been due to the ability of raising dietary lipid levels, with the consequent increase in dietary energy levels and consequent improved protein and energy nutrient utilization.

Extrusion cooking became the production method of choice due to the advantages these systems offer. It is generally accepted that the major reasons for extruded feeds in the salmon industry is the ability to expand the product so that it accepts the high oil levels to achieve the present growth rates, greatly reduced degradation of the ocean floor under the cages, stronger pellets for the automatic feeders and the ability to use a wider ranges of raw materials for the overall formulation adjustments for new and future possible protein sources (Kearns, 2005). The net result of these continuing improvements in feed formulation and feed manufacture, is that over the years fish growth has been steadily increasing, feed conversion ratio has been steadily decreasing, and as a result and more importantly fish production costs have been decreasing (Figure 1.8.1).

Figure 1.8.1. Farmed Atlantic Salmon: real production costs and selling prices (Source: LMC International Ltd)



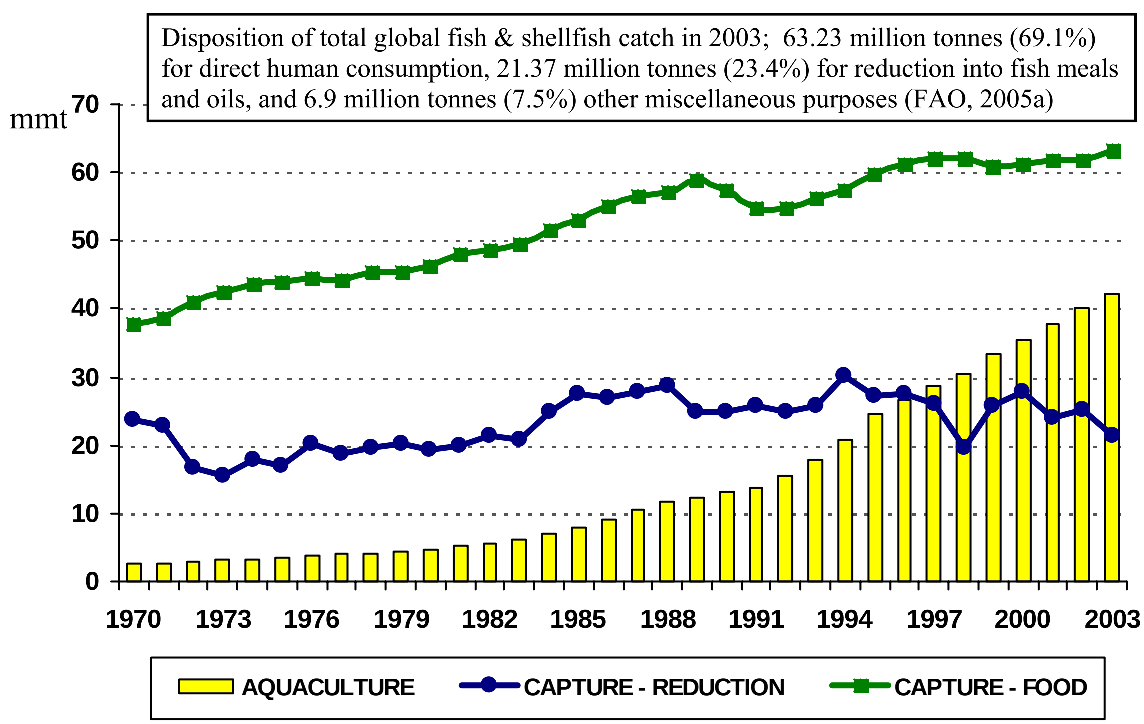
2. FISHERIES STATUS AND ECOSYSTEM IMPACTS FROM FISHMEAL AND FISH OIL USE

2.1 Fish landings destined for reduction

The quantities of landed fish and shellfish from capture fisheries destined for reduction into meals and oils and other non-food purposes has increased over seven-fold from 3 million tonnes in 1950 (representing 16.1% total capture fisheries landings) to 21.37 million tonnes in 2003 or 23.4% total capture fisheries landings (FAO, 2005a). With the exception of the El Nino year of 1998, the proportion of the fisheries catch (whole fish) destined for reduction into fishmeal and fish oil has fluctuated between 20 and 30 million tonnes (Figure 2.1.1).

However, this figure only refers to whole fish destined for reduction, and so excludes other fish scraps and processing wastes. In fact, industry estimates for the total quantity of whole fish and trimmings reduced into meals and oils in 2002 have been given as 33 million tonnes (includes 27.4 million tonnes of whole fish caught by dedicated fishing fleets and 5.6 million tonnes of trimmings and rejects from food fish; FIN, 2004). For example, within the European Union (EU) it is estimated that in 2002 about 33% of the fishmeal produced in the EU-15 was manufactured from trimmings from food fish processing, including Spain 100% trimmings, France 100%, Germany 100%, Italy 100%, UK 84%, Ireland 60%, Sweden 25%, and Denmark 10% (Huntington et al. 2004). At present no information is available from FAO concerning the total global production of fishmeals and oils produced from fishery and aquaculture trimmings and offal.

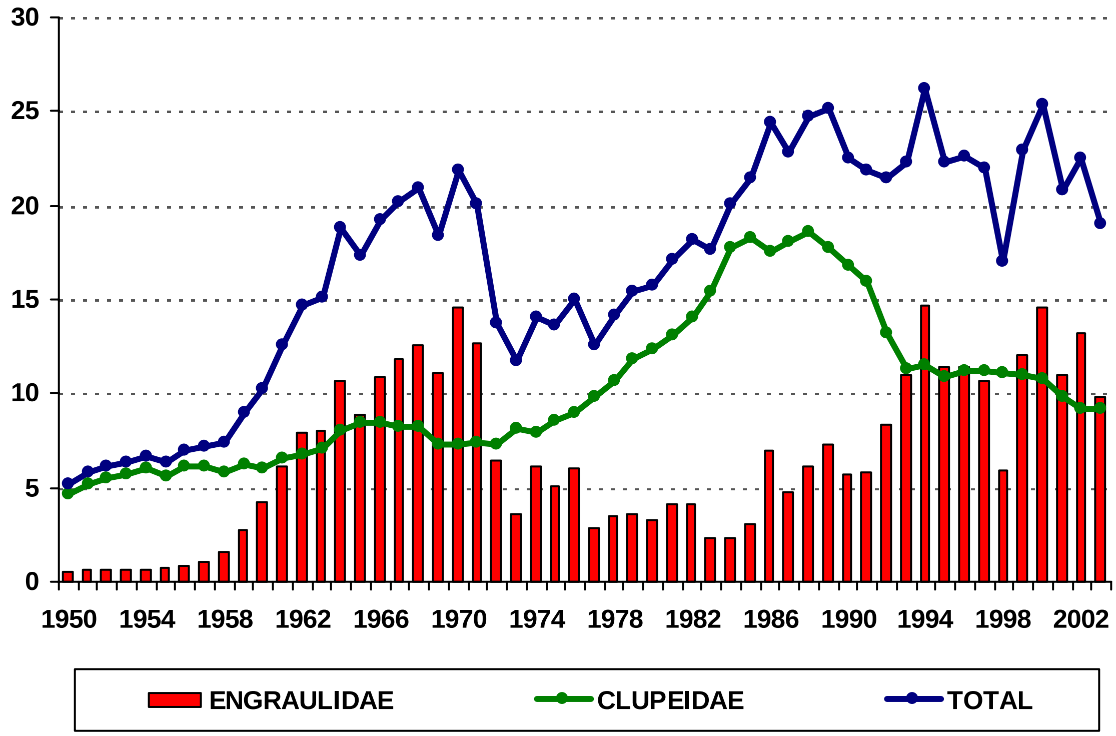
Figure 2.1.1. Total finfish and shellfish production from capture fisheries & aquaculture



2.2 Fish species trends and catching volumes

Small pelagic fish species form the bulk of capture fisheries landings usually destined for reduction, with anchovies (Family *Engraulidae*) and herrings, pilchards, sprats, sardines, menhaden (Family *Clupeidae*) totaling 18.99 million tonnes or 87% of the total estimated capture fisheries landings (21.72 million tonnes) destined for reduction in 2003, respectively (Figure 2.2.1).

Figure 2.2.1 Reported capture fisheries landings of small pelagic fish species destined for reduction into fishmeal and fish oil (Source: FAO, 2005a).



On a species basis, the top pelagic fish species destined for reduction in 2003 included:

- Peruvian anchovy - total reported landings 6,202,447 tonnes in 2003, Peru 86.2%, Chile 13.2%, Ecuador 0.5%, Figure 2.2.2;
- Blue whiting - 2,385,007 tonnes in 2003, Norway 35.7%, Iceland 21.0%, Russian Federation 15.1%, Faeroe Islands 13.7%, Denmark 3.7%, Sweden 2.7%, Netherlands 2.4%, Figure 2.2.3;
- Japanese anchovy - 2,088,744 tonnes in 2003, China 62.3%, Japan 25.6%, Korea Republic 12.0, Figure 2.2.2;

Figure 2.2.2 Reported capture fisheries landings of Peruvian & Japanese Anchovy (values given in million tonnes: FAO, 2005a).

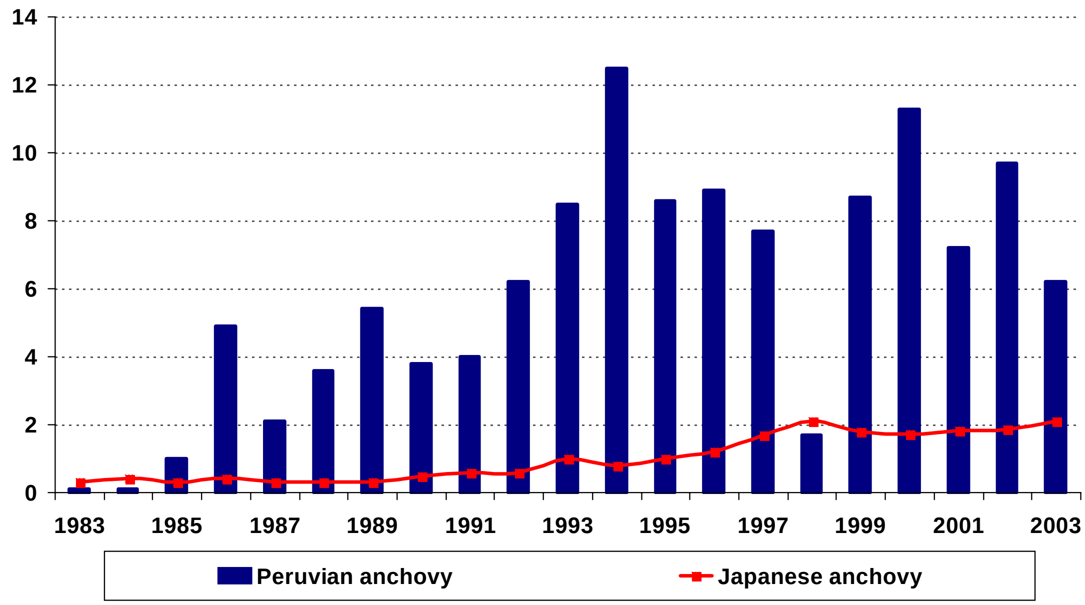


Figure 2.2.3 Reported capture fisheries landings of Blue whiting & Sandeels (values given in million tonnes: FAO, 2005a).

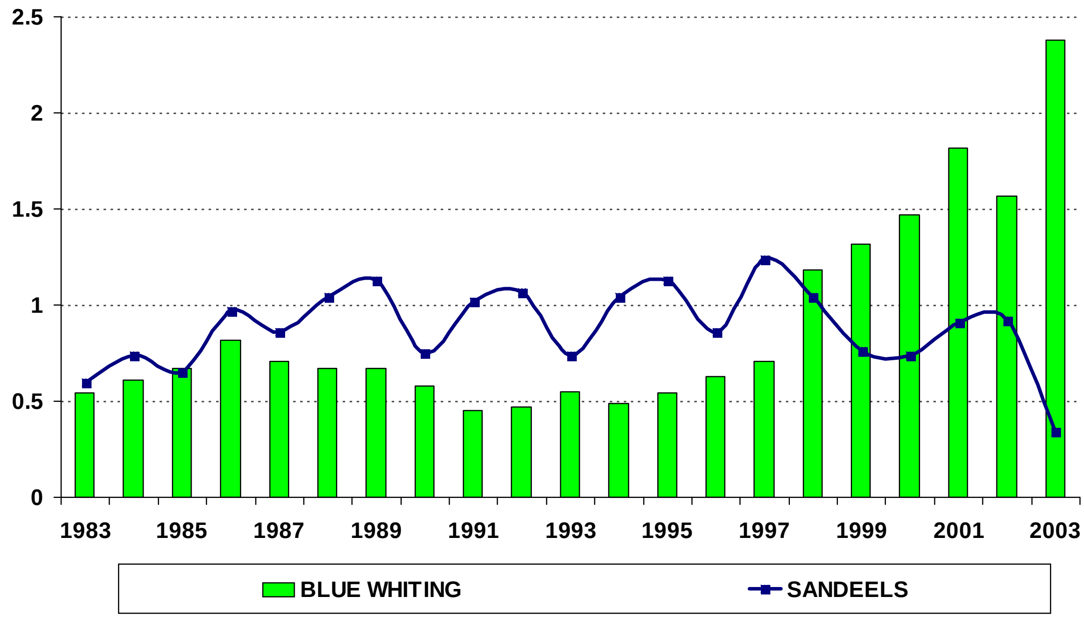


Figure 2.2.4 Reported capture fisheries landings of Capelin & Atlantic herring (values given in million tonnes: FAO, 2005a).

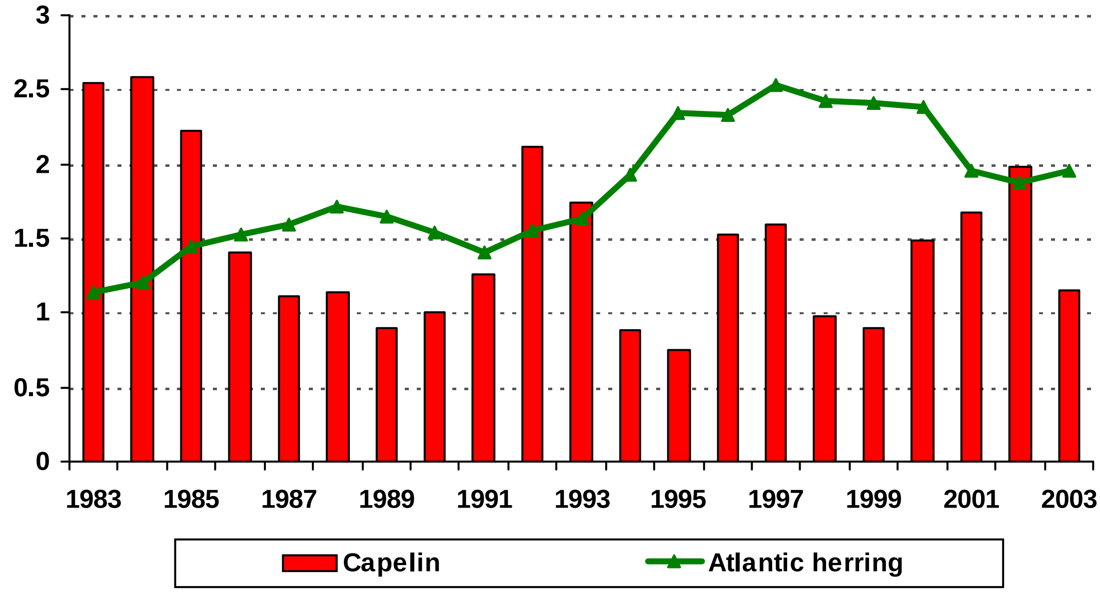


Figure 2.2.5 Reported capture fisheries landings of Chilean jack mackerel & Chub mackerel (values given in million tonnes: FAO, 2005a).

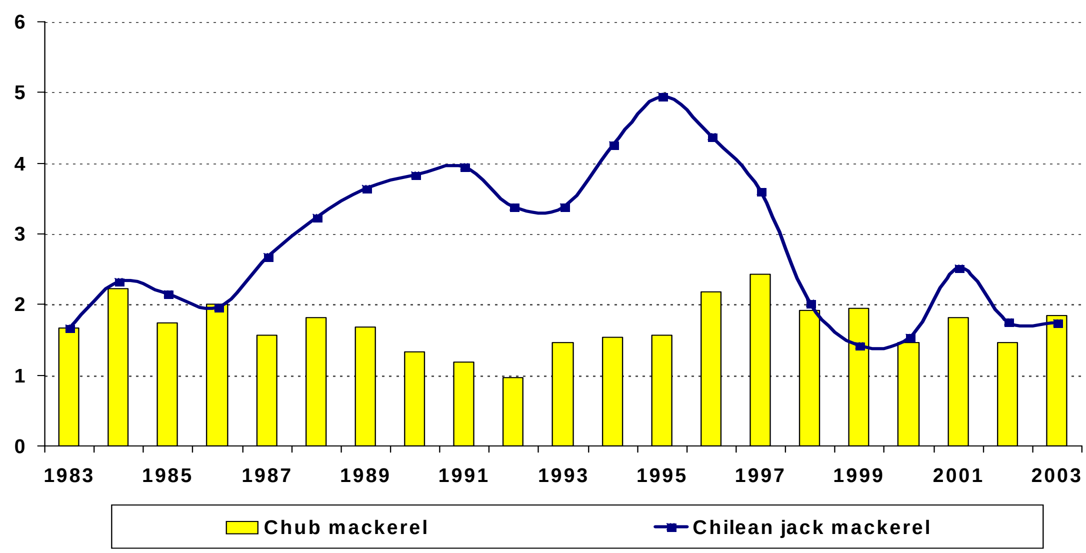


Figure 2.2.6 Reported capture fisheries landings of European pilchard & European sprat (values given in million tonnes: FAO, 2005a).

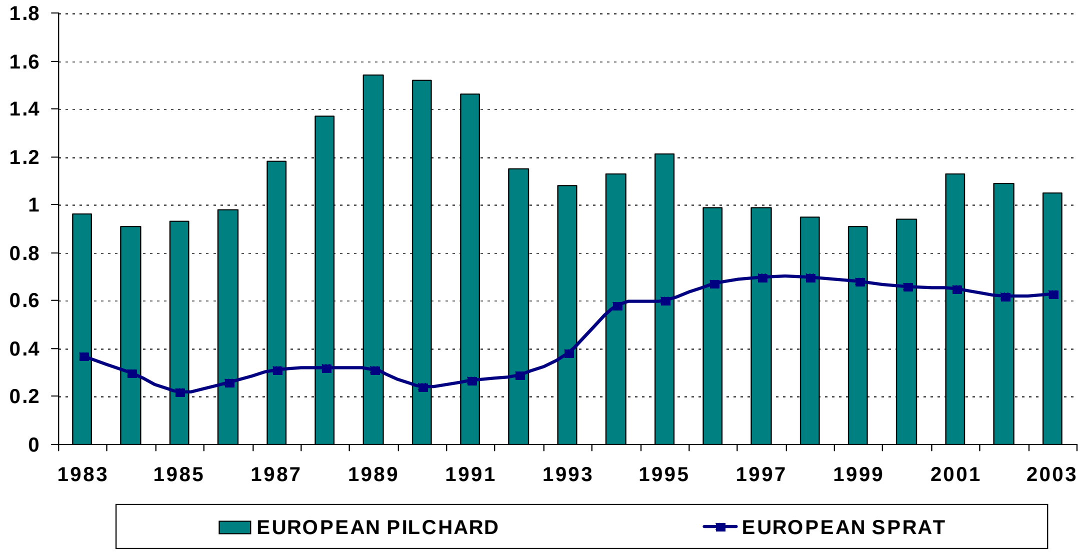


Figure 2.2.7 Reported capture fisheries landings of Californian Pilchard & Gulf menhaden (values given in million tonnes: FAO, 2005a).

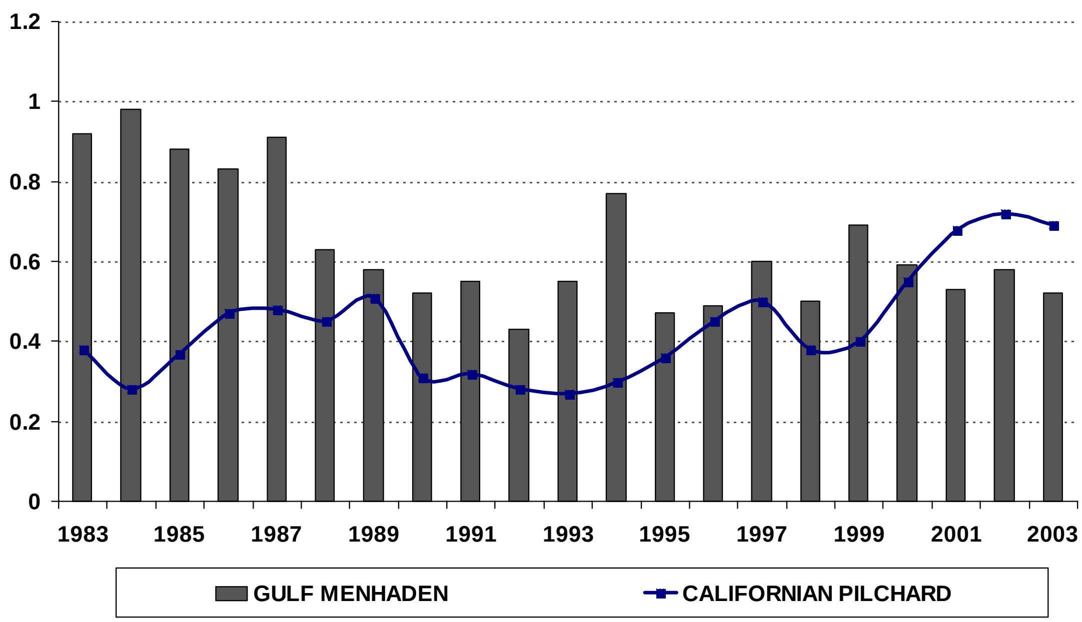
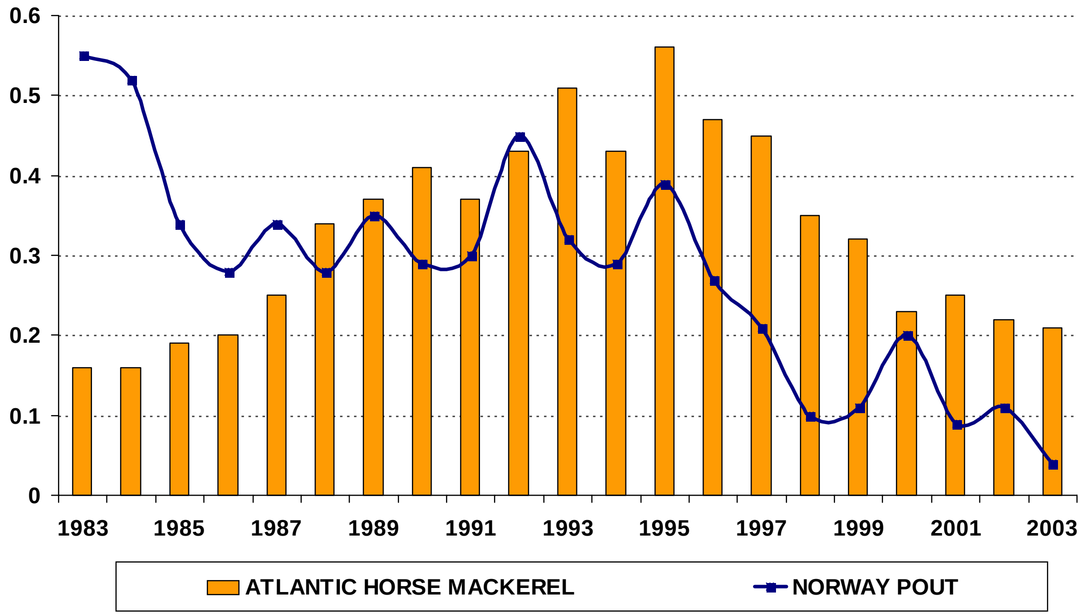


Figure 2.2.8 Reported capture fisheries landings of Atlantic horse mackerel & Norway pout (values given in million tonnes: FAO, 2005a).



- Atlantic herring 1,958,795 tonnes, Norway 28.7%, Iceland 12.8%, Canada 10.2%, Russian Federation 7.4%, Denmark (5.9%), USA 5.0%, Netherlands 4.8%, UK 4.6%, Sweden 4.4%, Figure 2.2.4;
- Chub mackerel 1,851,753 tonnes, Chile 30.9%, China 23.6%, Japan 17.8%, Korea Republic 6.6%, Peru 5.1%, Figure 2.2.5;
- Chilean jack mackerel 1,735,625 tonnes, Chile 81.9%, Peru 12.5%, China 5.4%, Figure 2.2.5;
- Capelin 1,148,106 tonnes in 2003, Iceland 59.2%, Norway 21.7%, Russian Federation 8.4%, Faeroe Islands 4.4%, Greenland 2.6%, and Denmark 1.5%, Figure 2.2.4;
- European pilchard 1,049,344 tonnes in 2003, Morocco 62.8%, Algeria 7.3%), Portugal 6.3%, Figure 2.2.6:
- Californian pilchard 691,625 tonnes, Mexico 89.6%, USA 10.4%, Figure 2.2.7;
- European sprat 631,823 tonnes, Denmark 41.5%, Poland 13.3%, Sweden 12.1%, Figure 2.2.6;
- Gulf menhaden 522,195 tonnes, USA 100%, Figure 2.2.7
- Sandeels 341,512 tonnes, Denmark 82.9%, Norway 8.7%, Sweden 6.4%, Figure 2.2.3;
- Atlantic horse mackerel 214,889 tonnes, Ireland 21.5%, Norway 9.5%, Germany 8.7%, Portugal 8.7%, Denmark 6.5%, France 5.4%, Figure 2.2.8; and

- Norway pout 37,833 tonnes, Denmark 60.9%, Norway 32.8%, Faeroe Islands 6.2%, Figure 2.2.8.

2.3 Status of exploitation of major reduction fisheries

Information concerning the global state of exploitation of wild fish stocks is only currently available for about 80% of total capture fisheries landings (FAO, 2005b). Table 2 summarizes the status of exploitation of the major pelagic and wild salmon fish stocks within the major fishing regions of the world according to the most recent FAO marine capture fisheries review (FAO, 2005b).

According to the review an estimated over 52% of the world fish stocks are considered as being fully exploited, and as such are producing catches 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. From the remaining, approximately 17% are over-exploited, 7% depleted and 1% recovering, and thus offer no room for further expansion.

In the case of the major pelagic reduction fisheries a combination of heavy fishing pressure and severe adverse environmental conditions associated with changes in the El Nino Southern Oscillation have recently led to a sharp decline in the three most abundant pelagic species in the southeast Pacific, 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 over exploited 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 2.2.2). Similarly, the South American pilchard has declined sharply as part of a decadal regime period and in 2002 yielded only 28,000 tonnes after reaching up to 6.5 million tonnes in 1985 (FAO, 2005b). 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 production of 5 million tonnes in 1994 (Figure 2.2.5).

In the northwest Pacific large changes in the abundance of Japanese pilchard, Japanese anchovy and Alaska Pollock have also occurred in response to heavy fishing and to natural decadal oscillations. This alternation of stocks follows a pattern also observed in other regions of the world that seem to be mainly governed by climatic regimes affecting stock distribution and overall fish abundance. At present the stocks of the Alaska Pollock in the northwest Pacific are considered as being fully or overexploited, while those in the northeast Pacific are considered full exploited. Moreover, in the northeast Atlantic catches of blue whiting have increased steeply (Figure 2.2.3) and the species is considered overexploited (Table 2). Similarly, most of the stocks of Atlantic cod in the area are also overexploited or depleted, while capelin and herring are exploited to their full potential (FAO, 2005b).

Table 2. Status of exploitation of the major pelagic and wild salmon fish stocks within the major fishing regions of the world according to FAO (2005b).

Species	Main fishing nations	Status
Key: U-underexploited, M-moderately exploited, F-fully exploited, O-overexploited, D-depleted, R-recovering		
Northwest Atlantic (FAO Statistical Area 21):		
Atlantic herring	Canada, USA	U-F-R
Atlantic menhaden	USA	F
Atlantic mackerel	Canada, USA	F
Capelin	Canada	F
Northeast Atlantic (FAO Statistical Area 27):		
Atlantic salmon	Norway, Finland, Denmark, Sweden	F-D
Blue whiting	Norway, Russian Fed., Iceland, Faeroe	O
Norway pout	Denmark, Norway	?-F
Sandeels	Denmark, Norway, Sweden	F
Atlantic herring	Norway, Iceland, Russian Fed., Denmark	F
European pilchard	Portugal, Spain, France, UK	?-F
European sprat	Denmark, Poland, Sweden, Latvia	?-F
Atlantic horse mackerel	Netherlands, Norway, Ireland, France	F
Atlantic mackerel	UK, Norway, Ireland, Russian Federation	F
Capelin	Iceland, Norway, Russian Federation	F
Western Central Atlantic (FAO Statistical Area 31):		
Atlantic menhaden	USA	F
Atlantic thread mackerel	USA, Cuba	?
Gulf menhaden	USA	F
Round sardinella	Venezuela	M/F
Northwest Pacific (FAO Statistical Area 61):		
Chum salmon	Japan, Russian Federation .	F
Pink salmon	Russian Federation, Japan	F
Japanese anchovy	China, Japan, Korea Rep.	F
Japanese pilchard	China, Japan	M
Chub mackerel	China, Japan, Korea Rep.	F
Japanese jack mackerel	Japan, Korea Rep.	F
Northeast Pacific (FAO Statistical Area 67):		
Chinook salmon	USA, Canada	F-O
Chum salmon	USA, Canada	F

Coho salmon	USA	F-O
Pink salmon	USA, Canada	F
Sockeye salmon	USA, Canada	F
Alaska pollock	USA	F
Pacific herring	USA, Canada	M-O

Eastern Central Pacific (FAO Statistical Area 77):

California pilchard	Mexico, USA	M-F
California anchovy	USA, Mexico	M-F
Pacific anchoveta	Panama	M-F
Pacific thread herring	Panama	M-F
Chub mackerel	Mexico, USA	M
Pacific jack mackerel	USA	U

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

2.4 Sustainability of reduction fisheries and criteria used

To date the criteria used by fisheries biologists, fisheries economists and fishery policy makers to determine the sustainability of specific reduction fisheries has been mainly based upon variations in reported landed stock biomass (usually on a traditional single species basis), fishing capacity and effort, and concerning the existence and implementation of adequate fisheries management regimes so to ensure that the landings of the target species are kept within agreed safe biological limits (Bjørndal et al. 2004; FIN, 2005; SEAFEEDS, 2003;Yndestad & Stene, 2002).

However, at present little or no consideration is usually given within the sustainability criteria used toward the consideration of wider ecosystem implications such as trophic interactions, habitat destruction, and potential social, economic and environmental benefits and risks (Bogstad & Gjosaeter, 2001; Carscadden et al. 2001; Dalsgaard et al. 1995; FAO, 1999; Folke et al. 1998; Furness, 2002; Huntington, 2004; Huntington et al. 2004; Jeroen et al. 1999; Lankester, 2005; Murawski, 2000; Pimentala, 2001; Royal Commission on Environmental Pollution, 2004; Tuominen & Esmark, 2003; University of Newcastle upon Tyne/Poseidon Aquatic Resource Management Ltd, 2004).

Clearly, it follows from the above discussion that if wider ecosystem and socio-economic factors are to be taken into consideration into revised and more broader ecologically-based sustainability assessments of reduction fisheries, then new revised definitions, principles and criteria will have to be developed (Huntington, 2004; Huntington et al. 2004; Lankester, 2005; SEAFEEDS, 2003). However, such principles and criteria will have to be crafted and implementable under real world conditions (with the participation of all major fishery stake holders) and due consideration given toward the special needs, requirements and capabilities of developing countries when ever possible.

Are feed producers able to trace their fish meals and oils back to the source?

The nutritional composition and consequent feed/economic value of fish meals and oils is highly variable depending upon species processed (species-mix composition, fishing season, fish age, material being processed – heads, guts, whole fish, freshness etc) and fishing method and meal/oil processing method employed. Thus to keep variations in meal/oil composition and quality to a minimum it is quite common for fishmeal and fish oil suppliers to sell blended meals and oils, and for feed manufacturers to buy and use more than one type of fishmeal and/or fish oil so as to ensure consistent feed quality throughout the growing season. The above is further complicated by the fact that both fishmeal and fish oil are highly perishable commodities (depending upon ambient storage conditions) and as such cannot be stored for prolonged periods of time so as to minimize variations in composition.

Moreover, at present 81.8% and 55% of total reported global fishmeal and fish oil production is not reported down to a single species level (Figure 2.4.1). Moreover, expressed on a regional basis the situation is even worse (Table 3). Although this may be just a reflection of the manner in which fishmeal and fish oil statistical information is collected and/or reported by countries to FAO (FAO, 2005a), clearly this situation needs to be remedied if feed manufacturers are to trace their fishmeals and fish oils back to specific fish stocks.

Despite the above, and the fact that traceability and quality assurance schemes gaining greater acceptability in the market place, it is generally believed that in future feed manufacturers will have no choice but to purchase fish meals and oils from known fisheries stocks and fishing vessels, all be it at an additional cost.

Is there sufficient research on the sustainability of reduction fisheries to certify them?

As mentioned previously, this will depend upon the definition of sustainability employed and criteria and indicators used for the certification of the reduction fishery. For example, Huntington (2004a) was unable to ascertain the sustainability of selected reduction fisheries based upon the modified `Sustainable Fishing' principles and criteria of the Marine Stewardship Council (MSC). At present there are no `certified' wild reduction fisheries available for sourcing fish for fishmeal and fish oil manufacture. The leading role of FAO, the International Council for the Exploration of the Sea (ICES) and non-government organizations such as MSC in the future development of internationally recognized and accepted criteria for ascertaining the sustainability of reduction fisheries is paramount.

Figure 2.4.1. Global reported fishmeal and fish oil production by major species group in 2003 (values given in million tonnes, as-fed basis: FAO, 2005a)

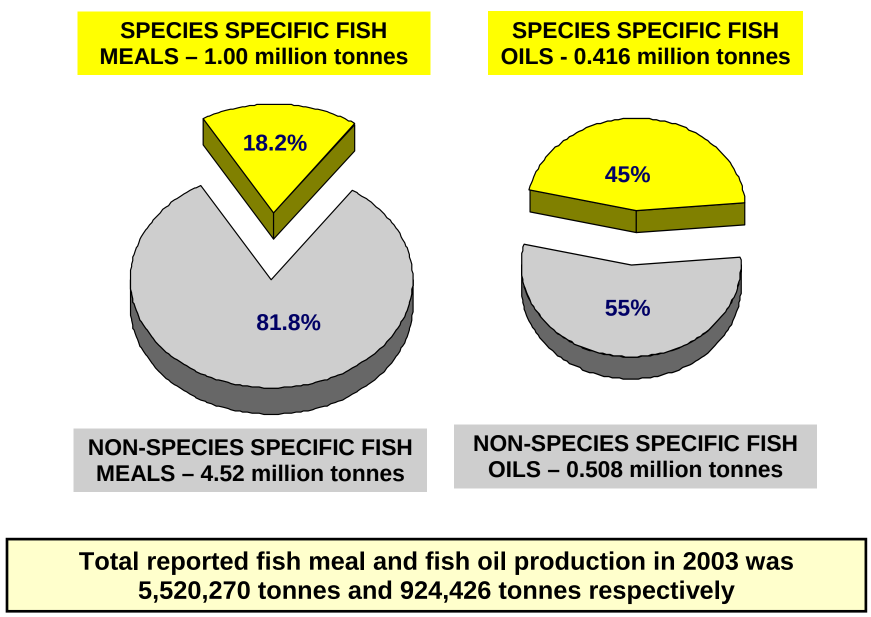


Table 3. Reported fishmeal and fish oil production by region in 2003 (values expressed in tonnes, and percent of production currently reported as non-species specific: calculated from FAO, 2005a)

Fishmeal	Production	%	Fish oil	Production	%
S. America	2,083,560	71.4	S. America	351,388	41.3
Asia	1,693,582	99.1	Europe	338,385	66.9
Europe	1,054,700	96.6	N. America	112,211	12.0
N. Amercia	422,307	45.1	Asia	98,308	97.0
Africa	223,884	89.1	Africa	21,284	100
Oceania	42,237	99.0	Oceania	2,850	100
Total	5,520,270	81.8	Total	924,426	55.0

Are the `by-product' fisheries sustainable and does focusing more pressure on them create incentives for more bycatch, or pressure on the sustainability of the target fisheries?

As mentioned previously, apart from industry estimates (FIN, 2004), no official information is currently available from FAO concerning the total global production of fishmeals and oils produced from fishery and aquaculture trimmings and offal (see section 2.1). Clearly this deficiency needs to be rectified if the sustainability of the particular target food fisheries is to be assessed.

As stated previously, there is a need for the aquafeed industry to utilize the largely untapped existing waste streams within the fisheries sector (provided that the fisheries are sustainably managed), including fisheries bycatch and discards (Alverson et al. 1994: recently estimated at over 7 million tonnes) and fishery processing wastes (Bechtel, 2003; Li et al. 2004; Rathbone et al. 2001; Tacon, 2003a).

Moreover, as stated in the FAO Code of Conducted for Responsible Fisheries (FAO, 1995) `States should encourage the use of fish for human consumption and promote consumption of fish whenever appropriate', and discourage the use of food-fish fit for human consumption for animal feeding.

According to the SCAHAW (2003) report concerning the use of fish by-products in aquaculture, within most European countries the fishmeal industry is the major receiver of by-products from traditional fisheries. However, the report mentioned that by-products also arise from the slaughter and processing of aquaculture produce, including farmed salmon (see also Wright, 2003, 2004). In this particular respect and in order to limit any risk of the transmission of fish diseases to fish or humans via the feeding of fish by-products processed into fishmeal/fishfeed (see also Gill, 2000), and in the light of the issue of intra-species recycling, the committee report recommended that:

- The by-products of farmed finfish should not be fed to farmed finfish
- The by-products of farmed invertebrates should not be fed to farmed invertebrates
- The feeding to fish of `wet' diets containing fresh or frozen but otherwise unprocessed fish by-products is not recommended
- The processes used for the production of feed or fertilizers from by-products of wild or farmed fish should be validated with regard to their ability to inactivate representative model organisms
- That current procedures used to process mortalities from fish farms should be validated in terms of their ability to inactivate fish pathogens and also in terms of the microbiological safety of the end-product.

Available information on energy consumption in fishing, reduction and transport?

Apart from general reviews concerning fuel use there are no comprehensive up-to-date reviews concerning energy consumption and use in reduction fisheries, fishmeal and fish oil reduction, and product transport to major markets (Huntington, 2004; Pimentel et al. 1996; Tyedmers, 2004; Watanabe et al. 1985). For example, the report of Tyedmers (2004) on fisheries and energy use indicated that North Atlantic fisheries for reduction consume less than 100 litres of diesel per tonne of fish landed, as compared with just over 500 litres for Industrial fisheries for direct human consumption.

Similarly, Huntington (2004) reviews the environmental cost considerations of shipping and transporting fishmeal by container from South America to Europe, including the fossil fuels burnt, CO_2 emissions and other noxious gas emissions. However, no hard data is presented or considering energy use per unit of usable output (not just in terms of edible protein equivalents) for reduction fisheries and/or for fishmeal and fish oil manufacture and transportation.

2.5 Key questions that have yet to be researched

These may be summarized as follows:

- Need to develop industry agreed ecosystem-based standards, principles and criteria for the sustainable development and exploitation of reduction fisheries. In line with the FAO Code of Conduct for Responsible Fisheries (FAO, 1995), the special needs and requirements of Developing Countries need to be taken into consideration when developing these standards and criteria;

- On the basis of the above agreed standards, principles and criteria for FAO/ICES or appropriate agreed NGO to then ascertain the sustainability of the major reduction fisheries upon which salmon feeds are dependent as a source of fishmeal and/or fish oil;

- Need to estimate the total global production of fishmeal and fish oil from fishery by-products and trimmings, including species composition, and the current use fishmeal and fish oils (at the species level) by the resident salmon aquafeed sector within the major salmon producing countries; and

- Need to develop practical models concerning energy consumption and use within the different major reduction fisheries, including fishing, meal/oil manufacture and transportation of meals/oil to major markets.

3. STATUS OF DEVELOPMENT AND USE OF DIETARY FISHMEAL AND FISH OIL SUBSTITUTES FOR SALMONIDS

3.1 Issues and obstacles related to reducing fishmeal and fish oil use

Fish do not have a specific dietary requirement for fishmeal or fish oil

Like humans and most other farmed animal species, salmonids have a specific dietary requirement for 40 or so essential dietary nutrients and *do not* have a specific dietary requirement for a particular ingredient such as fishmeal or fish oil. For example, in their natural environment, the diet of salmonids consists mainly of a mixture of crustaceans, molluscs and other benthic organisms, with fish usually being the chance encounter rather than the rule.

Not withstanding the above, fishmeal and fish oil has a nutritional profile which approximates closest to the known dietary requirements of salmonids, and as such usually has a high biological value and digestibility for salmonids compared with other non-marine animal feedstuffs. However, since the science of feed formulation is to formulate rations to a specific dietary available nutrient profile, it follows therefore that if the above has been carried out correctly, that fish growth should be equivalent on a diet composed of fishmeal or on an equivalent diet composed of other protein sources. Although this is relatively straight forward in the case of fishmeal, this has been more difficult in the case of fish oil where there are currently no commercial alternatives (of sufficient commercial scale of production) at present, and where fish oil is also used as a relatively inexpensive source of highly digestible energy and for the nutritional enhancement of the salmon carcass.

Use of high energy diets

As mentioned previously, there has been a progressive increase in dietary lipid and energy levels (and equivalent decrease in dietary protein levels) within salmon grow-out feeds since the mid eighties, with current dietary lipid levels (primarily in the form of fish oil) being as high as 38% of the total diet (see section 1.4; Figure 1.4.1). Although, the trend toward the use of lower protein and higher lipid, and consequently higher energy feeds (lipid having a gross energy level almost twice that of protein) has resulted in more cost-effective feeds in terms of faster fish growth and improved feed efficiencies (including better protein conversion efficiencies and consequent reduced nitrogen loss to the environment) there are some disadvantages.

For example, apart from the obvious increased market demand for fish oil within salmon feeds, the mean reported lipid content of farmed Atlantic salmon is currently almost twice that of wild Atlantic salmon (17-19% versus 8-10%, the lower lipid content of wild salmon believed to be due to their higher energy expenditures for migration and maturation: Skretting, unpublished data). Moreover, although the total essential fatty acid (EFA) content of farmed salmon flesh may be higher than that of wild salmon (due to the use of EFA-rich dietary fish oils), by the same token farmed salmon also runs the risk of containing higher levels of environmental contaminants from increased fish oil use. Thus, apart from having almost twice the body burden of contaminants by virtue of their higher carcass lipid content, dietary fish oils (depending upon their species, source and processing) may also be contaminated with persistent organic pollutants (POPs; Hites et al. 2004a, 2004b; Foran et al. 2005; Huntington, 2004). This aspect will be dealt with in greater detail in section 5 of this report.

Increasing consumer demands for wholesome and safe food

Concerns raised about the possible transfer of mammalian infectious agents such as Bovine Spongiform Encephalopathy (BSE) and other Transmissible Spongiform Encephalopathies (TSEs) through the use of rendered animal by-product meals within compound animal feeds (including aquafeeds; FAO, 1998, 2001; FIN, 2004; Pearl, 2000; SCAHAW, 2003; SSC, 2003) has led to increased consumer awareness and concerning feed and food safety, and the consequent introduction of stricter feed assurance schemes, including codes of practice concerning fishery products, fishmeal and feed manufacture and the development of improved rendering techniques and safer animal by-product meals (Gill, 2004b; Randell, 2004; Woodgate, 2004a).

As a result of the above, and the perceived attitudes and opinions of consumers towards food safety and `wholesomeness' or `quality'(including farmed fish), there has been a growing trend in some countries for major salmon producers and/or leading salmon retailers/supermarket chains to set guidelines to feed manufacturers as to what and what can or cannot be used within salmon feeds, including levels of maximum fishmeal and fish oil substitution. For example, the lower levels of fish oil and to a lesser extent fishmeal substitution within salmon feeds in the UK has been in part due to the formulation constraints imposed by leading salmon producers and/or retailers, including what ingredients or levels of substitution is considered acceptable or not (Huntington, 2004; see section 1.7 of this report). For example, the Scottish Quality Salmon (SQS) position on feeds and feed ingredients is set out in a series of EN45011 compliant quality manuals, covering freshwater/smolts, marine on-growing (the TQM scheme) and the Label Rouge Scheme for France (www.scottishsalmon.co.uk).

Sustainable use of available fishery resources

Concerns have been raised considering the long-term sustainability and ethics of using potentially food-grade fishery resources (and in particular jack mackerel, horse mackerel, blue whiting, pilchards, sardines, capelin) for animal feeding rather than for direct human consumption (Best, 1996; Goldburg & Naylor, 2005; Seafeeds, 2003; Tacon, 1997). In particular, in some major fishmeal and salmon producing countries such as Chile there has been a growing (all be it still small) shift toward selling a portion of the fish catch (and in particular the Chilean jack mackerel) for direct human consumption to African countries rather than for reduction (Wray, 2001; Zaldivar, 2004). For example, although the average reported price for frozen jack mackerel and fish meal was about the same, the yield was about 23% for meal production and 5-7% for oil production, as compared with 70-75% when frozen fish was produced (Wray, 2001). Clearly, under these circumstances selling the fish for direct human consumption would be much more profitable than reduction. In 2003 Chile reported total jack mackerel catches and meal production at 1,420,873 tonnes (wet basis) and 227,087 tonnes (dry basis), respectively (FAO, 2005a).

A similar case could also exist for Blue whiting, where market test studies have shown that the quality of blue whiting surimi made onboard from Atlantic blue whiting was judged to be significantly better than Alaskan Pollock surimi (Trondsen, 1998).

In addition to the above, there has been increasing public awareness and concern for the health and management of marine fisheries stocks and ecosystems, and the growing demand for assurance/certification schemes that fishery products are obtained from sustainable sources, including the increasing demand for traceability, labeling and transparency (FIN, 2004; Hole, 2004; Huntington, 2004; Huntington et al. 2004; Seafeeds, 2003; Wessells et al. 2001).

Moreover, there is a growing global awareness concerning resource-use efficiency in animal and aquaculture production and the consequent need to improve resource-use efficiency so as to reduce and/or minimize the negative social, environmental and/or ecological impacts of these farming systems (Anderson & Lindroth, 2001; Åsgård & Austreng, 1995; Bailey, 1997; Boyd, 2000; Costa-Pierce, 2003; Craig, 2001; Forster & Hardy, 2001; Orskov, 2001; Pimentel, 2001; Raven, 2002; Roth et al. 2000; Tidwell & Allan, 2001; Troell et al. 2004; Vorosmarty et al. 2000).

3.2 State of research on fishmeal and fish oil substitution

As discussed in section 1.4, Canada and Norway currently lead the way in terms of the current level of dietary marine protein (i.e. fishmeal) and marine lipid (i.e. fish oil) substitution at 55% and 50%, followed by Chile at 60% and 20%, and the UK at 45% and 10% with no apparent loss in fish growth or the nutritional quality of the fish carcass, respectively.

During the feed survey conducted for this report, the major fishmeal and fish oil replacers reportedly used, included:

- *Chile:* soybean meal, soy oil, rapeseed oil, maize gluten meal, canola, lupin, feather meal, poultry byproduct meal, crystalline amino acids;
- *Canada:* canola meal, pea meal, soybean meal, canola (rapeseed) oil, poultry oil, maize gluten meal, feather meal, poultry byproduct meal, soybean protein concentrate, crystalline amino acids;

- *Norway:* soybean protein concentrate, soybean meal, corn gluten meal, wheat gluten, rapeseed oil, crystalline amino acids; and
- *UK:* maize gluten, soya products (mostly extracted), wheat gluten, and crystalline amino acids.

Examples of recent research studies conducted on salmonids involving one or more of the above feed ingredient sources can be listed as follows:

Terrestrial plant proteins and oils

- Canola oil – Adelizi et al. (1998), Turchini et al. (2003a); Canola meal – Mwachireya et al. (1999), Satoh et al. (1998), Sajjadi & Carter (2004), Thiessen et al. (2003a, 2003b, 2004);
- Canola protein concentrate – Drew (2004), Forster et al. (1999);
- Coconut oil - Ballestrazzi et al. (2003);
- Corn gluten meal – Francesco et al. (2004);
- Cottonseed meal - Cheng & Hardy (2002a), Cheng et al. (2003), Lee et al. (2002), Rinchard et al. (2003a, 2003b);
- Groundnut meal - Adelizi et al. (1998);
- Linseed oil – Tocher et al. (2000, 2002, 2003);
- Lupin – Borquez et al. (2005), Burel et al. (1998, 2000a), Carter (2000), Carter & Hauler (2000), Farhangi et al. (2001), Glencross et al. (2002, 2003b, 2003d, 2004a, 2004b, 2005);
- Maize gluten meal - Mente et al. (2003), Opstvedt (2003); Olive oil – Torstensen et al. (2004);
- Palm oil - Bell et al. (2002), Ng (2004), Ng et al. (2004);
- Pea meal/products – Burel et al. (2000a), Carter (2000), Carter & Hauler (2000), Francesco et al. (2004), Gomes et al. (1995), Thiessen et al. (2003a, 2003b);
- Potato protein concentrate - Refstie & Tiekstra (2003); Rapeseed oil – Bell et al. (2001), Torstensen et al. (2004);
- Rapeseed & Linseed oils - Bell et al. (2003a, 2003b), Ng et al. (2004), Tocher et al. (2000, 2003);
- Rapeseed meal – Burel et al. (2000a), Francesco et al. (2004), Gomes et al. (1995);
- Rapeseed protein concentrate – Kissil et al. (2000), Teskeredžić et al. (1995);
- Soybean meal/full-fat – Adelizi et al. (1998), Bakke-McKellep et al. (2000), Buttle et al. (2001), Carter (2000), Carter & Hauler (2000), Cheng & Hardy (2004), Cheng et al. (2004b), Davies & Morris (1997), Davies et al. (1997), Davis & Arnold (2004), Kaushik et al. (1995), Krogdahl et al. (2000, 2003), Lee et al. (2002), Nordrum et al. (2000), Opstvedt et al. (2003), Refstie et al. (1998, 2000, 2001, 2005), Sujiura et al. (2001), Vielma et al. (2002, 2004);
- Soybean, full fat:corn gluten mixture (1:2) – Mundheim et al. (2004);
- Soybean protein concentrate – Adelizi et al. (1998), Dersjant-Li (2004), Glencross et al. (2004a, 2005), Kissil et al. (2000), Storebakken et al. (1998, 2000a), Sveier et al. (2001);

- Soybean oil - Grisdale-Helland et al. (2002b);
- Soybean meal:red blood cell extrudate – Selden et al. (2001);
- Sunflower oil - Bransden et al. (2003);
- Wheat gluten – Storebakken et al. (2000b);
- Whole wheat & Barley meals – Skrede et al. (2002).

Terrestrial animal byproducts

- Animal fats (review) – Bureau (2004);
- Animal byproduct, Cottonseed meal and Soybean meal mixture – Lee et al. (2002);
- Blood meal – Breck et al. (2003), Glencross et al. (2003e), Johnson & Summerfelt (2000), Luzier et al. (1995);
- Blood meal, Meat & Bone meal, Poultry byproduct meal - Cheng & Hardy (2002b), Pfeffer et al. (1995), Yu (2004);
- Feather meal, hydrolyzed – Bureau et al (1999, 2000), Pfeffer et al. (1994), Woodgate (2004b);
- Meat and Bone meal – Bureau et al. (1999, 2000), Yu (2004);
- Poultry byproduct meal, and Feather meal mixture – Yanik et al. (2003); Poultry fat & Pork lard – Liu et al. (2004), Turchini et al. (2003);
- Soybean meal:red blood cell extrudate – Selden et al. (2001);

Single cell proteins (SCP)

- Bacterial SCP – Berge et al. (2005), Perera et al. (1995), Storebakken et al. (2004);
- Yeast SCP – Cheng et al. (2004a), Yamamoto et al. (1995);

Complete dietary replacement of fishmeal and fish oil

Complete dietary fishmeal and fish oil replacement in salmonids has not been possible to date for a variety of different factors, the most important being the higher apparent sensitivity of salmonids to the anti-nutritional factors present within plant meals (Francis et. al. 2001), and the higher nutrition skills required to formulate rations to preset available dietary nutrient levels (Davies & Morris, 1997; Forster et al. 199; Fournier et al. 2004; Furuya et al. 2004; Hardy et al. 2001; Sajjadi & Carter, 2004; Storebakken et al. 1998; Sujiura et al. 2001; Takagi et al. 2000, 2001). To date, the most promising results obtained to date in other carnivorous fish species has been with low-ash terrestrial animal byproduct meals and extracted plant protein concentrates, including high protein SCP (Kaushik et al. 2004; Kissil et al. 2004; Millamena, 2002).

Total replacement of fish oil has also been more problematic, and further research is required concerning the use of finishing diets so as to manipulate the final salmonid tissue fatty acid profile and product quality (Bell et al. 2003a; Francesco et al. 2004;

Kaushik, 2004; Morris et al. 2005; Ng et al. 2004; Obach et al. 2001; Rosenlund et al. 2001a, 2001b; Seafeeds, 2003; Solberg, 2004.

Status, outlook, and concerns for use of GMO plant products in feed

Reference is made here to the recently completed Ph.D. thesis of Dr. Monica Sanden entitled `Genetically modified plant products in feed to farmed Atlantic salmon: effects on growth, feed utilization, fish health and assessment of potential risks' (Sanden, 2004). In particular, the conclusion of the thesis indicated that the use of low levels of GM plant proteins (soy and maize) in fish feed was safe for the salmon as fish showed no adverse implications related to nutritional performance, intestinal abnormalities, fish health or growth. The results also supported previous findings regarding fragmentation of DNA during feed production as only small GM DNA fragments could be detected in the fish feed with no traces of dietary GM DNA fragments in internal organs or in eatable fish products. However, significant differences were reported in the relative size of the spleen of fish fed the GM soy diet compared with fish fed a non-GM soy diet (Hemre et al. 2005). Clearly, further studies would be required to investigate why the spleen index was reduced and the possible risk of dietary exposure to GM plant products included at higher levels, and at longer exposures, preferably from fry to broodfish (Hemre et al. 2005).

Moreover, since there is a slight possibility of transgenic sequences from GM products being absorbed in the intestine by gut microflora and subsequently being incorporated and/or modified by these microorganisms, this aspect also needs to be evaluated.

Status, outlook, and concerns for use of land animal products in feed

Of the different sources of animal proteins and fats available for use within compound aquafeeds by the largest in terms of volumes available are the terrestrial animal by-product meals (Bureau, 2000, 2004; Shepherd, 1998; Tacon, 2000), including:

- Fats - industrial tallows, edible beef tallow, lard, yellow grease, feed grade fats;
- Animal protein meals - meat and bone meal (MBM), meat meal, hydrolyzed feather meal, poultry by-product meal, blood meal, and specialised protein blends; and
- Other miscellaneous products, including specific organ meals, such as liver meal and lung meals, chick hatchery waste, bone meal, hide fleshing meals, and blood/rumen contents meals.

Although no precise statistical information exists concerning the global production and availability of the above animal by-product meals, the worldwide rendering industry handles over 60 million metric tons of raw materials annually. Modern efficient renderers are mainly concentrated in North America, where they process nearly 25 million tons of raw materials per year, in the European Union (about 15 million tons per year) and in the leading livestock and meat processing countries of Argentina, Australia, Brazil and New

Zealand (roughly 10 million tons per year). It is estimated that the total global production of meat and bone meal is about 15 million tonnes (assumes a meal yield of about 25% from the raw processed material), with production being equal to that of total reported fat output from the rendering process in the form of total tallow and grease plus lard production.

Despite the above broad assumption, these animal by-product meals (ca. 15-30 million tonnes/annum, dry basis) exceed that of fishmeal and fish oils (6-8 million tonnes/annum, dry basis) by a factor of two to three and represent the largest source of animal proteins and lipids currently available in the market place for animal feed industry, including the aquafeed sector.

However, as mentioned previously, concerns raised about the possible transfer of mammalian infectious agents such as BSE and other TSEs through the use of rendered animal by-product meals within compound animal feeds (including aquafeeds) has led to the EU ban (as of August 2001) on the feeding of any processed animal protein (including fish meal) to animals kept, fattened or bred for the production of food, with the exception that fish meal is permitted for feeding to pigs, poultry and fish (FIN, 2004) and heightened consumer awareness concerning food and feed safety.

For example, in the UK robust, independently monitored systems for tracking the source, storage, handling, manufacture and distribution of all feed ingredients and finished feed, backed up by independent and government-approved tests, make sure the ban on MBM is watertight: these systems are also recognised as the benchmark for their own assurance schemes by the major supermarkets, including Tesco, Sainsbury and Waitrose

Blood products and blood meal have been allowed back into aquafeeds in the EU since September 1, 2003, thanks to Commission Regulation 1234/2003, which is an amendment to the transmissible spongiform encephalopathy (TSE) regulation 999/2001. However, the inclusion of blood products into aquafeeds can only take place in facilities restricted to aquafeed production. This in turn gives the industry very good traceability, which is what is required under the amendment 1234/2003 of the TSE regulation. The allowed use of hydrolyzed feather meal in non ruminant feeds, including aquafeeds in Europe, is allowed under EU regulation 1774/2002.

However, it should be clearly stated here that despite the recent changes in EU legislation allowing the use of selected non-ruminant rendered animal byproducts within aquafeeds, European salmon feed manufacturers currently do not use these products for fear of potential consumer concerns and attitudes, and current retail restrictions (Huntingdon, 2004).

Key questions that have yet to be researched

In addition to on-going studies on fishmeal and fish oil replacers, the effect of diet and nutrition on product quality, and concerning the use of feed enzymes to improve nutrient digestibility (Refstie et al. 2005), key questions that have yet to be researched, include:

- Evaluation and cost-efficiency of using refined de-contaminated fish oils in salmon starter, grower and finisher feeds;
- Development of a new generation of Ecosmart feeds based on the use of zero marine fish protein and lower dietary lipid/energy levels; and
- Development of designer feeds to tailor the nutrient profile of salmon to meet consumer dietary needs (i.e. lower fat, lower salt, lower cholesterol, higher DHA/EPA/w-3 fatty acid profile, higher antioxidant vitamins, higher mineral and trace element levels etc).

4. STATUS OF FEED EFFICIENCY

4.1 Trends in efficiency of feed use

Feed conversion efficiency

As mentioned previously, advances in feed formulation (Larrain et al. 2005; section 1.4), feed manufacturing technology (Kearns, 2005; section 1.8), and on-farm feed management (Larrain et al. 2005) have all resulted in increased fish growth, reduced fish production costs (Figure 1.8.1), and reduced FCRs. For example, since 1985 the mean calculated Economic FCR (Economic FCR = total feed fed ÷ total live fish produced, and so includes all fish mortality over the production cycle) for the salmon farming industry has decreased from over 2 to 1.3 as follows:

Period:	Economic FCR
1983-1985	> 2.0
1986-1990	1.7
1991-1995	1.6
1996-2000	1.5
2001-2003	1.4
Current 2003	1.3 (range 1 – 1.5)

It is important to mention here that the average Economic FCR for farmed salmon (includes large rainbow trout) is the lowest of all the major cultured/fed aquaculture species, ranging from a high of 2.4 (freshwater crustaceans), 2 (feeding carp, tilapia, milkfish, marine finfish, eel), 1.9 (marine shrimp), 1.6 (catfish) to a low of 1.3 (trout and salmon; Tacon, 2004a). These feed efficiency figures are even more significant bearing in mind that the length of the culture period for salmon can be up to 24 months (cold water species), with animal reaching up to a final market size of about 4 kg, as compared with a marine shrimp reaching a market size of only 20-30g in about 180 days (warm water species).

The importance to the adherence of Best Management Practices (BMPs) during feed manufacture (FAO, 2001) and on-farm feed management (Hardy, 2004) cannot be understated; both feed manufacture (including feed formulation) and on-farm feed management dictating to a large extent the efficiency of feed use on farm.

Fishmeal and fish oil conversion efficiency

On the basis of the total estimated fishmeal and fish oil consumed within aquafeeds by the major fed species groups in 2003 (section 1.3; Figure 1.3.1 & 1.3.2; Table 1) the apparent conversion efficiency of pelagics (wet weight basis; calculated by summing total fishmeal and fish oil consumption figures and then multiplying by 4 or 5) to farmed fish for the different species groups ranged from a low of 0.19-0.24 for feeding carp, 0.22/0.23-0.28 for catfish and tilapia, 0.30-0.37 for milkfish, 0.9-1.1 for freshwater crustaceans, 1.6-2.0 for marine shrimp, 2.5-3.2 for marine fish and trout, and 3.1-3.9 for marine eels and salmon.

Table 4.1 Total estimated fishmeal and fish oil use and species production in 2003 (values given in thousand tonnes; production figures from FAO, 2005a)

Species	Fishmeal	Fish oil	FM + FO	Production	FCE[1]
Salmon	573	409	982	1,259	3.1-3.9
Marine shrimp	670	58.3	728.3	1,805	1.6-2.0
Marine fish	590	110.6	700.6	1,101	2.5-3.2
Feeding carp	438	43.8	481.8	10,179	0.19-0.24
Trout	216	126	342	554	2.5-3.1
Marine eels	171	11.4	182.4	232	3.1-3.9
Fw. Crustaceans	139	13.9	152.9	688	0.9-1.1
Tilapia	79	15.8	94.8	1,678	0.23-0.28
Milkfish	36	5.2	41.2	552	0.30-0.37
Catfish	24	8	32	569	0.22-0.28

FCE[1] – Pelagic equivalent inputs (wet weight basis) per unit of farmed fish out put

The figures for fishmeal and fish oil consumption for salmon are based on a global average species group Economic FCR of 1.3, and an average dietary fishmeal and fish oil content of 35% and 25%, respectively.

However, recalculation of the salmon figures based on the observed variations in dietary fishmeal and fish oil content within the major salmon producing countries, reveal FCEs ranging from a low of 1.8–2.9 for Canada (20-25% FM: 15-20% FO), 2.9-4.2 for Chile (30-35% FM: 25-30% FO) and Norway (30-35% FM: 25-30% FO), and 3.2-4.7 for the UK (35-40% FM: 27-32% FO).

Meanwhile estimates for fishmeal and fish oil usage within aquafeeds for 2010 indicate that the FCE for salmon would decrease from an average of 3.1 to 3.9 in 2003 to 1.2 to 1.5 in 2010; mean dietary fishmeal and fish oil levels estimated to decrease to 20% and 8% by 2010, respectively (Tacon, 2004).

FCE (Fish input:output)	2003	2010[1]
Marine eels	3.1 – 3.9	(1.8-2.3)
Salmon	3.1 - 3.9	(1.2-1.5)
Marine fish	2.5 - 3.2	(1.5-1.9)
Trout	2.5 – 3.1	(0.8-1.0)
Marine shrimp	1.6 - 2.0	(1.0-1.2)
Freshwater crustaceans	0.9 - 1.1	(0.5-0.6)
Milkfish	0.30 - 0.37	(0.11-0.14)
Tilapia	0.23 - 0.28	(0.11-0.14)
Catfish	0.22 - 0.28	(0.16-0.20)
Feeding carp	0.19 - 0.24	(0.02)

[1]Tacon (2004)

Development of new technologies and management techniques to improve efficiency

There have been many new technologies and developments, but probably the most important has been the development and use of improved automated feeding regimes, including the use of under water cameras and feed catching devices to optimize feed intake and minimize feed wastage.

4.2 Key questions that have yet to be researched

Key questions that have yet to be researched, include:

- Comparative efficiency of modern salmon farming systems with other intensive animal food production systems, including other fish, poultry, hogs, in terms of edible food production, including energetic and food efficiency;
- Re-evaluation of the use of 24-h feeding systems so as to reduce the time taken to bring animals to market size, including the possible use of lower energy/higher protein diets and increased feeding frequencies;
- Re-evaluation of the possible use of extruded `floating' salmon feeds so as to further reduce feed wastage and accurately ascertain and maximize feed intake; and
- Development of improved top-coating techniques for the addition of heat-sensitive nutrients/feed additives onto the surface of extruded salmon feeds.

5. PUBLIC HEALTH ISSUES RELATED TO FEED

Which are the most important contaminants from a public health point of view?

Public health concerns have been raised about the potential accumulation of environmental contaminants within farmed salmon from the feeding of aquafeeds containing contaminated fishmeals and fish oils.

The most important contaminants related to feed from a public health perspective, can be listed as follows:

- Persistent Organic Pollutants (POPs; Bell et al. 2005; Berntssen et al. 2004, 2005; Bethune et al. 2005; Easton et al. 2002; EC, 2002; Foran et al. 2005; FIN, 2004b; Halseth, 2004; Herrmann et al. 2004; Hites et al. 2004a, 2004b; Isosaari et al. 2004; Jacobs et al. 2002; Joas et al. 2001; Julshamn et al. 2002; Karl, 2003; Lundebye et al. 2004; MacDonald et al. 2004; Smith et al. 2002):

  - Poly Chlorinated Dibenzo-p-Dioxins (PCDD) and Dibenzo Furans (PCDF) [Dioxins & Furans];
  - Poly Chlorinated Biphenyls (PCB's);
  - Dioxin-like PCBs;
  - Poly Brominated Diphenyl Ether (BDE, Brominated Flame Retardants - BFR); and
  - Chlorinated pesticides (DDT, Toxaphene, Aldrin etc).

- Heavy metals & minerals (Berntssen et al. 2003, 2004; Foran et al. 2004; Julshamn et al. 2002; Nash, 2001):

  - Mercury (Hg), Cadmium (Cd), Lead (Pb), Arsenic (As), Zinc (Zn).

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

However, in contrast to POPs, the study of Foran et al (2004) showed that the concentration of nine metals in the tissues of farmed Atlantic salmon did not pose a threat to human health (none of the contaminants exceeding federal standards or guidance levels).

Potential to remove contaminants from fishmeal and fish oil

Available options and technologies for the removal of POPs from fishmeal and/or fish oil have been reviewed by Berntssen et al. (2004), De Kock et al. (2004), Halseth (2004), Korsager (2004), Oterhals (2004) and Sørensen (2004), and have been summarized by Oterhals (2004) as follows:

- Fish oil:
  - selection of fish oils with lowest levels of POPs (so as to take advantage of existing seasonal variations in POP levels, depending upon species and fishing region; see Lundebye et al. 2004);
  - active carbon adsorption for removal of PCDD/PCDF > 90%, PCBs < 70% (mono-ortho PCBs < 15%), BFR – no effect)
  - short path distillation for removal of PCDD/PCDF > 90%, PCBs > 90%, BFR > 90% (for active carbon treatment and steam stripping see De Kock et al. 2004);

- Fish meal:
  - selection of fish meals with lowest levels of POPs (as above);
  - reduction in fat level through increased fat separation during the fishmeal manufacturing process (depending upon fish species and season);
  - fish meal solvent extraction. Effect 80-90%, but demands separate processing site;
  - press cake oil extraction. Effect 80-90%, and easily integrated in existing processing lines (see Oterhals, 2004; Sørensen (2004).

Coupled with the introduction of new EU directives and maximum limits/action levels for dioxins, furans and dioxin-like PCBs within animal feeds (including aquafeeds; IFFO, 2005), and the growing consumer awareness concerning food safety and the potential environmental contaminants which may (or may not) be contained within farmed fish, feed manufacturers have no choice but to source alternative fishmeals and fish oils from other less contaminated regions of the world (such as the South Pacific, for which there is already a high demand) or purchase more expensive *decontaminated* oils and meals.

For example, one of the largest fishmeal manufacturers in Europe (TripleNine Fish Protein a.m.b.a., Esbjerg, Denmark) has just announced that it is in the process of building a large facility that will remove dioxin from fishmeal with the aid of an isohexane extraction process; the net result being a new protein-rich and low-oil fishmeal (from which the oils containing dioxins and other POPs have been extracted, and a *cleansed* purified fish oil (TripleNine News No. 2, 2005; http://www.999.dk; see also Ley, 2001). Similar contaminant stripped products are also being developed in North America from the resident menhaden fisheries/manufacturing sector.

Although all these new processes will increase the cost of the new generation of emerging decontaminated meals and oils for aquafeed manufacturers, and could have a marked negative impact on feed prices, the only alternative for the feed industry is to reduce fish oil levels (and therefore potential contaminant levels) through dietary substitution with less contaminated vegetable and/or other terrestrial land animal fats and oils (Berntssen et al. 2004; EU-RAFOA, Q5Rs-200-30058 and National Research Council of Norway – 152641/130).

Impact of fish oil substitution on omega-3 level and omega 3/ omega 6 ratios in salmon

Considerable research effort has made concerning the impact of dietary fish oil substitution in salmonids. For example, Morris (2001) replaced up to 85 % of the fish oil in rainbow trout feeds without negatively impacting fish performance and fish quality. Similar studies with Atlantic salmon have demonstrated that vegetable oil blends can replace 100 % of the added fish oil in salmon feeds (Bell et al., 2001).

However, it well known that changes in the dietary lipid and fatty acid supply will also be reflected in changes in the lipid and fatty acid flesh composition of the target species (for review see Berntssen et al. 2005; Morris, 2005). For example, for those high health markets where maximisation of the omega-3 level of the fish is a priority, high omega-3 oils can be used in the pre-harvest period to elevate the EPA and DHA content of the flesh (Bell et al., 2003a, 2003b; Morris et al. 2005) and dilute the levels of n-6 fatty acids (Jobling, 2003).

For example, recent studies coordinated by the National Institute of Nutrition and Seafood Research (NIFES, Bergen) with Nutreco (Stavanger) and the School of Veterinary Medicine of the Ullevål University Hospital (Oslo) investigated the effects of feeding farmed salmon to heart patients; the salmon having been fed on diets containing either high, moderate of low levels of dietary omega-3 polyunsaturated fatty acids (n-3 PUFAs) of marine origin (fish oil). The results showed that the fatty acid composition of farmed Atlantic salmon greatly influenced serum lipid levels in patients with Coronary Heart Disease. Moreover, all patients displayed positive health effects from eating salmon, even including those consuming the salmon fed the low omega-3 diet containing 100% rapeseed oil. On a more sobering note, the salmon fed with extremely high levels of omega-3 fatty acids, gave the best health effect for the heart disease patients studied (Seierstad et al. 2004; see also Rembold, 2004; Sargent & Tacon, 1997; Sidhu, 2003).

Impact of fish protein substitution on nutritional value of the fish

There is no reported negative impact of fish protein substitution on the nutritional value of farmed salmon provided that diets are correctly formulated to the known dietary essential amino acid requirements of the farmed species on a available or digestible basis.

However, apart from possible changes in the fatty acid profile of the flesh of the target species, there may be differences in the mineral and trace element composition of the flesh. This is because fishmeal is usually an extremely good source of available essential minerals, including calcium, phosphorus, magnesium, salt, iron, zinc, manganese, copper, cobalt, iodine, fluorine, selenium and trivalent chromium (Hertrampf & Piedad-Pascual, 2000). It follows from the above therefore that special care must be given to meeting the trace mineral requirements of salmonids when attempting to replace fishmeal with vegetable and/or other terrestrial animal protein sources which may be deficient in these trace elements and/or may contain the anti-nutrient phytic acid (Cheng et al. 2004b; Francis et al. 2001).

Are fishmeal companies able to trace meal/oil back to the individual fisheries?

In general the answer to this question is yes, provided that the factory keeps good records of fish landings (including name of boat, species weight, size and composition) and that the fishmeal manufacturer does not blend different species groups together prior to shipment so as to maintain a particular nutrient profile for the intended client.

Is it known that some reduction fisheries are more contaminated than others? Has global mapping or research been done on this?

It is generally recognized that the pelagic fish species belonging to the reduction fisheries of the Atlantic and European region are more contaminated than their Southern and Northern Pacific counterparts (EC, 2002; Herrmann et al. 2004; Joas et al. 2004; Korsager, 2004; Oterhals, 2004; SCAN, 2000; Seafeeds, 2003; Sørensen, 2004).

However, no comprehensive global assessment has been made to date of the contaminant loadings of all the major reduction fisheries (over a complete fishing season), and in particular those of the Southeast Pacific, Eastern Central Pacific, Western Central Atlantic, Indian Ocean, and Asia-Pacific region.

Key questions that have yet to be researched

Key questions that have yet to be researched, include:

- Regional assessment of environmental contaminant levels within the major reduction fisheries stocks of the North, Central & South Pacific over a complete fishing season;

- Comparative global assessment of environmental contaminant levels within wild marine food fish stocks, including salmon, tuna, sword fish, cod, haddock;

- Need to publish existing research findings on contaminant levels within fish stocks, including relevant feeding/spot-check analytical studies with farmed salmonids, within higher profile peer reviewed non-aquaculture journals, including key medical and environmental science journals for wider distribution and readership; and

- Need to assess the potential health impact of dietary contaminants (including POPs and heavy metals) in the finished product compared to other foods using accurate and current data.

6. FEEDS, FEEDING AND THE ECOSYSTEM

Does feeding potentially contribute to additional nutrient loading around cages?

Of course the answer to this question is yes, and this may include nutrient loading and pollution from uneaten feed, fish faeces and excreta. However, the potential impact (negative or positive) of these nutrients from the cages will in-turn depend upon the environmental carrying capacity of the coastal zone/area where the cages are geographically located and the water depth/water current under the cages (for review see Beveridge, 2004 and Eleftheriou & McIntyre, 2005) and type of culture system (open cage or closed tank; Buschman et al. 2005; Tacon & Forster, 2003).

Whilst in the past these digestive and excretory waste products have usually been considered in a negative sense, they are really waste `*nutrients*' and as such could be harnessed for the co-culture of associated filter feeding species such as mussels or absorbed directly from the water column by aquatic plants or seaweeds rather than just released into the open sea and lost.

Such integrated coastal aquaculture culture systems have been proposed by numerous authors as a means of harnessing the waste nutrients arising from intensive salmon farming operations (see Buschman et al. 2005; Troell, Kautsky & Folke, 1999; Troell et al., 2005) and from the eutrophication of coastal waters (Lindahl et al. 2005). In this respect it is important to remember that the total production of farmed marine aquatic plants and molluscs in 2003 amounted to 12.48 and 12.30 million tonnes respectively, or just under half (45.2%) of total global aquaculture production in 2003 (FAO, 2005a).

Does substitution of fishmeal and/or fish oil have any impact of nutrient loading to the ocean or benthos?

The dietary substitution of fishmeal and/or fish oil with less digestible plant and animal protein and lipid sources will result in increased nutrient loading and potential loss in fish growth and feed efficiency. However, such negative impacts could be greatly reduced by selecting the use of highly digestible ingredient sources and/or through the use of enzyme treated plant proteins and/or exogenous dietary feed enzymes (for example see Cheng et al. 2004b; Refstie et al 2005).

Key questions that have yet to be researched.

Key questions that have yet to be researched include:

- Development of cost-effective satellite-assisted automated water quality monitoring techniques for measuring nutrient outputs from salmon farms, including benthos sediment inputs, and assessing the environmental impact of near-shore and off-shore salmon farming operations;

- Development of environmentally and ecologically sustainable multi-trophic culture systems based on the co-culture of salmon, filter feeding molluscs, and seaweeds;

- Development of cost-effective bioremediation techniques for the exploitation and regeneration of sediments under salmon farms, including the possible culture of benthic invertebrates;

- Development of cost-effective closed salmon farming systems, including tank-based farming systems using water recirculation and multi-species; and

- Need to assess the long term impacts of nutrient loading and potential dietary contaminants (including POPs and heavy metals) on benthos/organisms and on water quality within the surrounding area.

7. LOOKING TO THE FUTURE

Brief comments on the applicability of research on salmonid feed to other feeds. Are there critical research needs related to other species that do not apply to salmon?

Although salmonid nutrition and feed development leads the world in terms of scientific understanding of dietary nutrient requirements and feeding technology (including on-farm feed performance – Economic FCR; see section 4.1 for discussion), research on salmonid feeds is only strictly applicable to other coldwater carnivorous finfish species cultured within clear-water culture systems.

However, the research approach and general issues and challenges related to fishmeal and fish oil use, including the sustainability of reduction fisheries, feed efficiency & energy use, public health issues related to feeds and feeding, and potential environment and ecosystem impacts will be essentially the same.

Effects of emerging carnivorous finfish aquaculture species.

Carnivorous finfish species consumed 52.8% and 81.9% of the total fishmeal and fish oil used in compound aquafeeds in 2003, with farmed salmon alone consuming 13.9% and 51.0% total fishmeal and fish oil used within aquafeeds, respectively (Figure 1.3.1 & Figure 1.3.2). Clearly, however, if the sector for carnivorous finfish species is to be sustainable in the long-run it must reduce its dependence upon these finite commodities. In the short term this is of most concern for fish oil, and could be partly resolved through the use of plant oils and animal fats as dietary energy sources supplemented with marine fish oils reserved only as dietary providers of essential fatty acids.

What will the projected growth of salmon aquaculture (and other carnivorous finfish species) do to the various issues investigated?

Salmon aquaculture is expected to reach over 2 million tonnes by 2010 (Forster, 2003) and total global aquaculture production is expected to exceed total capture fisheries production by 2015. The above projected growth in salmon and aquaculture production is expected to have the following effects on the issues discussed in this report, namely:

- Trend toward decreasing farmed fish prices due to increased aquaculture production;

- Increasing pressure to further reduce feed and farm production costs so as to maintain profitability;

- Long term increase in demand and price for fishmeal and fish oil, including decontaminated fishmeals and purified fish oils;

- Increasing demands by consumers for cleaner and more healthy foods, including aquaculture products;

- Increasing and more stringent controls placed on permitted contaminant levels within feed ingredients and processed foods (the EU leading the way);

- Increasing reliance placed within aquaculture on market development against other major proteins (such as beef, pork and chicken), with salmon joining in on the fight for increased market share at the centre of the plate; and

- Increasing worldwide consumer demand for fish as food in the global fight against malnutrition; under-nutrition and obesity being the number one killer and cause of suffering on this planet.

China – the unknown factor

China is the only country which could make significantly impact on the above assumptions, for the following reasons:

- China produced over 70.5% of global aquaculture production in 2003 at 38.64 mmt, with finfish production at 17.56 mmt in 2003 (96.1 % freshwater fish, 2.9% marine fish, & 1.0% diadromous fish);

- To satisfy its rapidly growing aquaculture sector, China has a booming domestic animal feed manufacturing sector (second largest in the world after the USA) and is the world's largest compound aquafeed producer at 7.98 million tonnes in 2003;

- China is the world's largest importer of fishmeal at 802,840 tonnes in 2003 or 23.4% of total global fishmeal exports (FAO, 2005a), with industry estimates for 2004 at 1.1 million tonnes (IFFO, 2005);

- China is the world's largest importer of soybeans, accounting for about one third of world soybean imports (surpassing the EU in terms of imports; Tuan et al. 2004);

- China is the world's largest producer of carnivorous finfish species (1,099,833 tonnes in 2003 or about 30% of total global production, including marine finfish, black carp, river eels and mandarin fish) and marine shrimp (493,061 tonnes: FAO, 2005a);

- China is reportedly the largest global user of low value fish or `trash fish' as feed inputs for aquaculture; 4 million tonnes reportedly being used in 2000, primarily for marine finfish species (D'Abramo et al. 2002);

- China's booming economy is currently growing at an average rate of 9.5% per year and is expected to continue to fuel rising incomes and demand for farmed aquatic produce (Brugere & Ridler, 2004c; Delgado et al. 2003; Hishamunda & Subasinghe, 2003), including the demand and production of higher value carnivorous finfish and crustacean species for domestic consumption and/or export.

In view of the above, it is clear that current and future `aquaculture government policies and incentives' in China will play a major role in dictating the future use and price of fishery resources used in aquaculture, and the long term sustainability or not of global aquaculture as we current know it.

8. CONCLUSIONS

- Current dependence of the salmon aquaculture and salmon feeds upon fishmeal and fish oil and the need to reduce this dependency for the long term sustainability of the salmon aquaculture sector;

- Absence of agreed standards and criteria for assessing the sustainability of reduction fisheries;

- Current ability of the feed manufacturing sector to reduce up to 70% and 50% of the fishmeal and fish oil content of salmon feeds with alternative more sustainable dietary protein and lipid sources, respectively;

- Increasing awareness concerning the relative efficiencies of different terrestrial and aquatic food production systems, including modern salmon production systems, and the consequent need to undertake a comparative analysis of these farming systems in terms of edible food production and energy usage;

- Increasing awareness concerning the presence of environmental contaminants within the marine environment, including reduction fisheries and food fish, and the need to reduce these contaminant loads either through extraction/purification, increasing legislative controls, or through the use of alternative feedstuffs or dietary feeding strategies;

- Increasing awareness and need to assess the potential health impact of dietary contaminants (including POPs and heavy metals) in the finished product compared to other foods using accurate and current data;

- Increasing awareness and need to assess the long term impacts of nutrient loading and potential dietary contaminants (including POPs and heavy metals) from salmon farming on benthos/organisms and on water quality;

REFERENCES CITED

Adelizi, P.D., Rosati, R.R., Warner, K., Wu, Y.V., Muench, T.R., White, M.R., Brown, P.B., (1998). Evaluation of fishmeal free diets for rainbow trout, *Oncorhynchus mykiss*. Aquacult. Nutr. 4, 255-262.

Akiyama, T., Murai, T., Hirasawa, Y. & T. Nose. (1984). Supplementation of various meals to fish meal diet for chum salmon fry. Aquaculture, 37(3):217-222.

Allan, G. (2004). Fish for feed vs fish for food, pp.20-26. In: A.G. Brown (editor), Fish, Aquaculture and Food Security: Sustaining Fish as a Food Supply. Record of a conference conducted by ATSE Crawford Fund, Parliament House, Cambera, 11 August 2004 (http://www.crawfordfund.org/awareness/fish_aqua_food.pdf)

Alverson, D.L., Freeberg, M.H., Murawski, S.A. & Pope, J.G. (1994). A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper, No. 339. Rome, FAO. 233p.

Anderson, J.O. & M. Lindroth (2001). Ecologically unsustainable trade. Ecological Economics, 37(1):113-122.

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. April 2003, 57p (http://www.nora.fo/docs/Dioxin_Final_report.pdf)

Arndt, R.E., Hardy, R.W., Sugiura, S.H. & F.M. Dong. (1999). Effects of heat treatment and substitution level on palatability and nutritional value of soy defatted flour in feeds for Coho Salmon, *Oncorhynchus kisutch*. Aquaculture, 180(1):129-145.

Asche, F. & S. Tveteras. (2004). On the relationship between aquaculture and reduction fisheries. Journal of Agricultural Economics, 55(2):245-265.

Åsgård, T. & E. Austreng. (1995). Optimal utilization of marine proteins and lipids for human interest, pp.79-87. In: H. Reinertsen & H. Haaland (eds.), Sustainable fish farming. A.A. Balkema, Rotterdam, Netherlands.

Bailey, C. (1997). Aquaculture and basic human needs. World Aquaculture, 28(3):28-31.

Bakke-McKellep, A.M., Press, C.M., Baeverfjord, G., Krogdahl, A. & T. Landsverk. (2000). Changes in immune and enzyme histochemical phenotypes of cells in the intestinal mucosa of Atlantic salmon, *Salmo salar* L., with soybean meal-induced enteritis. Journal of Fish Diseases, 23(2):115-127.

Ballestrazzi, R; Rainis, S; Tulli, F; Bracelli, A. (2003). The effect of dietary coconut oil on reproductive traits and egg fatty acid composition in rainbow trout (*Oncorhynchus mykiss*). Aquaculture International, 11(3):289-299.

Barlow, S. (2003). World market overview of fish meal and fish oil, pp. 11-25. In: Bechtel, P.J. (editor), Advances in Seafood Byproducts: 2002 Conference Proceedings. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, 566 pp.

Barrows, F.T. & W.A. Lellis. (1999). The effect of dietary protein and lipid source on dorsal fin erosion in rainbow trout, *Oncorhynchus mykiss*. Aquaculture, 180(1):167-175.

Bechtel, P.J. (2003). (Editor), Advances in Seafood Byproducts: 2002 Conference Proceedings. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, 566 pp.

Bell, J.G., Tocher, D.R., Farndale, B.M., Cox, D.I., McKinney, R.W. & Sargent, J.R., (1997). The effect of dietary lipid on polyunsaturated fatty acid metabolism in Atlantic salmon (*Salmo salar*) undergoing parr-smolt transformation. Lipids 32(5), 515-525.

Bell, J.G., McEvoy, J., Tocher, D.R. & J.R. Sargent. (2000). Depletion of alpha-tocopherol and astaxanthin in Atlantic salmon (*Salmo salar*) affects autoxidative defense and fatty acuid metabolism. Journal of Nutrition, 130:1800-1808.

Bell, J.G., McEvoy, J., Tocher, D.R., McGhee, F., Campbell, P.J., Sargent, J.R., (2001). Replacement of fish oil with rapeseed oil in diets of Atlantic salmon (*Salmo salar*) affects tissue lipid compositions and hepatocyte fatty acid metabolism. J. Nutr. 131, 1535-1543.

Bell, JG; Tocher, DR; Henderson, RJ; Tocher, DR; McGhee, F; Dick, JR; Porter, A; Smullen, RP; Sargent, JR. (2002). Substituting Fish Oil with Crude Palm Oil in the Diet of Atlantic Salmon (*Salmo salar*) Affects Muscle Fatty Acid Composition and Hepatic Fatty Acid Metabolism. J. Nutr., 132: 222-230.

Bell, JG; Tocher, DR; Henderson, RJ; Dick, JR; Crampton, VO. (2003a). Altered Fatty Acid Compositions in Atlantic Salmon (*Salmo salar*) Fed Diets Containing Linseed and Rapeseed Oils Can Be Partially Restored by a Subsequent Fish Oil Finishing Diet. J. Nutr., 133: 2793-2801.

Bell, J.G., McGhee, F., Campbell, P.J. & Sargent, J.R. (2003b). Rapeseed oil as an alternative to marine fish oil in diets of post-smolt Atlantic salmon (*Salmo salar*): changes in flesh fatty acid composition and effectiveness of subsequent fish oil 'wash out'. Aquaculture, 218 (1-4):515-528.

Bell, J.G., McGhee, F., Dick, J.R. & D.R. Tocher. (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.

Berge, G.E., Goodman, M., Espe, M. & E. Lied. (2004). Intestinal absorption of amino acids in fish: kinetics and interaction of the in vitro uptake of l-methionine in Atlantic salmon (*Salmo salar* L.). Aquaculture, 229:265-273.

Berge, G.M., Baeverfjord, G., Skrede, A. & T. Storebakken. (2005). Bacterial protein grown on natural gas as protein source in diets for Atlantic salmon, *Salmo salar*, in saltwater. Aquaculture, 244:233-240.

Berntssen, M.H.G., Wagboo, R., Toften, H. & A.K. Lundebye. (2003). Effects of dietary Cd on Ca-homeostasis, Ca mobilisation and bone deformities in Atlantic salmon *(Salmo salar* L) parr. Aquaculture Nutrition: 9(3):175-183.

Berntssen, M.H.G., Hemre, G.-I. & Ø. Lie. (2004). Biotechnology and quality of `fish as food' – food supply. Paper presented at the Aquaculture Europe 2004 Conference Biotechnologies for Quality, 20-23 October 2004, Barcelona, Spain.

Berntssen, M.H.G., Lundebye, A.K. & B.E. Tortensen (2005). Reducing the levels of diosxins and dioxin-like PCBs in farmed Atlantic salmon by substitution of fish

oil with vegetable oil in the feed. Aquaculture Nutrition: 11:219-231.
Best, P. (1996). Should fish meal be cowed by the ethics of environmentalism? Feed International, 17(8):4
Bethune, C., Julshamn, K. & A-K. Lundebye. (2005). A preliminary comparison of polybrominated diphenyl ether concentrations relative to lipid content and to levels of dioxin-like polychlorinated biphenyls in Norwegian farmed Atlantic salmon (*Salmo salar*). International Journal of Food Science & Technology, 40(2):143-148.
Beveridge, M C M. (2004). Cage Aquaculture. 3d Edition. Blackwell, Oxford.
Bimbo, A.P. & Crowther, J.B. (1992). Fish meal and fish oil: current uses. Journal of the American Oil Chemists Society, 69(3):221-227.

Bjørndal, T., Gordon, D., Kaitala, V. & M. Lindroos. (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.

Bogstad, B. & H. Gjosaeter. (2001). Predation of cod (*Gadus morhua*) on capelin (Mallotus villosus) in the Barents Sea: implications for capelin stock assessment. Fisheries Research, 53(2):197-209.

Bórquez, A., Serrano, E., Sáez, P., Hettich, C., Dantagnan, P. & J. Carrasco. (2005). Partial replacement of fishmeal with whole grain white lupin (*lupinus albus*) in extruded feed for rainbow trout: effects on the growth and feeding parameters, apparent digestibility coefficient and muscle fatty acids composition (in press)
Boyd, C.E. (2000). Water use in aquaculture. The Global Aquaculture Advocate, 3(3):12-13.
Bransden, M.P; Carter C.G; Nichols PD. (2003). Replacement of fish oil with sunflower oil in feeds for Atlantic salmon (*Salmo salar* L.): effect on growth performance, tissue fatty acid composition and disease resistance. Comparative Biochemistry and Physiology, Part B., 135(4):611-625.
Breck, O., BjerkAs, E., Campbell, P., Arnesen, P., Haldorsen, P. & R. Waagbo. (2003). Cataract preventative role of mammalian blood meaql, histidine, iron and zinc in diets for Atlantic salmon (Salmo salar L.) of different strains. Aquaculture Nutrition, 9(5):341-350.
Brugere, C. & N. Ridler. (2004). Global aquaculture outlook in the next decades: an analysis of national aquaculture production forecasts to 2030. FAO Fisheries Circuar No. 1001. FAO. Rome, 47p.
Bureau, D. (2000). Aquaculture feeds: opportunities and potential for rendered products. Render, 29(4):10-12.
Bureau, D. (2004). Animal fats as aquaculture feed ingredients: nutritive value, product quality and safety. Aquafeed International, 7 (1):32-37.
Bureau, D.P., Harris, A.M. & C.Y. Cho. (1999). Apparent digestibility of rendered animal protein ingredients for rainbow trout (*Oncorhynchus mykiss*). Aquaculture, 180:345-358.

Bureau, D.P., A.M. Harris, D.J. Bevan, L.A. **Simmons, P.A. Azevedo & C.Y. Cho, (2000).** Use of feather meals and meat and bone meals from different origins in the diet for rainbow trout (*Oncorhynchus mykiss*). Aquaculture, 181:281-291.

Burel, C., Boujard, T., Corraze, G., Kaushik, S.J., Boeuf, G., Mol, K.A., Van Der Geyten, S. & E.R. Kühn. (1998). Incorporation of high levels of extruded lupin in diets for rainbow trout (*Oncorhynchus mykiss*): nutritional value and effect on thyroid status. Aquaculture, 163:325-345.

Burel, C., Boujard, T., Tulli, F. & S.J. Kaushik. (2000a). Digestibility of extruded peas, extruded lupin, and rapeseed meal in rainbow trout (*Oncorhynchus mykiss*) and turbot (*Psetta maxima*). Aquaculture, 188:285-298.

Burel, C., Boujard, T., Kaushik, S.J., Boeuf, G., Van Der Geyten, S., Mol, K.A., Kühn, E.A., Quinsac, A., Krouti, M. & D. Ribaillier. (2000b). Potential of plant-protein sources as fish meal substitutes in diets for turbot (*Psetta maxima*): growth, nutrient utilisation and thyroid status. Aquaculture, 188:363-382.

Buschman, A.H., Riquelme, V., Cortés, E. & M.C. Hernández-González. (2005). Chilean aquaculture policy, environmental issues, and prospects. Paper presented at the `Role of Aquaculture in Integrated Coastal & Ocean Management: an Ecosystem Approach. Aquaculture Interchange Program (The Oceanic Institute), Honolulu, Hawaii, April 17-22, 2005.

Buttle, L.G., Burrells, A.C., Good, J.E., Williams, P.D., Southgate, P.J. & C. Burrels. (2001). The binding mof soybean agglutinin (SBA) to the intenstinal epithelium of Atlantic salmon, *Salmo salar* and rainbow trout, *Oncorhynchus mykiss*, fed high levels of soybean meal. Veterinary Immunology & Immunopathology, 80(3):237-244.

Carscadden, J.E., Frank, K.T. & W.C. Leggett. (2001). Ecosystem changes and the effects on capelin (*Mallotus villosus*), a major forage species. Canadian Journal of Fisheries and Aquatic Sciences, 58(1):73-85.

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

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

Cheng, ZJ; Hardy, RW. (2002a). Apparent digestibility coefficients and nutritional value of cottonseed meal for rainbow trout (*Oncorhynchus mykiss*). Aquaculture, 212(1-4):361-372.

Cheng, ZJ; Hardy, RW. (2002b). Apparent digestibility coefficients of nutrients and nutritional value of poultry by-product meals for rainbow trout *Oncorhynchus mykiss* measured in vivo using settlement. Journal of the World Aquaculture Society, 33(4):458-465.

Cheng, ZJ; Hardy, RW. (2004). MHA supplementation in soy-based diets improves performance of rainbow trout. Global Aquaculture Advocate, 7(4):72-73.

Cheng, ZJ; Hardy, RW; Usry, JL. (2003). Effects of lysine supplementation in plant protein-based diets on the performance of rainbow trout (*Oncorhynchus mykiss*) and apparent digestibility coefficients of nutrients. Aquaculture, 215(1-4):255-265.

Cheng, Z.J., Hardy, R.W. & N.J. Huige. (2004a). Apparent digestibility coefficients of nutrients in brewer's and rendered animal by-products for rainbow trout (*Oncorhynchus mykiss* (Walbaum). Aquaculture Research, 35(1):1-9.

Cheng, Z.J., Hardy, R.W., Verlhac, V. & J. Gabaudan. (2004b). Effects of microbial phytase supplementation and dosage on apparent digestibility coefficients of nutrients and dry matter in soybean product-based diets for rainbow trout *Oncorhynchus mykiss*. Journal of the Wolrd Aquaculture Society, 35(1):1-15.

Costa-Pierce, B.A. (2003). Ecological Aquaculture. Blackwell Publishing, London, 328p.

Craig, P.P. (2001). Energy limits on recycling. Ecological Economics, 36(3):373-384.

Coutteau, P. (2004). Filling the nutritional gaps in shrimp feed formulation. International Aquafeed, 7(5):18-27.

D'Abramo, l.R., Mai, K. & Deng, Dong-Fang. (2002). Aquaculture feeds and production in the People's Republic of China – progress and concerns. World Aquaculture, 33(1):25-27.

Dalsgaard, J.P.T., Lightfoot, C. & V. Christensen. (1995). Towards quantification of ecological sustainability in farming systems analysis. Ecological engineering, 4:181-189.

Davies, S.J., Morris, P.C., (1997). Influence of multiple amino acid supplementation on the performance of rainbow trout, *Oncorhynchus mykiss* (Walbaum) fed soya based diets. Aquaculture Research, 28:65-74.

Davies, S.J., Morris, P.C., Baker, R.T.M., (1997). Partial substitution of fishmeal and full-fat soya bean meal with wheat gluten and influence of lysine supplementation in diets for rainbow trout, *Oncorhynchus mykiss* (Walbaum). Aquacult Research, 28:317-328.

Deguara, S. (2001). Seeking sustainable supplies for salmon. Fish Farming Today, No. 146, January 2001, p. 9.

De Kock, J., De Greyt, W., Ayala, J.V., Vanheerswynghels & M. Kellens. (2004). Removal of dioxins and PCB's from marine oils: current status and future developments. Paper presented at the 11th International Symposium on Nutrition and Feeding in Fish, 2-7 May 2004, Phuket Arcadia Hotel, Phuket Island, Thailand

Delgado, C.L., Wada, N, & M.W. Rosegrant. (2003). Fish to 2020: supply and demand in changing global markets. Washington, DC: International Food Policy Research Institute and Penang, Malaysia: WorldFish Center.

Drew, M.D. (2004). Canola protein concentrate as a feed ingredient for salmonid fish. In: L. E. Cruz Suarez, D. Ricque Marie, M. Gpe. Nieto Lopez, D.A. Villarreal Cavazos, U. Scholz & M.L. Gonzalez Felix (Editors), Proceedings of the VII International Symposium on Aquaculture Nutrition, Hermosillo, Mexico, 16-19 November 2004. Programa Maricultura, Facultad de Ciencia Biologicas, Universidad Autonoma de Nuevo Leon, Mexico.

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

EC (European Commission). (2002). Preparatory actions in the field of dioxin and PCBs. Executive Summary, European POPs Expert Team, April 2002, 14pp. (http://www.bipro.ed/uploads/EPET_ExecSum.pdf)

Eleftheriou, A. & A. McIntyre. (2005). Methods for the study of marine benthos, third edition. Blackwell Publishing, Ames, USA, 440 p.

FAO. (1995). Code of Conduct for Responsible Fisheries. Rome, FAO. 41 p.

FAO. (1998). Animal feeding and food safety. Food and Nutrition paper 69. Rome, FAO. 48p. (http://www.fao.org/WAICENT/FAOINFO/ECONOMIC/ESN/ animal/ animapdf/ contents.htm).

FAO. (1999). Indicators for sustainable development. FAO Technical Guidelines for Responsible Fisheries. No.8. Rome, FAO. 1999. 68p.

FAO. (2001). Good aquaculture feed manufacturing practice. FAO Technical Guidelines for Responsible Fisheries. No.5.1. Rome, FAO. 2001. 50p.

FAO. (2005a). FAO Fisheries Department, Fishery Information, Data and Statistics Unit. Fishstat Plus: Universal software for fishery statistical time series. Aquaculture production: quantities 1950-2003, Aquaculture production: values 1984-2003; Capture production: 1950-2003; Commodities production and trade: 1950-2003; Total production: 1970-2003, Vers. 2.30

FAO. (2005b). Review of the state of world marine fishery resources. FAO Fisheries Technical Paper 457. Rome, FAO. 235p.

Farhangi, M; Carter, CG. (2001). Growth, physiological and immunological responses of rainbow trout (*Oncorhynchus mykiss*) to different dietary inclusion levels of dehulled lupin (*Lupinus angustifolius*). Aquaculture Research, #2(1):329-340.

FIN (Fishmeal Information Network). (2004). Fishmeal facts and figures – November 2004 update (http://www.gafta.com/fin/finfacts.html)

FIN (2004b). Contaminants in fish and fishmeal – A Fish Meal Information Network Summary, 14 October 2004 (http://www.gafta.com/fin/finfacts.html)

FIN. (2005). Annual review of the feed grade fish stocks used to produce fishmeal and fish oil for the UK market. March 2005. (http://www.gafta.com/fin/finnews.html)

Folke, C., Kautsky, N., Berg, H. , Jansson, A. & M. Troell. (1998). The ecological foorprintconcept for sustainable seafood production: a review. Ecological applications, 8(1):S63-S70.

Foran, J.A, Hites, R.A., Carpenter, D.O, Hamilton, C., Amos, M. & S.J. Schwager. (2004). A survey of metals in tissues of farmed Atlantic and wild Pacific salmon. Environmental Toxicology and Chemistry, 23(9):2108-2110.

Foran, J.A, Carpenter, D.O, Coreen Hamilton M, Knuth, B.A. & S.J. Schwager. (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.

Forster, I., D.A. Higgs, B.S. **Dosanjh, M. Rowshandeli, & J. Parr. *(*1999*)*.** Potential for dietary phytase to improve the nutritive value of canola protein concentrate and decrease phosphorus output in rainbow trout (*Oncorhynchus mykiss*) held in 11oC fresh water. Aquaculture 179(1-4):109-125.

Forster, J. (2003). Salmon farming: aquaculture for the mass market. The Global Aquaculture Advocate, 6(1):52-54.

Forster, J. & R. Hardy. (2001). Measuring efficiency in intensive aquaculture. World

Aquaculture, June 2001, pp.41-45.

Francis, G; Makkar, H.P.S. & Becker, K. (2001) Antinutritional factors present in plant derived alternate fish feed ingredients and their effects in fish. Aquaculture, 199(3-4):197-227.

Fournier, V., Huelvan, C. & E. Desbruyeres. (2004). Incorporation of a mixture of plant feedstuffs as substitutes for fish meal in diets of juvenile turbot (*Psetta maxima*). Aquaculture, 236:451-465.

Francesco, M., Parisi, G., Médale, F., Lupi, P., Kaushik, S.J., Poli, B.M., (2004). Effect of long-term feeding with a plant protein mixture based diet on growth and body/fillet quality traits of large rainbow trout (*Oncorhynchus mykiss*). Aquaculture 236, 413-429.

Furness, R.W. (2002). Management implications of interactions between fisheries and sandeel-dependent seabirds and seals in the North Sea. ICES Journal of Marine Science, 59(2):261-269.

Furuya, W.M., Pezzato, L.E., Barros, M.M., Pezzato, A.C., Furuya, V.R.B. & E.C. Miranda. (2004). Use of ideal protein concept for precision formulation of amino acid levels in fish-meal-free diets for juvenile Nile tilapia (*Oreochromis niloticus* L.). Aquaculture Research, 35(12):1110-1116.

Gill, C. (2005). World feed panorama: disease takes toll, but feed output bounces back. Feed International, 26(1): 4-9.

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

Glencross, B., Curnow, J., Hawkins, W. & M. Felsing (2002). Evaluation of yellow lupin *Lupinus luteus* meal as an alternative protein resource in diets for sea-cage reared Rainbow trout *Oncorhynchus mykiss*. Journal of the World Aquaculture Society, 33(3):287-296.

Glencross, BD; Boujard, T; Kaushik, SJ . (2003b). Influence of oligosaccharides on the digestibility of lupin meals when fed to rainbow trout, *Oncorhynchus mykiss*. Aquaculture, 219(1-4):703-713.

Glencross, B.; Curnow, J; Hawkins, W. (2003d). Evaluation of the variability in chemical composition and digestibility of different lupin (*Lupinus angustifolius*) kernel meals when fed to rainbow trout (*Oncorhynchus mykiss*). Animal Feed Science and Technology, 107(1):117-128.

Glencross, B., Hawkins, W. & J. Curnow. (2003e). Cataract preventative role of mammalian blood meal, histidine, iron and zinc in diets for Atlantic salmon (*Salmo salar* L.) of different strains. Aquaculture Nutrition, 9(5):341-350.

Glencross, B.D., Carter, C.G., Duijster, N., Evans, D.R., Dods, K., McCafferty, P., Hawkins, W.E., Maas, R., Sipas, S., (2004a). A comparison of the digestibility of a range of lupin and soybean protein products when fed to either Atlantic salmon (*Salmo salar*) or rainbow trout (*Oncorhynchus mykiss*). Aquaculture 237, 333-346.

Glencross, B., Evans, D., Hawkins, W. & B. Jones. (2004b). Evaluation of dietary inclusion of yellow lupin (*Lupinus luteus*) kernel meal on the growth, feed utilisation and tissue histology of rainbow trout (*Oncorhynchus mykiss*). Aquaculture, 235:411-422.

Glencross, B., Evans, D., Dods, K., McCafferty, P., Hawkins, W., Maas, R. & S. Sipsas. (2005). Evaluation of the digestible value of lupin and soybean protein concentrates and isolates when fed to rainbow trout, *Oncorhynchus mykiss*, using either stripping or settlement faecal collection methods. Aquaculture, 245:211-220.

Goldburg, R. & R. Naylor. (2005). Future escapes, fishing, and fish farming. Front. Ecol. Environm., 2005; 3(1):21-28.

Gomes, E.F., Rema, P., Kaushik, S.J. (1995). Replacement of fishmeal by plant proteins in the diet of rainbow trout, *Oncorhynchus mykiss*: digestibility and growth performance. Aquaculture 130, 177-186.

Grisdale-Helland, B; Ruyter, B; Rosenlund, G; Obach, A; Helland, SJ; Sandberg, MG; Standal, H; Rosjo, C. (2002). Influence of high contents of dietary soybean oil on growth, feed utilization, tissue fatty acid composition, heart histology and standard oxygen consumption of Atlantic salmon (*Salmo salar*) raised at two temperatures. Aquaculture, 207(3):311-329.

Halseth, V. (2004). Challenges with various POP levels in fish feed and raw materials. Paper presented at a Workshop on `Possibilities of decontamination of fish oil and fish meal for dioxins, PCBs and other persistent organochlorine compounds. Brussels, September 3, 2004.

Hardy, R.W. (2003). Marine byproducts for aquaculture, pp. 141-152. In: Bechtel, P.J. (editor), Advances in Seafood Byproducts: 2002 Conference Proceedings. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, 566 pp.

Hardy, R.W. (2004). Best management practices for salmon feeds. The Global Aquaculture Advocate, 7(2):43-48.

Hardy, R.W. & Tacon, A.G.J. (2002). Fish meal: historical uses, production trends and future outlook for supplies, pp.311-325. In: Stickney, R.R. & MacVey, J.P. (eds.), Responsible Marine Aquaculture. CABI Publishing, New York, 391pp.

Hardy, R.W., Higgs, D.A., Lall, S.P. & Tacon, A.G.J. (2001). Alternative dietary protein and lipid sources for sustainable production of salmonids. Fisken og Havet, No.8, 53pp. (May 31, 2001: Institute of Marine Research, Bergen, Norway; http://www.imr.no)

Hemre, G.-I., Sanden, M., Bakke-McKellep, A.M., Sagstad, A. & A. Krogdahl. (2005). Growth, feed utilization and health of Atlantic salmon *Salmo salar* L. fed genetically modified compared to non-modified commercial hybrid soybeans. Aquaculture Nutrition, 11:157-167.

Herrmann, T., Collingro, C. & O. Papke. (2004). Overview of levels of dioxins, PCBs and other POPs found in fish meal, fish oil and fish feed marketed in the EU, pp.2122-2126. In: Organohalogen Compounds, Volume 66 (http://dioxin2004.abstract-management.de/overview/a597.htm)

Hertrampf, J.W. & Piedad-Pascual, F. (2000). Handbook on Ingredients for Aquaculture Feeds. Kluwer Academic Publishers, Dordrecht, Boston, London, 573p.

Hishamunda, N. & Subasinghe, R. (2003). Aquaculture development in China. The role of public sector policies. FAO Fisheries Technical Paper No. 427, FAO, Rome, Italy. 66p.

Hites, R.A, Foran, J.A, Carpenter, D.O, Coreen Hamilton M, Knuth, B.A. & S.J.

Schwager. (2004a). Global assessment of organic contaminants in farmed salmon. Science, 303:226-229.

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

Hole, R. (2004). Food safety: a question of assessment and communication. Aquafeed International, 7 (1):40-43.

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. Poseidon Aquatic Resource Management Ltd, Lymington, Hampshire, UK. August 2004.(http://www.wwf.org.uk/ filelibrary/ pdf/feedingthefish.pdf)

Huntington, T., C. Frid, R. Banks, C. Scott & O. Paramor. (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). Poseidon Aquatic Resource Management Ltd, Lymington, Hampshire, UK. June 2004. (http://www.rspb. org. uk/Images/fishmeal_tcm5-58613.pdf)

IFOMA (International Fishmeal and Oil Manufacturers Association). (2000). Predicted use of fishmeal and fish oil in aquaculture – revises estimate. IFOMA Update No. 98, April 2000, Potters Bar, UK.

IFFO International Fishmeal and Fish Oil Organisation (IFFO). (2005). New draft EU directive sets maximum limits and action levels for dioxins, furans and PCBs. IFFO Update No. 155, February 2005, St. Albans, UK.

Isosaari, P., Kiviranta, H., Lie, O., Lundebye, A.K., Ritchie, G. & T. Vartianinen. (2004). Accumulation and distribution of polychlorinated cibenzo-p-dioxin, dibenzofuran, and polychlorinated biphenyl congeners in Atlantic salmon. Environ. Toxicol. Chem., 23(7):1672-1679.

Jacobs M.; Ferrario J.; Byrne C. (2002). Investigation of polychlorinated dibenzo-p-dioxins, dibenzo-p-furans and selected coplanar biphenyls in Scottish farmed Atlantic salmon (*Salmo salar*). Chemosphere, 47(2):183-191.

Jeroen, C.J.M., Bergh, van den & H. Verbruggen. (1999). Spatial sustainability, trade and indicators: an evaluation of the `ecological footprint'. Ecological economics, 29:61-72.

Joas, R., Potrykuse, A. & G. Chambers. (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, 55p. (http://www.europarl.eu.int/stoa/publi/pdf/ stoa101_en.pdf)

Jobling, M., (2003). Do changes in Atlantic salmon, *Salmo salar* L., fillet fatty acids following a dietary switch represent wash-out or dilution. Test of a dilution model and its application. Aquacult. Res. 34, 1215-1221.

Johnson, J.A. & R.C. Summerfelt (2000). Spray-Dried Blood Cells as a Partial Replacement for Fishmeal in Diets for Rainbow Trout *Oncorhynchus mykiss*. Journal of the World Aquaculture Society, 31(1):96-104.

Julshamn,K., Lundebye, A-K., Berntssen, M.H.G. & B. Bøe. (2002). Contaminants (metals, DDT and PCB) in Norwegian salmon feed and fillets – results from monitoring programmes between 1995 and 2001. Institute of Nutrition, Directorate of Fisheries, P.O. Box 185 Sentrum, N-5804 Bergen (http://www.nifes.no/contaminants.pdf)

Jystad, P.T. (2001). Fishmeal and oil or vegetable alternatives: will high volume production spoil premium fish products? An IntraFish Industry Report, 9p. (http://www.intrafish.com/intrafish-analysis/fm1_2001_12_eng/print.php3)

Karl, H., Kuhlmann, H. & U. Ruoff. (2003). Transfer of PCDDs and PCDFs into the edible parts of farmed rainbow trout, *Oncorhynchus mykiss* (Walbaum), via feed. Aquaculture Research, 34(12):1009-1014.

Kaushik, S.J. (2004). Fish oil replacement in aquafeeds. Aqua Feeds: Formulation & Beyond, 1(1):3-15.

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

Kaushik, S.J., Covès, D., Dutto, G. & D. Blanc. (2004). Almost total replacement of fish meal by plant protein sources in the diet of a marine teleost, the European seabass, *Dicentrarchus labrax*. Aquaculture, 230:391-404.

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

Kissil, G.W. & I. Lupatsch. (2004). Successful replacement of fishmeal by plant proteins in diets for the Gilthead seabream, *Sparus aurata* l. The Israeli Journal of Aquaculture – Bamidgeh 56(3): 188-199.

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 organochlorine compounds. Brussels, September 3, 2004.

Krogdahl, A., Bakke-McKellep, A.M., Røed, K.H. & G. Baeverfjord. (2000). Feeding Atlantic salmon *Salmo salar* L. soybean products: effects on disease resistance (furunculosis), and lysozyme and IgM levels in the intestinal mucosa Aquaculture Nutrition, 6(2):77-84.

Krogdahl, A., Bakke-McKellep, A.M. & G. Baeverfjord. (2003). Effects of graded levels of standard soybean meal on intestinal structure, mucosal enzyme activities, and pancreatic response in Atlantic salmon (*Salmo salar* L.), Aquaculture Nutrition, 9(6):361-371.

Lankester, K. (2005). Sustainability in the anchoveta fisheries in Peru: descriptive background document. Report to the Netherlands Committee for IUCN. Amsterdam, The Netherlands, 24p. (in press)

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

Lee, KJ; Dabrowski, K; Blom, JH; Bai, SC; Stromberg, PC. (2002). A mixture of cottonseed meal, soybean meal and animal byproduct mixture as a fish meal substitute: growth and tissue gossypol enantiomer in juvenile rainbow trout (*Oncorhynchus mykiss*). Journal of Animal Physiology and Animal Nutrition, 86(7):201-213.

Ley, C. (2001). Triple Nine's answer to new regulations. Fish Farmer, 24(3):21-22.

Li, P., Wang, X., Hardy, R.W. & D.M. Gatlin III, D.M. (2004). Nutritional value of fisheries by-catch and by-product meal in the diet of red drum (Sciaenops ocellatus). Aquaculture, 236: 485-496.

Lindahl, O., Hart, R., Hernroth, B., Kolberg, S., Loo, L-O., Olrog, L., Rehnstam-Holm, A-S., Svensson, J., Svensson, S. & U. Syversen. (2005). Improving marine water quality by mussel farming – a profitable solution for Swedish society. Ambio, 34(2):129-136.

Liu, K.K.M., Barrows, F.T., Hardy, R.W. & F.M. Dong. (2004). Body composition, growth performance, and product quality of rainbow trout (*Oncorhynchus mykiss*) fed diets containing poultry fat, soybean/corn lecithin, or menhaden oil. Aquaculture, 238:309-328.

Lundebye, A.-K., Berntssen, M.H.G., Lie, O., Ritchie, G., Isosaari, P., Kiviranta, H. & T. Vartiainen. (2004). Dietary uptake of dioxins (PCDD/PCDFs) and dioxin-like PCBs in Atlantic salmon (*Salmo salar*). Aquaculture Nutrition, 10(3):199-207.

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

MacDonald, N., Bradbury, N. & J. Roberts. (2004). AIC (Agricultural Industries Confederation) Fish Feed Sub-Committee statement on dioxins and PCBs in feed for farmed salmon and trout (http://www.agindustries.org.uk/news/position statements/dioxins-pcbs.asp)

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

Millamena, O.M. (2002). Replacement of fish meal by animal by-product meals in a practical diet for grow-out culture of grouper *Epinephelus coioides*. Aquaculture, 204(1-2):75-84.

Morris, P.C., (2001). The potential for vegetable oils in trout feeds. Outlook 16, 12-16. Skretting, Northwich UK.

Morris, P.C., (2005). The vegetarian trout: opportunities for replacing fishmeal and fish oil in feeds for rainbow trout. International Aquafeed, 8(1):41-46.

Morris, P.C., Beattie, C., Elder, B., Finlay, J., Gallimore, P., Jewison, W., Lee, D., Mackenzie, K. McKinney, R., Sinnott, R., Smart, A. & M. Weir. (2005). Application of a low oil pre-harvest diet to manipulate the composition and quality of Atlantic salmon, *Salmo salar* L. Aquaculture, 244:187-201.

Mundheim, H., Aksnes, A. & B. Hope (2004). Growth, feed efficiency and digestibility in salmon (*Salmo salar* L.) fed different dietary proportions of vegetable protein sources in combination with two fish meal qualities. Aquaculture, 237:315-331.

Murawski, S.A. (2000). Definitions of overfishing from an ecosystem perspective. ICES Journal of Marine Science, 57:649-658.

Mwachireya, S.A., Beames, R.M., Higgs, D.A. & Dosnjh, B.S. (1999). Digestibility of canola protein products derived from the physical, enzymatic and chemical processing of commercial canola meal in rainbow trout *Oncorhynchus mykiss* (Walbaum) held in fresh water. Aquaculture Nutrition, 5(2):73-82.

Nash, C.E. (editor). (2001). The net-pen salmon farming industry in the Pacific Northwest. From contributions by Kenneth M. Brooks (consultant), William T. Fairgrieve, Robert N. Iwamoto, Conrad V.W. Mahnken, Colin E. Nash, Michael B. Rust, Mark S. Strom, and F. William Waknitz. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-49, 125p. September 2001 (http://www.nwfsc.noaa.gov/publications /techmemos/tm49/TM49.htm)

New, M.B. & Csavas, I. (1995). The use of marine resources in aquafeeds, pp.43-78. In: H. Reinertsen & H. Haaland (eds.), Sustainable fish farming. A.A. Balkema, Rotterdam, Netherlands.

New, M.B. & U.N. Wijkström. (2002). Use of fishmeal and fish oil in aquafeeds: further thoughts on the fishmeal trap. FAO Fisheries Circular No. 975. Rome. 61 pp.

Ng, W-G. (2004). Palm oil use in salmon feeds. Aqua Feeds: Formulation & Beyond, 1(1):7-9.

Ng, W-G., Sigholt, T. & J.G. Bell. (2004). The influence of environmental temperature on the apparent nutrient and fatty acid digestibility in Atlantic salmon (*Salmo salar* L.) fed finfishing diets containing different blends of fish oil, rapeseed oil and palm oil. Aquaculture Research, 35(13):1228-1237.

Nordrum, S., Bakke-McKellep, A.M., Krogdahli, A. & R.K. Buddington (2000). Effects of soybean meal and salinity on intestinal transport of nutrients in Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*). Comparative Biochemistry & Physiology, 125(3):317-335.

Obach, A., Bendksen, E.A., Rosenlund, G. & Gisvold, M. (2001). Impact of dietary lipid source on muscle fatty acid composition and sensory evaluation of Atlantic salmon (*Salmo salar* L.) In: *Farmed Fish Quality* (Eds, Kestin, S. & Warriss, P). Fishing News Books, Blackwell Science, UK. 391-392.

Oliva-Teles, A., Gouveia, A.J., Gomes, E., Rema, P., (1994). The effect of different processing treatments on soybean meal utilisation by rainbow trout, *Oncorhynchus mykiss*. Aquaculture 124, 343-349.

Olli, J.J., Krogdahl, A., (1995). Alcohol soluble components of soybeans seem to reduce fat digestibility in fish-meal-based diets for Atlantic salmon, *Salmo salar* L. Aquacult Res. 26, 831-835.

Opstvedt, J; Aksnes, A; Hope, B; Pike, IH. (2003a). Efficiency of feed utilization in Atlantic salmon (*Salmo salar* L.) fed diets with increasing substitution of fish meal with vegetable proteins. Aquaculture, 221(1-4):365-379.

Opstvedt, J; Nygard, E; Samuelsen, TA; Venturini, G; Luzzana, U; Mundheim, H. (2003b). Processing effects on protein quality of extruded fish feed. Journal of the Science of Food and Agriculture, 83(8):775-782.

Orskov, E.R. (2001). Matching animal potential to climate and feed resource. Journal of

Animal and Feed Sciences, 10(Suppl 1):43-50.

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, September 3, 2004.

Pearl, G. (2000). Rendering role in biosecurity and emerging diseases. Render, 29(2):46-54.

Perera, W.M.K., Carter, C.G., Houlihan, D.F., (1995). Feed consumption, growth and growth efficiency of rainbow trout (*Oncorhynchus mykiss* Walbaum) fed on diets containing a bacterial single-cell protein. Br. J. Nutr. 73, 591-603.

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

Pfeffer, E., Kinzinger, S. and M. Rodehutscord, (1995). Influence of the proportion of poultry slaughter by-products and of untreated or hydrothermically treated legume seeds in diets for rainbow trout, *Oncorhynchus mykiss* (Walbaum), on apparent digestibilities of their energy and organic compounds. Aquaculture Nutrition, 1(2): 111-117

Pike, I. H. (1998). Future supplies of fish meal and fish oil: quality requirements for aquaculture. International Aquafeed Directory and Buyers Guide 1998. pp. 39-49.

Pike, I. (2005). Eco-efficiency in aquaculture: global catch of wild fish used in aquaculture. International Aquafeed, 8(1):38-40.

Pike, I.H. & S.M. Barlow (2003). Impact of fish farming on fish stocks. International Aquafeed--Directory and Buyers' Guide 2003. pp. 24-29. Turret West Ltd, Bartham Press, Luton, UK.

Pimental, D., Shanks, R.E. & J.C. Rylander. (1996). Bioethics of fish production: energy and the environment. J. Agriculure, Environment & Ethics, 9(2):144-164.

Pimentel, D. (2001). Pricing biodiversity and ecosystem services. BioScience, 51(4):270-171.

Rathbone, C.K., Babbitt, J.K., Dong, F.M. & R.W. Hardy. (2001). Performance of juvenile Coho Salmon *Oncorhynchus kisutch* fed diets containing meals from fish wastes, deboned fish wastes, or skin-and-bone by-product as the protein ingredient. Journal of the World Aquaculture Society, 32(1):21-29.

Raven, P.H. (2002). Science, sustainability and the human prospect. Science, 297:954-958.

Refstie, Sl; Tiekstra, HA. (2003). Potato protein concentrate with low content of solanidine glycoalkaloids in diets for Atlantic salmon (*Salmo salar*). Aquaculture, 216(1-4):283-298.

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

Refstie, S., Korsoeen, O.J., Storebakken, T., Baeverfjord, G., Lein, I. & Roem, A.J. (2000). Differing nutritional responses to dietary soybean meal in rainbow trout (*Oncorhynchus mykiss*) and Atlantic salmon (*Salmo salar*). Aquaculture, 193(1-

2):91-106.

Refstie, S., Storebakken, T., Baeverfjord, G. & Roem, A.J. (2001). Long-term protein and lipid growth of Atlantic salmon (*Salmo salar*) fed diets with partial replacement of fish meal by soy protein products at medium or high lipid level. Aquaculture, 193(1-2):91-106.

Refstie, S. Olli, J.J. & H. Standal (2004). Feed intake, growth, and protein utilisation by post-smolt Atlantic salmon (*Salmo salar*) in response to graded levels of fish protein hydrolysate in the diet. Aquaculture, 239:331-349.

Refstie, S., Sahlstrom, S., Brathen, E., Baeverfjord, G. & P. Krogedal. (2005). Lactic acid fermentation eliminates indigestible carbohydrates and antinutritional factors in soybean meal for Atlantic salmon (*Salmo salar*). Aquaculture, 246:331-345.

Rembold, C.M. (2004). Letter to the Editor – The health benefits of eating salmon. Science, 305:475.

Rinchard, J; Lee, K; Dabrowski, K; Ciereszko, A; Blom, J; Ottobre, J. (2003a) Influence of gossypol from dietary cottonseed meal on haematology, reproductive steroids and tissue gossypol enantiomer concentrations in male rainbow trout (*Oncorhynchus mykiss*). Aquaculture Nutrition, 9(4):275-282.

Rinchard, J., Lee, K.J., Czesny, S., Ciereszko, A. & K. Dabrowski. (2003b). Effect of feeding cottonseed meal-containing diets to broodstock rainbow trout and their impact on the growth of their progenies. Aquaculture, 227:77-87.

Rosenlund, G., Obach, A., Bendksen, E.A.,, Gisvold, M. & Ruyter, B., (2001a). Effect of dietary fatty acid profile on fatty acid composition in salmon (*Salmo salar* L.) when replacing fish oils with vegetable oils. In: *Farmed Fish Quality* (Eds, Kestin, S. & Warriss, P). Fishing News Books, Blackwell Science, UK. 403-404.

Rosenlund, G., Obach, A., Sandberg, M.G., Standal, H., Tveit, K., (2001b). Effect of alternative lipid sources on long-term growth performance and quality of Atlantic salmon (*Salmo salar* L.). Aquacult. Research 32 (Suppl. 1), 323-328.

Roth, E., Rosenthal, H. & Burbridge, P. (2000). A discussion of the use of the sustainability index: ecological footprint for aquaculture production. Aquatic Living resources, 13:461-469.

Royal Commission on Environmental Pollution (2004). Turning the tide: addressing the impact of fisheries on the marine environment. Twenty-fifth Report Cm 6392, December 2004, London, UK.

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

Sanden, M. (2004). Genetically modified plant products in feed to farmed Atlantic salmon: effects on growth, feed utilization, fish health and assessment of potential risks. Dissertation for the degree of Doctor Scientiarum, University of Bergen, Bergen, Norway

Sargent, J.R. & Tacon, A.G.J. (1999). Development of farmed fish: a nutritionally necessary alternative to meat. Proceedings of the British Nutrition Society, 58:377-383.

Satoh, S., Higgs, D.A., Dosanjh, B.S., Hardy, R.W., Geoffrey Eales, J., Deacon, G., (1998). Effect of extrusion processing on the nutritive value of canola meal for Chinook salmon (*Oncorhynchus tshawytscha*) in seawater. Aquacult. Nutr. 4, 115-122.

SCAHAW (Scientific Committee on Animal Health and Animal Welfare). (2003). The use of fish by-products in aquaculture. Report of the Scientific Committee on Animal Health and Animal Welfare, Adopted 26th February 2003. European Commission, (http://europa.eu.int/comm/food/fs/sc/scah/out87_en.pdf)

SCAN (Scientific Committee on Animal Nutrition). (2000). European Commission, DG Health and Consumer Protection: 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.

Selden Jr., G.L., Brown, P.B., Ostrowski, A.C., Flores, R.A. & L.A. Johnson (2001). Evaluation of Soybean Meal-Red Blood Cell Coextruded Feed Ingredient in Diets Fed to Rainbow Trout *Oncorhynchus mykiss*. Journal of the World Aquaculture Society, 32(4):409-415.

Seierstad, S.L., Seljeflot, I., Johansen, O., Hansen, R., Haugen, M., Rosenlund, G., Froyland, L. & H. Arnesen. (2005). Dietary intake of differently fed salmon: the influence on markers of human atherosclerosis. European Journal of Clinical Investigation, 35(1):52-59.

Shepherd, T. (1998). Rendered products in aquaculture feeds. International Aquafeed, 4:13-16.

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

Sidhu, K.S. (2003). Health benefits and potential risks related to consumption of fish or fish oil. Regulatory Toxicology and Pharmacology, 38(3):336-344.

Skrede, G., Storebakken, T., Skrede, A., Sahlstrom, S., Sorensen, M., Shrearer, K.D. & E. Slinde. (2002). Lactic acid ferementation of wheat and barley whole meal flours improves digestibility of nutrients and energy in Atlantic salmon (*Salmo salar*) diets. Aquaculture, 210:305-321.

Smith G.C.; Hart A.D.M.; Rose M.D.; MacArthur R.; Fernandes A.; White S.; Moore D.R.J. (2002). Intake estimation of polychlorinated dibenzo-p-dioxins, dibenzofurans (PCDD/Fs) and polychlorinated biphenyls (PCBs) in salmon: the inclusion of uncertainty. Food Additives and Contaminants, 19(8):770-778.

Solberg, C. (2004). Influence of dietary oil content on the growth and chemical composition of Atlantic salmon (*Salmo salar*). Aquaculture Nutrition, 10(1):31-37.

Sørensen (2004). Practical experiences. Paper presented at a Workshop on `Possibilities of decontamination of fish oil and fish meal for dioxins, PCBs and other persistent organochlorine compounds. Brussels, September 3, 2004.

SSC (Scientific Steering Committee). (2003). Opinion on the feeding of wild fishmeal to farmed fish and recycling of fish with regard to the risk of TSE. Report of the

Scientific Steering Committee, Adopted 6-7th March 2003. European Commission (http://europa.eu.int/comm/food/fs/sc/ssc/out320_en.pdf)

Storebakken, T., Shearer, K.D., Roem, A.J., (1998). Availability of protein, phosphorous and other elements in fishmeal, soy-protein concentrate and phytase-treated soy-protein-concentrate-based diets to Atlantic salmon, *Salmo salar*. Aquaculture, 161, 365-379.

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

Storebakken, T., Shearer, K.D., Baeverfjord, G., Nielsen, B.G., Åsgård, T., Scott, T. & A. De Laporte. (2000b). Digestibility of macronutrients, energy and amino acids, absorption of elements and absence of intestinal enteritis in Atlantic salmon, *Salmo salar*, fed diets with wheat gluten. Aquaculture, 184:115-132.

Storebakken, T., Baeverfjord, G., Skrede, A., Olli, J.J. & G.M. Berge. (2004). Bacterial protein meal in diets for Atlantic salmon, Salmo salar, in freshwater. Aquaculture, 241:413–425.

Sujiura, S.H., Gabaudan, J., Dong, F.M., Hardy, R.W., (2001). Dietary microbial phytase supplementation and the utilisation of phosphorous, trace minerals and protein by rainbow trout (*Oncorhynchus mykiss* Walbaum) fed soybean meal-based diets. Aquaculture Research. 32, 583-592.

Sveier; Nordas; Berge & Lied. (2001). Dietary inclusion of crystalline D- and L-methionine: effects on growth, feed and protein utilization, and digestibility in small and large Atlantic salmon (*Salmo salar* L.). Aquaculture Nutrition, 7(3):169-181.

Tacon, A.G.J. (1997). Feeding tomorrow's fish: keys for sustainability. In: Feeding Tomorrow's Fish (A.G.J. Tacon and B. Basurco, editors). Cahiers Options Mediterraneennes, Vol. 22. Zaragoza, Spain. pp. 11-33.

Tacon, A.G.J. (1998). Global trends in aquaculture and aquafeed production. In: International Aquafeed Directory and Buyers' Guide 1997/1998, Turret Rai Group PLC, Rickmansworth, UK. pp. 5-37.

Tacon, A.G.J. (2000). Rendered animal by-products: a necessity in aquafeeds for the new millennium. The Global Aquaculture Advocate, 3(4):18-19.

Tacon, A.G.J. (2003a). Growing Requirements for Fish Meals and Fish Oils, pp. 27-42. In: Bechtel, P.J. (editor), Advances in Seafood Byproducts: 2002 Conference Proceedings. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, 566 pp.

Tacon, A.G.J. (2003b). Global trends in aquaculture and global aquafeed production. International Aquafeed--Directory and Buyers' Guide 2003. pp. 4-25. Turret West Ltd, Bartham Press, Luton, UK.

Tacon, A.G.J. (2004a). Use of fish meal and fish oil in aquaculture: a global perspective. Aquatic Resources, Culture & Development, 1(1):3-14 .

Tacon, A.G.J. & I.P. Forster. (2001). Global trends and challenges to aquaculture and aquafeed development in the new millennium. International Aquafeed--Directory and Buyers' Guide 2001. pp. 4-25. Turret RAI, Uxbridge, Middlesex, UK.

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

Takagi, S., H. Hosokawa, S. Shimeno, S. & M. Ukawa. (2000). Utilisation of poultry by-product meal in a diet for red sea bream *Pagrus major*. Nippon Suisan Gakkaishi, 66(3):428-438.

Takagi, S; Shimeno, S; Hosokawa, H; Ukawa, M. (2001). Effect of lysine and methionine supplementation to a soy protein concentrate diet for red sea bream *Pagrus major*. Fisheries Science, 67(6):1088-1096.

Thiessen, D; Campbell, G*; Adelizi, P. (2003a). Digestibility and growth performance of juvenile rainbow trout (*Oncorhynchus mykiss*) fed with pea and canola products. Aquaculture Nutrition, 9(2):67-75.

Thiessen, D; Campbell, G; Tyler, R. (2003b). Utilization of thin distillers' solubles as a palatability enhancer in rainbow trout *(Oncorhynchus* mykiss) diets containing canola meal or air-classified pea protein. Aquaculture Nutrition, 9(1);1-10.

Thiessen, D.L., Maenz, D.D., Newkirk, R.W., Classen, H.L. & M.D. Drew. (2004). Replacement of fishmeal with canola protein concentrate in diets fed to rainbow trout (*Oncorhynchus mykiss*). Aquaculture Nutrition, 10(6):379-388.

Thompson, K.D., Tatner, M.F. & Henderson, R.J. (1996). Effects of dietary (n-3) and (n-6) polyunsaturated fatty acid ratio on the immune response of Atlantic salmon, *Salmo salar*. Aquaculture Nutrition, 2:21-31.

Tidwell, J.H. & G.L. Allan. (2001). Fish as food: aquaculture's contribution. EMBO reports, 21(11):958-963.

Tocher, D.R., Bell., J.G., Dick, J.R., Henderson, R.J., McGhee, F., Mitchell, D., Morris, P.C., (2000). Polyunsaturated fatty acid metabolism in Atlantic salmon (*Salmo salar*) undergoing parr-smolt transformation and the effects of dietary linseed and rapeseed oils. Fish Physiol. Biochem. 23, 59-73.

Tocher, DR; Fonseca-Madrigal, J; Bell, JG; Dick, JR; Henderson, RJ; Sargent, JR. (2002). Effects of diets containing linseed oil on fatty acid desaturation and oxidation in hepatocytes and intestinal enterocytes in Atlantic salmon (*Salmo salar*). Fish Physiology and Biochemistry, 26(2):157-170.

Tocher, D.R., Bell, J.G., McGhee, F., Dick, J.R. **& J. Fonseca-Madrigal. (2003).** Effects of dietary lipid level and vegetable oil on fatty acid metabolism in Atlantic salmon (*Salmo salar* L) over the whole production cycle. Fish Physiology and Biochemistry, 29(3):193-209.

Torstensen, B.E., Froyland, L. & O. Lie. (2004). Replacing dietary fish oil with increasing levels of rapeseed oil and olive oil – effects on Atlantic salmon (*Salmo salar* L.) tissue and lipoprotein lipid composition and lipogenic enzyme activities. Aquaculture Nutrition, 10(3):175-192.

Teskeredžić, Z., Higgs, D.A., Dosanjh, B.S., McBride, J.R., Hardy, R.W., Beames, R.M., Jones, J.D., Simell, M., Vaara, T., Bridges, R.B., (1995). Assessment of undephytinised and dephytinised rapeseed protein concentrate as sources of dietary protein for juvenile rainbow trout, *Oncorhynchus mykiss*. Aquaculture 131, 261-277.

Troell, M., Kautsky, N. & C. Folke. (1999). Applicability of integrated coastal aquaculture systems. Ocean Coastal Management, 42:63-69.

Troell, M., Tyedmers, P., Kautsky, N. & P. Ronnback. (2004). Aquaculture and energy use, pp.97-108. In: Encyclopedia of Energy, Volume 2. Elsevier Inc.

Troell, M., Neori, A., Chopin, T. & A.H. Buschmann. (2005). Biological wastewater treatment in aquaculture – more than just bacteria. World Aquaculture, March 2005, pp.27-29..

Trondsen, T. (1998). Blue whiting surimi: new perspectives on the market value. Fisheries Research, 34(1):1-15.

Tuominen, T-R. & M. Esmark. (2003). Food for thought: the use of marine resources in fish feed. Report 2/03, WWF-Norway, February 2003. (http://www.panda.org/downloads/marine/foodforthoug.pdf).

Tyedmers, P. (2004). Fisheries and energy use, pp.683-693. In: Encyclopedia of Energy, Volume 2. Elsevier Inc., New York

University of Newcastle Upon Tyne (UK), Poseidon Aquatic Resource Management Ltd (UK). (2004). The fishmeal & fish oil industry: its role in the common fisheries policy. Directorate-General for research, Working Paper. European Parliament, Fisheries Series, FISH 113 EN (www.europarl.eu.int/studies).

Utne, F. & K.E. Gulbransen. (1984). Pigmentation and growth in Atlantic salmon using stabilized krill meal in the feed. Norsk Fiskeoppdrett., 9(12):15-16.

Vielma, J., Ruohonen, K., Peisker, M., (2002). Dephytinization of two soy proteins increases phosphorous and protein utilisation by rainbow trout, *Oncorhynchus mykiss*. Aquaculture 204, 145-156.

Vielma, J., Ruohonen, K., Gabaudan, J. & K. Vogel. (2004). Top-spraying soybean meal-based diets with phytase improves protein and mineral digestibilities but not lysine utilization in rainbow trout, *Oncorhynchus mykiss* (Walbaum). Aquaculture Research, 35(10):955-964.

Watanabe, H. (1985). An estimation of energy input in the manufacture of fish meal. Bulletin of the Japanese Society for Scientific Fisheries, 51(9):1533-1536.

Wessells, C.R., Cochrane, K., Deere, C., Wallis, P. & R. Willmann. (2001). Product certification and ecolabelling for fisheries sustainability. FAO Fisheries Technical Paper No. 422. Rome, FAO. 2001. 83p.

Woodgate, S.L. (2004a). Terrestrial animal by-products: the new European Union regulation on animal by-products: an update. International Aquafeed, 7(1):29-32.

Woodgate, S.L. (2004b). Terrestrial animal by-products in aquafeeds: An update. Aquafeed International, 7 (1):27-32.

Wray, T. (2001). Making the most of jack mackerel. Seafood International, July 2001, pp.39-43.

Wright, I. (2003). Fish hydrolysate: more than just a flavour enhancer? Aquafeed International, Issue 6 (3):8-12.

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

Yamamoto, T., T. Unuma and T. Akiyama. (1995). The effect of combined use of several alternative protein sources in fingerling rainbow trout diets. Fisheries Science, 61(6): 915-920.

Yanik, T., Dabrowski, K. & S.C. Bai. (2003). Replacing fish meal in rainbow trout (*Oncorhynchus mykiss*) diets. The Israeli Journal of Aquaculture – Bamidgeh, 55(3):179-186.

Yu. Y. (2004). Replacement of fishmeal with poultry byproduct meal and meat and bone meal in shrimp, tilapia and trout diets. In: L. E. Cruz Suarez, D. Ricque Marie, M. Gpe. Nieto Lopez, D.A. Villarreal Cavazos, U. Scholz & M.L. Gonzalez Felix (Editors), Proceedings of the VII International Symposium on Aquaculture Nutrition, Hermosillo, Mexico, 16-19 November 2004. Programa Maricultura, Facultad de Ciencia Biologicas, Universidad Autonoma de Nuevo Leon, Mexico.

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

Zaldivar M.J. (2004). Review of the commercial situation of fishmeal and fish oil and the new requirements imposed on them. Paper presented at Tecnica Aqua Sur 2004 (Chile), March 2004 (http://www.iffo.org.uk/tech/TecnAqua.htm)

Appendix 1. Outline of the feed report and questions to be answered

Background:

- Trends in volume of feed produced and used in salmon aquaculture
- Overview of total global use of fishmeal (FM) & fish oil (FO), including purposes
  - How does salmon/carnivorous finfish feed production fit into this context?
- Trends in Feed Conversion Ratio (FCR)
- Trends in quantity of fishmeal and oil used in feed
- Trends in percentage of FM/FO used in feed
  - How much are produced from by-products?
  - What impact have FM&FO prices on use?
- Trends in use of other ingredients in feed
- Trends in feed manufacturing techniques used to produce salmon feeds

Status of fisheries and ecosystem impacts from fishmeal and oil use:

- Trends in species used in salmon feed
- Catching volumes – last 20 years by species, and main market for meal & oil
- Status of these reduction fisheries
  - If these fisheries are seen as sustainable – what criteria are used?
  - Existing evidence of ecosystem damage/stress from these fisheries (e.g. bird & other fish forage availability)
- Potential for use of sustainable reduction fisheries
  - Is it realistic to say that a certified reduction fishery could be used for FM/FO production - are feed producers able to trace their meal/oil back to the source?
  - Is there sufficient research on the sustainability of reduction fisheries to certify them?
- Potential for use of fishery byproducts for minimizing demand on reduction fisheries
  - Are the "byproduct" fisheries sustainable and does focusing more pressure on them create incentives for more bycatch, or pressure on the sustainability of the target fisheries?
- Any available info on energy consumption in fishing, reduction and transport
- Key questions that have yet to be researched

Status of development & use of dietary fishmeal & oil substitutes for salmonids:

- Issues and obstacles related to reducing FM/FO used in feeds, such as impacts of reducing use on salmon growth, FCR, fish health, nutritional value of the fish, pollution from feeding, contaminant level in the fish and consumer perception.
- State of research of these issues/obstacles (what has been resolved, what work is in progress)
- Key questions that have yet to be researched
- Status, outlook, and concerns for use of GMO plant and land animal products (both protein and fat) in feed

Status of feed efficiency:

- Trends in efficiency of feed use (and source of efficiency: management, technology, feed formulation, etc.)
- Identification/evaluation of new technologies/management techniques to improve efficiency
- New technologies in development
- Key questions that have yet to be researched

Public health issues related to feed:

- Which are the most important contaminants from a public health point of view?
- Potential to strip contaminants from FM/FO during processing - which ones can be stripped?
- Impact of FO substitution on omega-3 level and omega 3/ omega 6 ratios in salmon
- Impact of fish protein substitution on nutritional value (e.g. fat type and content) of the fish
- Are FM companies able to trace meal/oil back to the individual fisheries?
- Is it known that some reduction fisheries are more contaminated than others? Has global mapping or research been done on this?
- Key questions that have yet to be researched

Feed/feeding and ecosystem

- Does feeding potentially contribute to additional contaminant loading (persistent organic pollution) around net cages
- Does substitution of FM/FO have any impact of nutrient loading to the ocean, or on benthics.
- Key questions that have yet to be researched.

Looking to the future

- Brief comments on the applicability of research on salmonid feed to other feeds. Are there critical research needs related to other species that do not apply to salmon? Effects of emerging carnivorous finfish aquaculture species.
- What will the projected growth of salmon aquaculture (and other carnivorous finfish species) do to the various issues investigated?

Conclusions and Recommendations

Appendix 2. Organisations and persons consulted who provided

Belgium:

European Commission, Brussels

- Richard Bates, Environment & Health Unit, Directorate-General of Fisheries & Maritime Affairs

Canada:

Dalhousie University, Halifax

- Peter Tyedmers Ph.D., Professor

Skretting/Nutreco, Vancouver

- Greg Deacon, Sales Manager/Nutritionist

Taplow Feeds, Armstrong

- Brad Hicks Ph.D., Vice President

Chile:

AquaChile, Puerto Montt

- Marianna Silva, Head of Nutrition & Quality Control
- Rodger Miranda, Technical Manager
- Victor Pérez, Farm Planning Manager

Aquafarma., Santiago

- Samuel Valdebenito, Head of Aquaculture Division

BioMar Chile S.A., Puerto Montt

- Jaime Carrasco C., Product Developer
- Yuri Vennekool M., Technical Assistance Manager

Cultivos Marinos Chiloe Ltd, San Sebastián, Chiloé

- Jaime Veragua C., Head Feed Plant Development
- Patricio Briano P., Feed Plant Manager

DSM Nutritional Products, Puerto Varas

- Claudio Larraín C., Technical Director

FeedMaster, Puerto Montt

- Renato Abarca Salas, Manager

Hinrichsen Trading, Santiago

- Jimena Camus A., Comercial Manager
- Juan Pablo Hinrichsen, Managing Director

Salmofood, Castro, Chiloe

- Pablo Leyton Miranda, Technical Manager
- Paulo Alarcon Bruce, Technical Advisor

Universidad de Temuco, Temuco

- Aliro Borquez, Profesor

Italy:

Fisheries Dept., Food & Agriculture Organization of the United Nations (FAO), Rome

- Jorge Csirke, Chief, Marine Resources Service

- Stefania Vannuccini, Statistician, Fishery Information, Data & Statistics Unit

Norway:

Ewos A.S., Stavanger
- Karl Marius Lillevik, Purchasing Manager

Ewos Innovation, Dirdal
- Adel El-Mowafi, Scientist – Nutrition
- Harald Sveier Ph.D., Senior Scientist
- Jan Vidar Jakobsen, R & D Manager Bioscience
- Per Olav Skjervold Ph.D., Managing Director

Marine Harvest Ltd, Stavanger
- Øistein Jakobsen, Project Manager Specialities

National Institute of Nutrition and Seafood Research (NIFES), Bergen
- Anne-Katrine Lundebye Haldorsen Ph.D., Principal Scientist
- Ernest M. Hevrøy Ph.D., Senior Scientist
- Gro-Ingunn Hemre Ph.D., Principal Scientist
- Livar Frøyland Ph.D., Principal Scientist/Professor
- Øyvind Lie Ph.D., Director/Professor II

Norwegian Institute of Fisheries & Aquaculture, Fyllingsdalen
- Anders Aksnes Ph.D., Senior Scientist
- Ola Flesland, Department Diector

Nutreco Aquaculture Research Centre A.S., Stavanger
- Grethe Rosenlund, Ph.D., Senior Researcher Nutrition
- Nanne Jørum, Food Safety & Quality System Manager
- Viggo Halseth, Managing Director
- Wolfgang Koppe Ph.D., Manager Nutrition

Skretting A.S., Stavanger
- Hans Abrahamsen, Managing Director

Sweden:

The Beijer Institute, Stockholm
- Max Troell Ph.D., Professor

The Netherlands:

Scomber, Amsterdam
- Kees Lankester, Consultant

UK:

BioMar Ltd., Grangemouth
- Nick Bradbury, Technical Support Manager

Fishmeal Information Network (FIN), London
- Anne Chamberlain, Coordinator

Institute of Aquaculture, University of Stirling, Stirling

- Gordon Bell Ph.D., Senior Lecturer
- John Bostock Ph.D., Stirling Aquaculture
- Randolph Richards Ph.D., Professor/Director

International Fish meal & Fish oil Organisation (IFFO), St. Albans

- Ian Pike Ph.D., Nutrition Consultant
- Jean François Mittaine, Commercial Director
- Jonathan Shepherd, Director General

Marine Harvest Ltd, Fort William

- Andrew Jackson Ph.D., Processing & Logistics Director

Rossynew Ltd, Greenock

- Ian Wright, Sales Director

Skretting Ltd, Renfrew

- Paul Morris Ph.D., Research Manager

United Fish Products (UFI), Aberdeen

- David Mack, Business Advisor

Webster Rae, Crieff

- John L. Webster Ph.D., Technical Consultant to SQS

USA:

Environmental Defense, New York

- Rebecca Goldburg Ph.D., Senior Scientist

Forster Consulting Inc., Port Angeles

- John Forster Ph.D., Consultant & Fish Farmer

H.J.B. Baker & Bro. Inc., Stamford

- Paul Guzman, Feed International Product Manager

H.M. Johnson & Associates, Jacksonville

- Howard Johnson, President

Nelson & Sons Inc., Murray

- Richard Nelson, VP Purchasing & Adminstration

Northwest Fisheries Science Center, Seattle

- Mike E. Rust Ph.D., Marine Enhancement & Aquaculture Research Team

Wenger Inc., Sabetha

- Joe P. Kearns, Corporate Sales Manager